School of Engineering Design,

Technology and Professional Programs

213 Hammond Building

University Park, PA 16802-2701

October 29, 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 recent flood has destroyed a heavily trafficked bridge located in College Township, Centre County, PA. Travelers must now be re-routed more than 10 miles around the destroyed bridge, making transportation for medical and law enforcement officials much more difficult, and increasing the risk for residents in State College.

Objective. (PennDOT) 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.

Design Criteria. 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. Members are solid steel bars as well as hollow steel tubes.

Technical Approach.

Phase 1: Economic Efficiency. Economic efficiency (cost) shall be determined using the Engineering Encounters Bridge Design 2015 software based on the requirements, constraints, and performance criteria specified herein.

Phase 2: Structural Efficiency. A prototype bridge shall be designed and built for both a Warren through truss bridge and a Howe through truss bridge by each design team. Each prototype bridge shall be load tested in the lab to catastrophic failure. The truss bridge type that exhibits the best structural efficiency when tested to failure in prototype shall be determined.

Results.

Phase 1: Economic Efficiency. As a whole, the Warren Truss Bridge that we designed using Bridge Builder 2015 was the most economically efficient. Based on the simulation, the bridge was able to support a single centre-lane truck as it made a full trip across. We were able to do this while keeping the overall price of the bridge at $233,901.92. We were able to do the same thing with our Howe Truss Bridge, but for the price of $246,168, yielding a price difference of $12,266.08.

Phase 2: Structural Efficiency. As a whole, the Howe Truss Bridge created was the most structurally efficient. Even though it weighed a little more than the Warren, the fact that the Howe supported 99.7 lbs of weight in comparison to the 55.4 lbs the Warren supported easily makes up for any additional amount of weight. The structural efficiency of the Howe bridge was 1.26 while the structural efficiency of the Warren was 0.68.

Mean: 0.815 Median: 0.833 Mode: 1.26 ---> Howe
Mean: 0.790 Median: 0.685 Mode: 1.28 ---> Warren

Best Solution. Based on both the economic and structural efficiencies of the Warren and Howe Truss Bridges, the best solution to the problem stated above is to incorporate the Howe Truss design when repairing the destroyed bridge. The Howe bridge that was created was able to support 99.7 lbs of weight, being the best out of all other teams, while the Warren was only able to support 55.4 lbs. The Howe Bridges also had the best structural efficiency values in comparison to the Warren Bridges. While the price of the Howe might be greater than that of the Warren by $12,266.08, we are looking to build a solid bridge that will last, and in terms of long term cost, it would be more economically efficient to spend

more now than to possibly have to start over completely if a similar failure were to happen in the future. Based on these two rationales, the best solution would be to use the Howe Truss Bridge design.

Conclusions and Recommendations.
Based on the results from the actual prototypes, as well as the ones created using Bridge Builder 2015, our design team recommends replacing the bridge destroyed by the recent extreme flood with our Howe through truss bridge. Recommendations for the next step that should be accomplished to advance the project into final design are researching better assembly techniques that improve structural efficiency further.

Respectfully,

Daniel Gatte
Engineering Student
EDSGN100 Section 002
Design Team 5
College of Engineering
Penn State University

Bridget Johnson
Engineering Student
EDSGN100 Section 002
Design Team 5
College of Engineering
Penn State University

Katherine Leahy
Engineering Student
EDSGN100 Section 002
Design Team 5
College of Engineering
Penn State University

Brady McDonough
Engineering Student
EDSGN100 Section 002
Design Team 5
College of Engineering
Penn State University

ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss. Attachment one shall include all pertinent detailed results from the economic efficiency study in the form of descriptive paragraphs and shall include appropriate discussion and details, as well as output results from EEBD 2015 for the Howe Truss.

Warren Truss. Attachment one shall include all pertinent detailed results from the economic efficiency study in the form of descriptive paragraphs and shall include appropriate discussion and details, as well as output results from EEBD 2015 for the Warren Truss.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss. Attachment two shall include detailed results from the structural efficiency study and shall include appropriate discussion and details, as well as all results of the lab load testing and calculations for the Howe truss bridge.

Prototype Bridge. The Howe Truss bridge design used all 60 of the popsicle sticks supplied. The bridge used a single layer of vertical struts sandwiched between a double layer of popsicle sticks for the top and bottom chord. To connect the two halves of the truss popsicle sticks were glued to the vertical struts of the bridge as opposed to the top and bottom chord. This was done in order to better resist lateral shifting of the structure.

Load Testing. The Load at bridge failure results, bridge weights and calculation of structural efficiencies for all Howe truss bridges must be collected and presented as Table 7

Forensic Analysis. The Howe Truss Bridge failure was the result of the glue bond along the bottom chord failing. The bridge separated cleanly in half, with no damage to any structural members. This suggests that the bridge failed because the joint with the weakest glue bond separated. As illustrated in figure 4, the bridge separated at laterally and vertically adjacent joints along the top and bottom cords, starting at the left front joint on the bottom chord and unravelling around the diameter of the bridge.

Results.
Please reference figure 7 to compare structural efficiencies shown in table 7.

Warren Truss. Attachment two shall include detailed results from the structural efficiency study and shall include appropriate discussion and details, as well as all results of the lab load testing and calculations for the Warren truss bridge

Prototype Bridge. For the Warren Truss Bridge, all 60 of the popsicle sticks were used. The center members were strengthened as much as possible by doubling the number of popsicle sticks and the same method was used on the end members. With the entirety of the weight centered on the center of the bridge, it was important to reinforce the end and center members/joints as much as possible. When the two sides were completed, they were connected by using a similar double member method for the deck, and adding an additional popsicle positioned upright as well as flat. The top part of the bridge was held together with two members to hold the load test.

Load Testing. The Warren Truss Bridge failure was also due to the result of the glue bond, as well as structural members of the bottom cord, diagonal, end post, and floor beam. It was much weaker in comparison to the Howe design. It was not as structurally efficient as our team had hoped; it had weak supports and a less-calculated plan. Before the load test, the bridge weighed 80.9 grams. It was able to hold 55.4 pounds of sand before the failure. Both of these values are rather average compared to other results from different design teams, although the load test was a little lower compared to others. Our values here fell within the median range of the togetherness of other design teams' data. However, there was one extreme that outshined the rest; it was able to hold over 100 pounds of sand. The minimum value for the weight of the bridge was 74.9 grams and the maximum value was 90.1 grams. The minimum value

for the weight of sand the Warren bridge could hold was 33.9 pounds. The maximum value was 104.6 pounds.

Forensic Analysis. The bridge failed primarily around the front right structural members and glued joints. This is a direct result of poorly glued joints and weak supports that weakened the surrounding supports as well.

Results. An EXCEL bar chart (graph) shall be included as Figure 8 comparing Structural Efficiencies as presented in Table 8

TABLES

Table 1
Howe Truss Bridge

Cost Calculation Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	High Strength Low-Alloy Steel Hollow Tube Carbon Steel Solid Bar		
Connection Cost (C)		(20)($500)(2)=	**$20,000**
Product Cost (P)	4-130x130mm Bar 2-140x140mm Bar 2-110x110mm Bar 4-90x90mm Bar 3-75x75mm Bar 4-70x70mm Bar 2-280x280mm Tube 2-260x260mm Tube 2-240x240mm Tube 3-220x220mm Tube 1-200x200mm Tube 4-190x190mm Tube 2-170x170mm Tube 2-140x140mm Tube	(%s per Product)=	**$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000** **$1,000**
Site Cost (S)	Deck Cost	(11)($5,300)=	**$58,300**
	Excavation Cost	(19,900 cubic m)($1)	**$19,900**
	Abutment Cost	(2)($7,000)=	**$14,000**
	Pier Cost	no pier=	**$0.00**
	Cable Anchorage Cost	no anchorage=	**$0.00**

TOTAL COST	M+C+P+S		**$246,168**

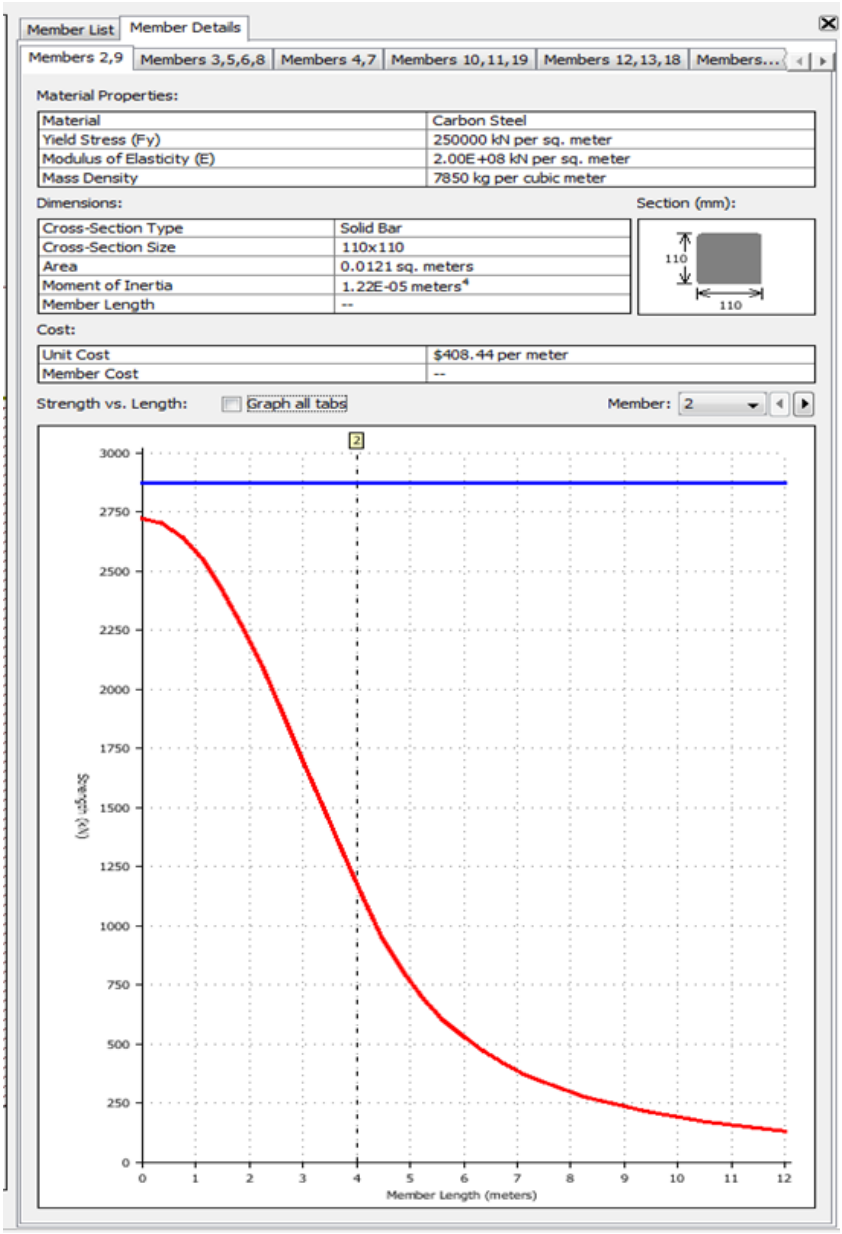
Table 2
Howe Truss Bridge
Load Test Results Report from Bridge Designer 2015

Member List | Member Details

Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Bar	90	4.00	153.96	0.00	0.74
2	CS	Bar	110	4.00	125.97	0.00	0.88
3	CS	Bar	130	4.00	106.59	0.00	0.82
4	CS	Bar	140	4.00	98.97	0.00	0.81
5	CS	Bar	130	4.00	106.59	0.00	0.98
6	CS	Bar	130	4.00	106.59	0.00	0.98
7	CS	Bar	140	4.00	98.97	0.00	0.81
8	CS	Bar	130	4.00	106.59	0.00	0.81
9	CS	Bar	110	4.00	125.97	0.00	0.85
10	CS	Bar	90	4.00	153.96	0.00	0.72
11	CS	Bar	90	4.00	153.96	0.00	0.73
12	CS	Bar	75	4.00	184.75	0.00	0.86
13	CS	Bar	75	4.00	184.75	0.00	0.66
14	CS	Bar	70	4.00	197.95	0.00	0.53
15	CS	Bar	70	4.00	197.95	0.00	0.54
16	CS	Bar	70	4.00	197.95	0.00	0.50
17	CS	Bar	70	4.00	197.95	0.00	0.73
18	CS	Bar	75	4.00	184.75	0.00	0.83
19	CS	Bar	90	4.00	153.96	0.00	0.72
20	HSS	Tube	190	4.00	54.07	0.87	0.00
21	HSS	Tube	190	4.00	54.07	0.85	0.00
22	HSS	Tube	220	5.66	66.21	0.79	0.00
23	HSS	Tube	190	5.66	76.46	0.95	0.00
24	HSS	Tube	170	5.66	85.43	0.93	0.00
25	HSS	Tube	200	5.66	72.83	0.99	0.00
26	HSS	Tube	190	5.66	76.46	0.92	0.00
27	HSS	Tube	170	5.66	85.43	0.88	0.00
28	HSS	Tube	280	4.00	36.78	0.90	0.00
29	HSS	Tube	280	4.00	36.78	0.89	0.00
30	HSS	Tube	240	4.00	42.91	0.85	0.00
31	HSS	Tube	260	4.00	39.61	0.93	0.00
32	HSS	Tube	260	4.00	39.61	0.92	0.00
33	HSS	Tube	240	4.00	42.91	0.83	0.00
34	HSS	Tube	220	5.66	66.21	0.96	0.00
35	HSS	Tube	220	5.66	66.21	0.94	0.00
36	HSS	Tube	140	5.66	104.04	0.96	0.07
37	HSS	Tube	140	5.66	104.04	0.88	0.11

Table 3
Howe Member Details Report from Bridge Builder 2015



Member List | Member Details

Members 2,9 | Members 3,5,6,8 | Members 4,7 | Members 10,11,19 | Members 12,13,18 | Members...

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	Solid Bar
Cross-Section Size	110x110
Area	0.0121 sq. meters
Moment of Inertia	1.22E-05 meters^4
Member Length	--

Section (mm):

Cost:

Unit Cost	$408.44 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member: 2

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

Cost Calculations Report

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(5297.1 kg) x ($4.30 per kg) x (2 Trusses) =	$45,554.83
	High-Strength Low-Alloy Steel Solid Bar	(296.6 kg) x ($5.60 per kg) x (2 Trusses) =	$3,322.46
	High-Strength Low-Alloy Steel Hollow Tube	(5044.6 kg) x ($7.00 per kg) x (2 Trusses) =	$70,624.63
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	4 - 60x60 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 65x65 mm High-Strength Low-Alloy Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 70x70 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 75x75 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 90x90 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 100x100 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 110x110 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 120x120x6 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 130x130 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 140x140x7 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 160x160x8 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 180x180x9 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 200x200x10 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 240x240x12 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 260x260x13 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	3 - 280x280x14 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =	$47,000.00
	Excavation Cost	(19,900 cubic meters) x ($1.00 per cubic meter) =	$19,900.00
	Abutment Cost	(2 standard abutments) x ($5,250.00 per abutment) =	$10,500.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	**M + C + P + S**	**$119,501.92 + $21,000.00 + $16,000.00 + $77,400.00 =**	**$233,901.92**

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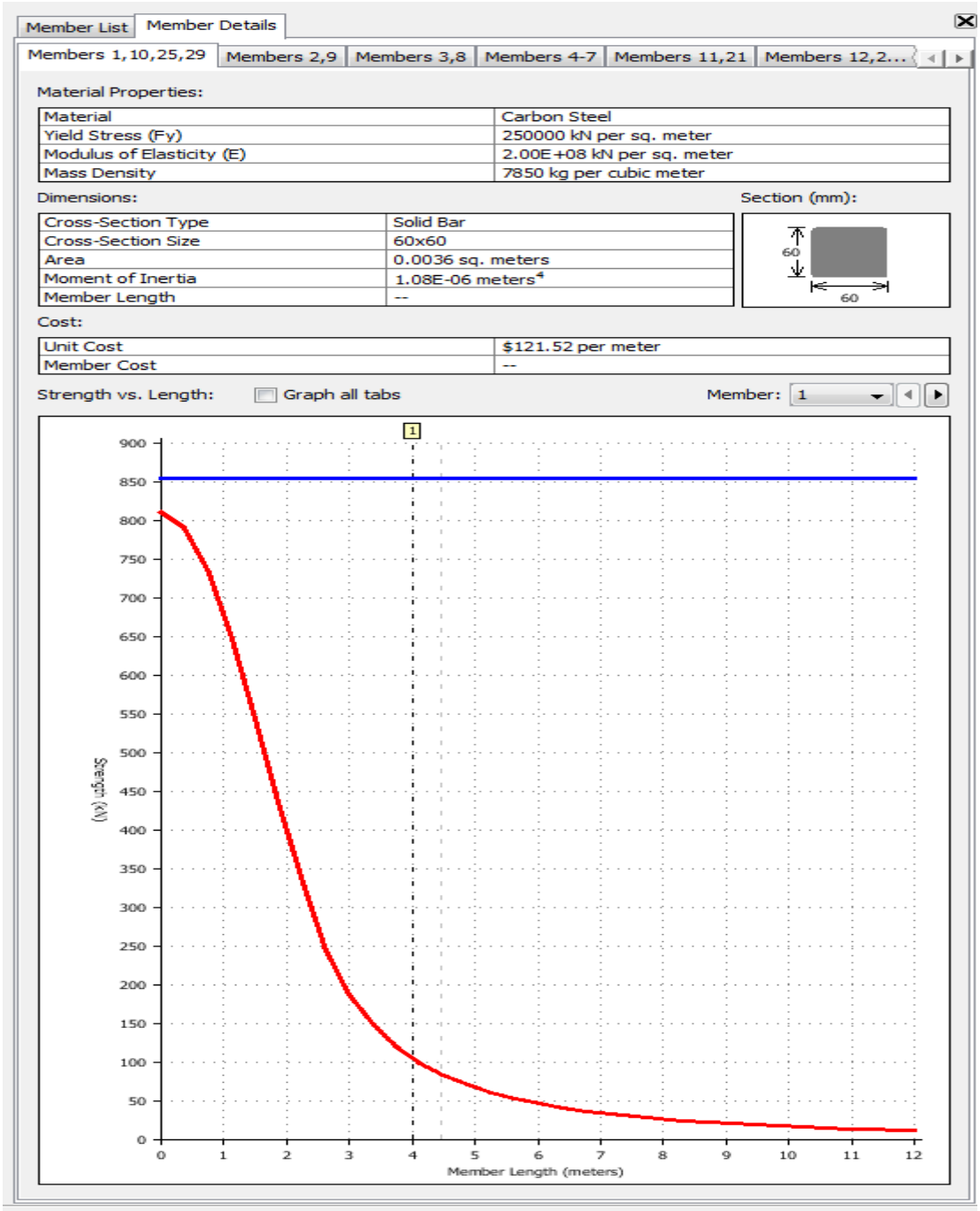
Table 5
Warren Truss Bridge
Load Test Results Report from Bridge Designer 2015

Member List | Member Details

Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Bar	60	4.00	230.94	0.00	0.82
2	CS	Bar	100	4.00	138.56	0.00	0.81
3	CS	Bar	110	4.00	125.97	0.00	0.99
4	CS	Bar	130	4.00	106.59	0.00	0.86
5	CS	Bar	130	4.00	106.59	0.00	0.93
6	CS	Bar	130	4.00	106.59	0.00	0.94
7	CS	Bar	130	4.00	106.59	0.00	0.86
8	CS	Bar	110	4.00	125.97	0.00	0.99
9	CS	Bar	100	4.00	138.56	0.00	0.80
10	CS	Bar	60	4.00	230.94	0.00	0.81
11	HSS	Tube	200	4.47	57.58	0.85	0.00
12	HSS	Tube	180	4.00	57.22	0.93	0.00
13	HSS	Tube	240	4.00	42.91	0.84	0.00
14	HSS	Tube	260	4.00	39.61	0.92	0.00
15	HSS	Tube	280	4.00	36.78	0.89	0.00
16	HSS	Tube	280	4.00	36.78	0.93	0.00
17	HSS	Tube	280	4.00	36.78	0.89	0.00
18	HSS	Tube	260	4.00	39.61	0.91	0.00
19	HSS	Tube	240	4.00	42.91	0.82	0.00
20	HSS	Tube	180	4.00	57.22	0.91	0.00
21	HSS	Tube	200	4.47	57.58	0.83	0.00
22	CS	Bar	90	4.47	172.13	0.00	0.82
23	CS	Bar	75	4.47	206.56	0.00	0.96
24	CS	Bar	70	4.47	221.31	0.00	0.85
25	CS	Bar	60	4.47	258.20	0.00	0.81
26	CS	Bar	90	4.47	172.13	0.00	0.80
27	CS	Bar	75	4.47	206.56	0.00	0.93
28	CS	Bar	70	4.47	221.31	0.00	0.82
29	CS	Bar	60	4.47	258.20	0.00	0.77
30	HSS	Tube	180	4.47	63.97	0.91	0.00
31	HSS	Tube	160	4.47	71.97	0.96	0.00
32	HSS	Tube	140	4.47	82.25	0.99	0.00
33	HSS	Tube	120	4.47	95.96	0.93	0.07
34	HSS	Tube	120	4.47	95.96	0.85	0.11
35	HSS	Tube	140	4.47	82.25	0.94	0.00
36	HSS	Tube	160	4.47	71.97	0.92	0.00
37	HSS	Tube	180	4.47	63.97	0.88	0.00
38	HSS	Bar	65	4.47	238.34	0.63	0.29
39	HSS	Bar	65	4.47	238.34	0.93	0.26

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

Members 1,10,25,29 | Members 2,9 | Members 3,8 | Members 4-7 | Members 11,21 | Members 12,2...

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	Solid Bar
Cross-Section Size	60x60
Area	0.0036 sq. meters
Moment of Inertia	1.08E-06 meters^4
Member Length	--

Section (mm):

Cost:

Unit Cost	$121.52 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member: 1

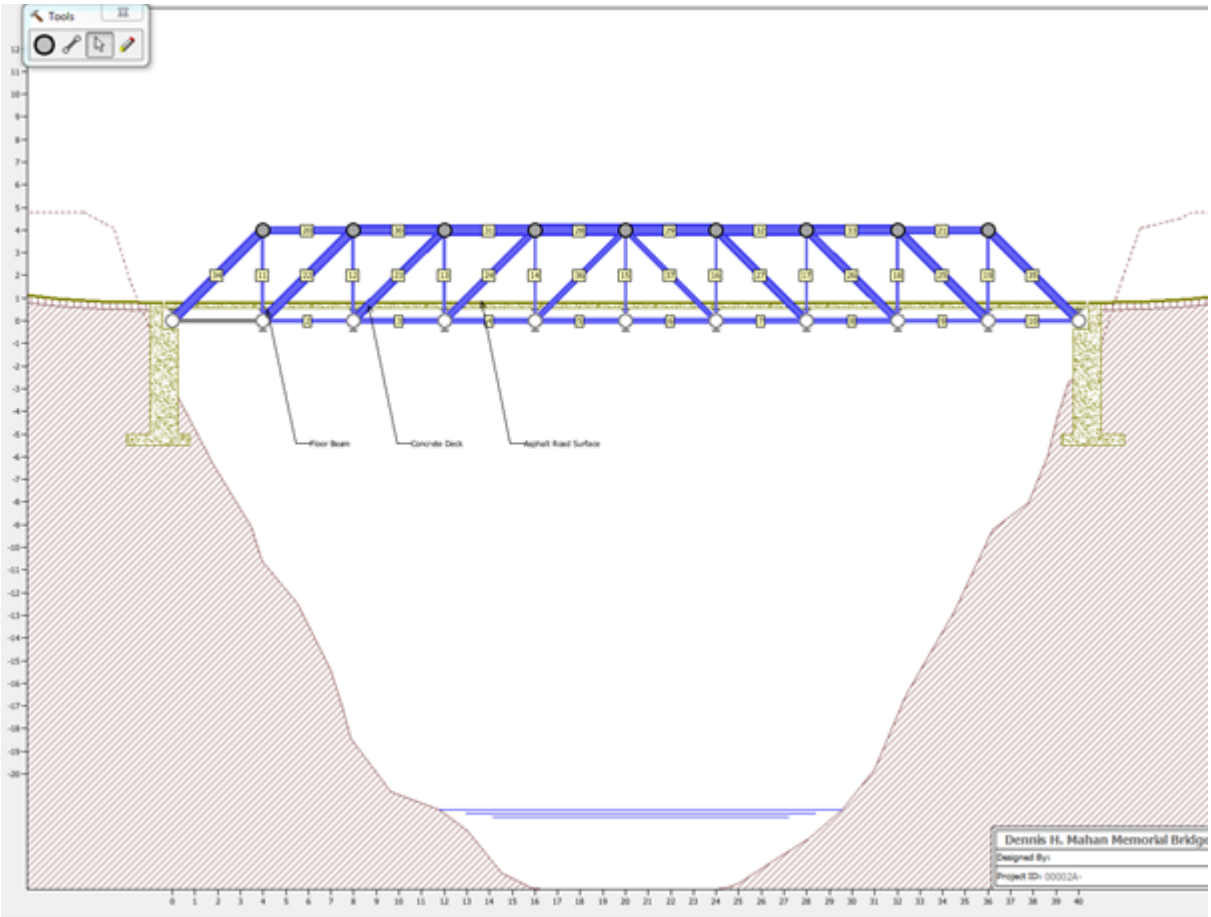
Table 7 Howe Truss Bridge Load Testing Results

Howe Truss Bridge			
Design Team No.	**Actual Bridge Weight (grams)**	**Load at failure (lbs.)**	**Structural Efficiency**
1	**81.3**	**69.7**	**0.857**
2	**64.3**	**33.8**	**0.526**
3	**95.8**	**59.6**	**0.622**
4	**78.5**	**65.4**	**0.833**
5	**79.4**	**99.7**	**1.26**
6	**80.4**	**84.2**	**1.05**
7	**84.7**	**71.0**	**0.838**
8	**82.6**	**44.3**	**0.536**

Table 8 Warren Truss Bridge Load Testing Results

Warren Truss Bridge			
Design Team No.	**Actual Bridge Weight (grams)**	**Load at failure (lbs.)**	**Structural Efficiency**
1	**81.9**	**104.6**	**1.28**
2	**77.1**	**33.9**	**0.439**
3	**74.9**	**50.8**	**0.678**
4	**75.7**	**38.2**	**0.505**
5	**80.9**	**55.4**	**0.685**
6	**90.1**	**75.8**	**0.841**
7	**87.0**	**70.9**	**0.815**
8	**83.6**	**90.3**	**1.08**

FIGURES



Howe Truss Bridge from Bridge Builder 2015

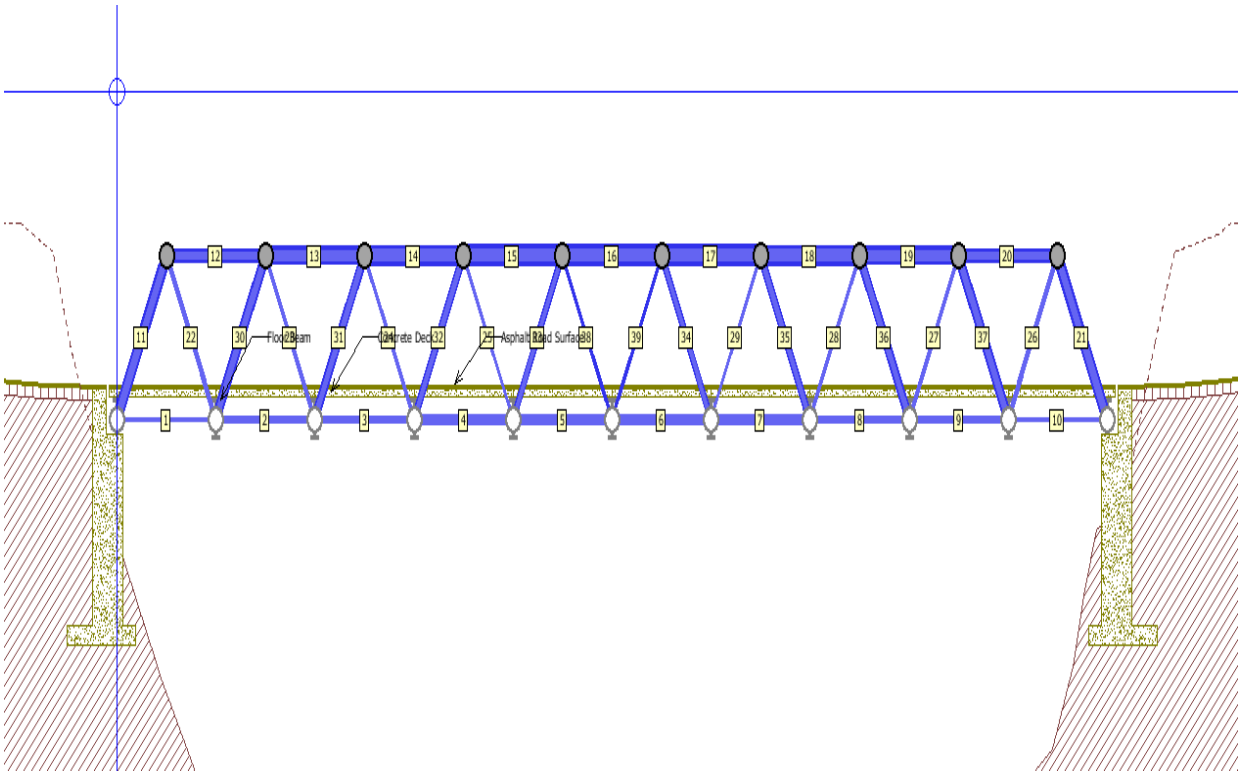


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

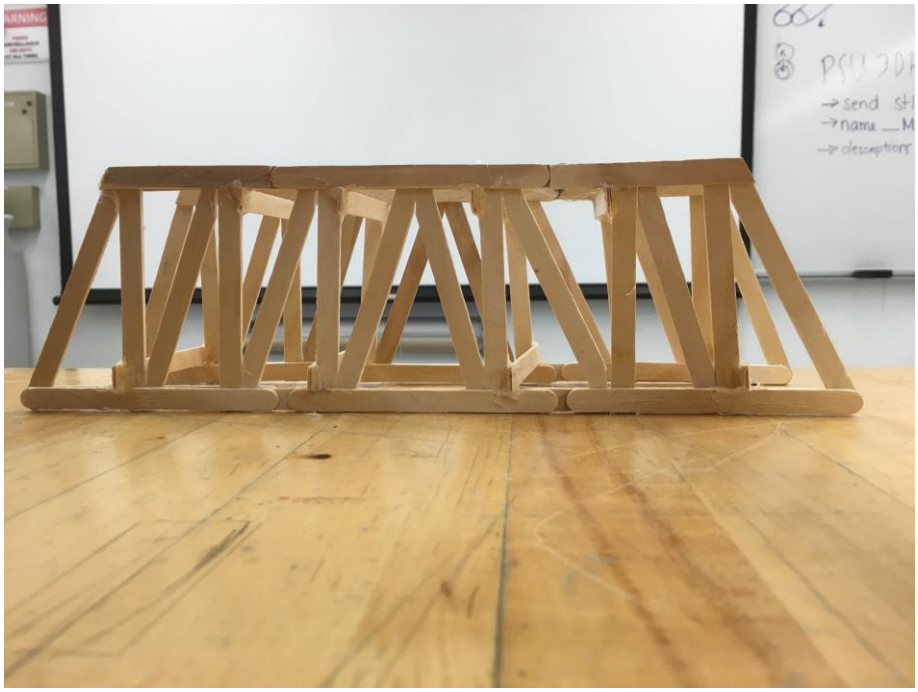


Figure 3. Howe Truss Bridge Prototype before Load Testing

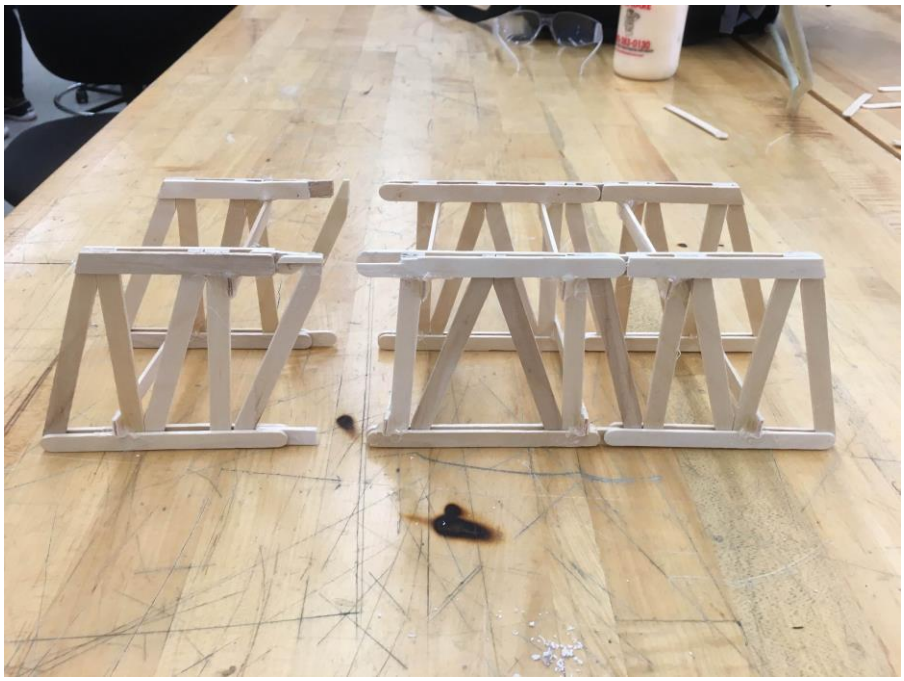


Figure 4. Howe Truss Bridge Prototype Failure after Load Testing

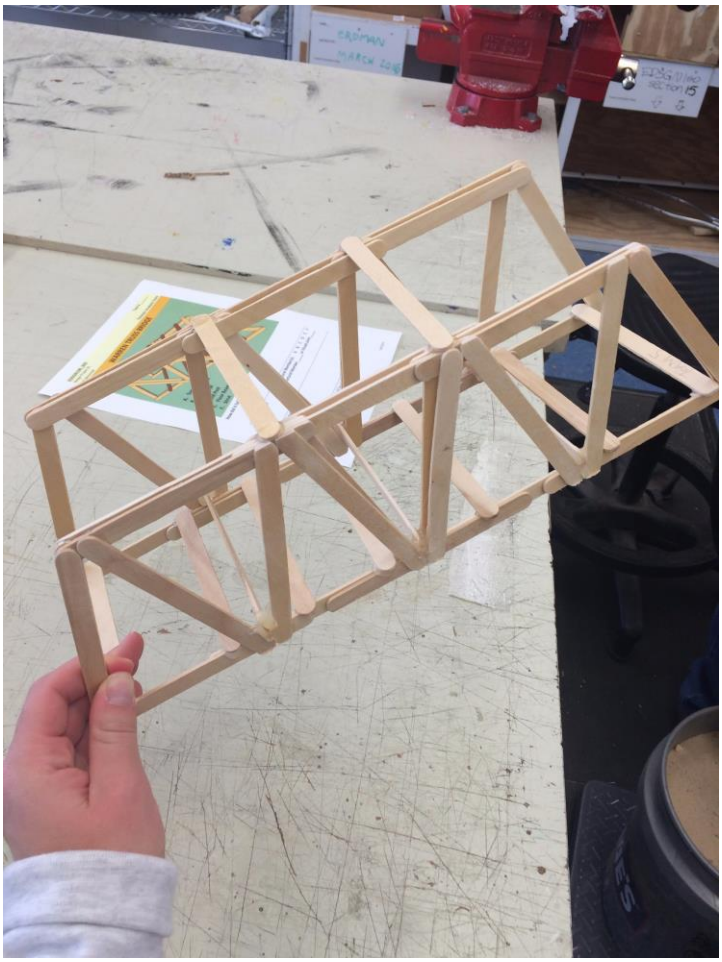


Figure 5: Warren Truss Bridge Prototype before Load Testing

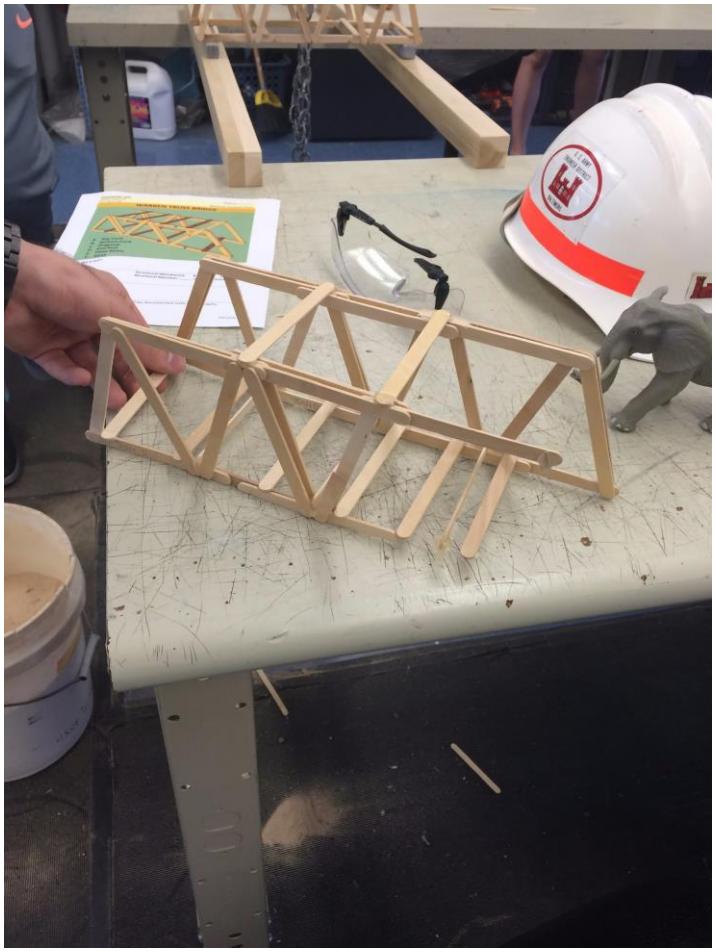


Figure 6: Warren Truss Bridge Prototype Failure after Load Testing

Figure 7 Howe Truss Bridge Structural Efficiency

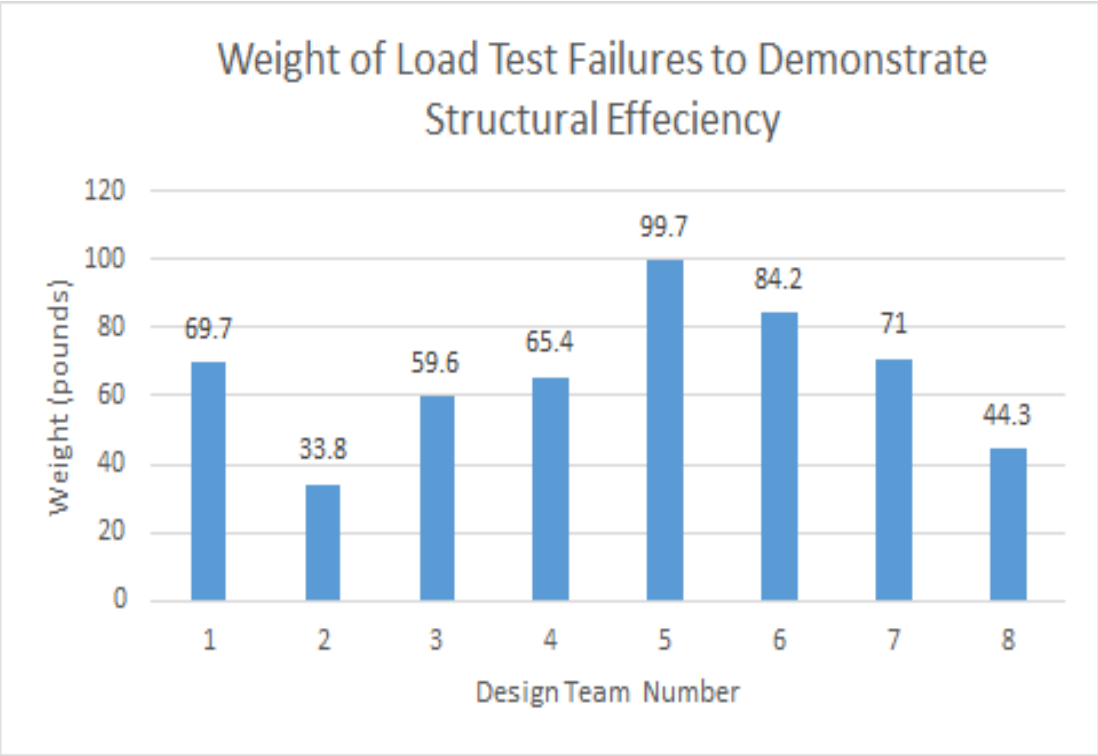
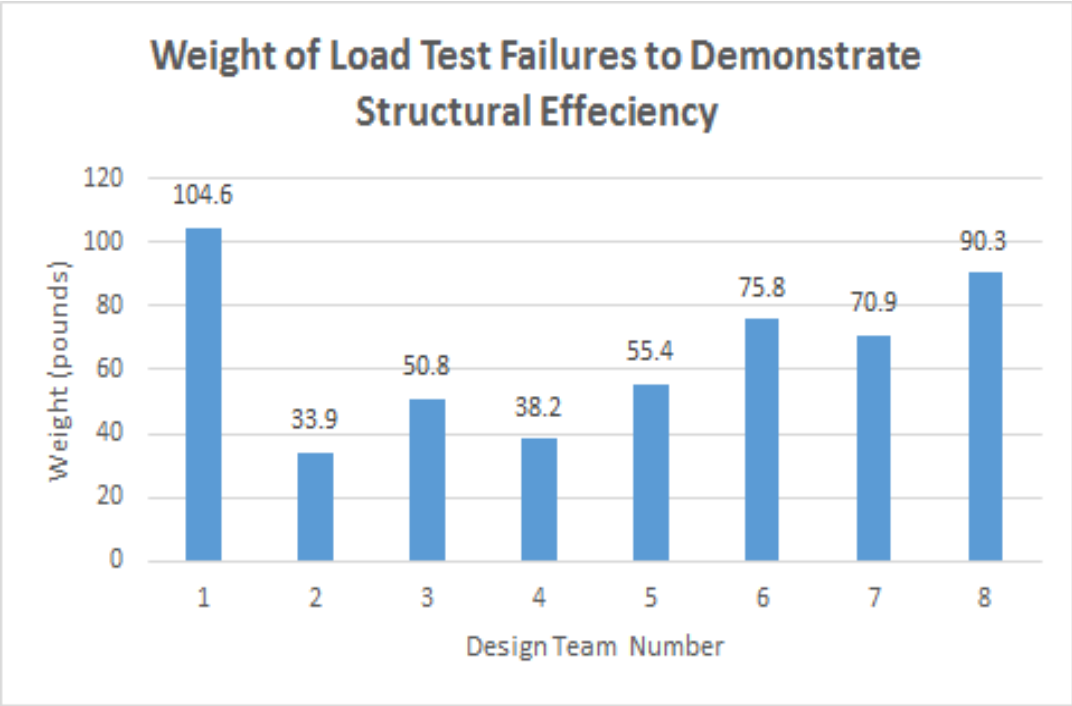



Figure 8 Warren Truss Bridge Structural Efficiency