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. Local flooding from a recent hundred year flood event has completely destroyed a structurally deficient vehicle bridge located in Pennsylvania Department of Transportation (PennDOT) Engineering District 2-0. The destroyed bridge is along a heavily traveled local road and is designated as a vital lifeline for vehicle access to the Mt. Nittany Medical Center located in State College, PA. All traffic must now be re routed more than 10 miles around the destroyed bridge, thereby disrupting residential traffic flow, local commerce, and exposing State College residents to considerable risk, since police and emergency vehicles do not have easy access to that area of College Township. The damaged bridge also severely restricts general regional vehicle access to the Mt. Nittany Medical Center.

Objective. Pennsylvania Department of Transportation of (PennDOT) Engineering District 2-0 has initiated an emergency, fast-track project to expedite the design of a new vehicle bridge over Spring Creek to replace the bridge destroyed by the recent extreme flood event.

Design Criteria. PennDOT District 2-0 has established the design criteria for the replacement bridge to include: standard abutments, no piers (one span), deck material shall be medium strength concrete (0.23 meters thick), no cable anchorages and designed for the load of two AASHTO H20-44 trucks (225kN) with one in each traffic lane. The 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. All other design criteria, such as: steel member type, steel cross section type, and steel member size shall be selected by each EDSGN100 design team.

Technical Approach.

Phase 1: Economic Efficiency. Economic efficiency (cost) was determined using the Engineering Encounters Bridge Design 2015 (EEBD 2015) software based on the requirements, constraints, and performance criteria specified herein. EEBD 2015 was used to perform a systematic and iterative analysis to design a stable Warren and Howe through truss bridge, which was optimized to keep the cost of the

replacement bridge as low as possible; as well as to ensure that the replacement bridge could support its own weight (dead load), plus the weight of a standard truck loading (live load).

Phase 2: Structural Efficiency.

A prototype (i.e., a scale model bridge) bridge was designed and built for both a Warren through truss bridge and a Howe through truss bridge using standard (4-1/2 x 3/8 x 1/12 inch) wooden (white birch) Popsicle (craft) sticks and Elmer's white glue. Hot glue was used to attach the eight struts/floor beams between the two adjacent truss sections. To keep the results consistent, each prototype bridge shall have a maximum of sixty (60) Popsicle sticks, with approximate final bridge dimensions of 13.5 inches in length, 4 inches in height and 4.5 inches in width. All materials used to construct the prototype were provided by PennDOT District 2-0. Each prototype bridge was load tested in the lab to catastrophic failure by test loading the top cord of the truss with a loading block attached to a load suspended from the block. Structural efficiency is the ability of the truss bridge to safely dissipate live loads. Structural Efficiency (SE) is calculated by dividing the load of the bridge supports at failure by the weight of the prototype bridge. The weight of each bridge type shall also be calculated (estimated) based upon a weight study of typical bridge members. All prototype bridges shall also be accurately weighed and recorded prior to load testing. The load at failure of the prototype bridge shall also be accurately measured and recorded. The truss bridge type that exhibited the best structural efficiency when tested to failure in prototype was determined. The design objective was to determine and report which prototype through truss bridge design was more effective at dissipating the force of a load, a Howe through truss bridge or the Warren through truss bridge. After loading and bridge failure, a forensic engineering investigation was performed to determine the cause of bridge failure. The forensic investigation included: why it failed; where it failed; and how it failed. All structural members and joints of each bridge were uniquely identified and marked prior to loading and failure. Both trusses were suitably and uniquely marked, and these markings were used to identify the location and type of failure.

Results.

Phase 1: Economic Efficiency. It was determined that because of the scope of the project, the shape of the Howe truss bridge could be limited in order to save on materials cost. Refer to Attachment 1.

Phase 2: Structural Efficiency. The Howe through truss bridge weighed 0.176 lbs and was constructed out of 58 popsicle sticks. It failed at a live load of 34.3 lbs at the struts connecting the two trusses. The Warren through truss bridge weighed 0.166 lbs and was constructed out of 52 popsicle sticks. It failed at a live load of 55.6 lbs at multiple joints and struts.

Best Solution. The "Best Solution" between the two bridge designs is the Warren through truss bridge. The Warren truss bridge held 21.4 more lbs of live load than the Howe truss bridge. The Warren truss bridge was also only $35,449.93 more than the Howe truss bridge. While the Howe truss bridge would be much more cost efficient, it is inferior in holding live load weight and overall structural efficiency than the Warren truss bridge This data is represented in the tables below.

Conclusions and Recommendations. The previous bridge destroyed by the recent extreme flood event was not structurally stable and able to resist such flood. Therefore, tests should be done to assure that the next bridge will be able to withstand storms that may occur in the area. In addition, the piers should be taller and stronger so that the bridge will not collapse. The next step that should be accomplished to advance the project into Final Design for the replacement bridge is to contact fabricators and contract. For our physical bridges, make sure they are more structurally stable, for example, reducing the wobble.

Respectfully,

James Ross
Engineering Student
EDSGN100 Section 001
Design Team 7
Design Team Armadillo
College of Engineering
Penn State University

Dan Weisner
Engineering Student
EDSGN100 Section 001
Design Team 7
Design Team Armadillo
College of Engineering
Penn State University

Marisa Coltabaugh
Engineering Student
EDSGN100 Section 001
Design Team 7
Design Team Armadillo
College of Engineering
Penn State University

Arianna Vetrano
Engineering Student
EDSGN100 Section 001
Design Team 7
Design Team Armadillo
College of Engineering
Penn State University

ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss. The primary goal for designing the bridge was functionality. The bridge had to hold the required weight without failing. From there, the secondary goal was to reduce the cost of the bridge to the lowest value possible. This was accomplished through a trial and error method to determine the optimal combination of size, type of steel, and hollow/solid tubing. It was determined that structural members used for compression were more cost efficient when hollow tubes were used, and structural members used for tension were more cost efficient when solid bars were used. Quenched and tempered steel was used for the top chords and end posts because they provided the required structural integrity for the lowest cost. For the same reason, carbon steel was used for the hip verticals and diagonals, and high-strength low-alloy steel was used for the bottom chord. It was determined the optimal shape of the bridge was a flat bottom with a semicircle top. The final cost of the bridge was $210,905.88. The tabulated cost calculation report is shown in Table 1. The tabulated load test report is shown in Table 2. A tabulated member detail report for the member with the highest compressive force/strength ratio (Member 28) is shown in Table 3.

Warren Truss. Much like the Howe Truss, trial and error was used to test which materials, structural member types, and sizes would be used to create a cost efficient, yet stable bridge. The tension force/strength and compression force/strength were monitored to assure that the design was at its optimal price. Tension and compression had to be kept below 1.00 in order for the bridge to avoid failure. The final design included a combination structural members. Solid bars were used for the top chords, bottom chords, and end points while hollow tubes were used for the diagonals. The center chords were chosen to be constructed out of carbon steel while the outers chords were high-strength low-Alloy steel. Carbon steel was the cheapest material, so it was used whenever possible. Lastly, the size of the structural members were determined through trial and error by slowly decreasing the size until the bridge collapsed. This helped indicate the smallest possible size the beam could be. The final cost of the warren bridge was $246,355.81.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss

Prototype Bridge. 4-½ x ⅜ x 1/12 inch, white birch, craft Popsicle sticks were used for the prototype's structural members. A concoction of Elmer's white glue and water was used at the joints to hold the structure together. Hot glue was used to attach the struts/floor feams between the two adjacent truss sections. A total of 58 Popsicle sticks were used: 25 sticks per side and 8 sticks to connect the struts/floor beams to the sides of the bridge. The load strength of the prototype was concentrated toward the center of the bridge because it was believed the structural members in the middle would have the highest tension/compression. The prototype can be seen under Figure 3.

Load Testing. The bridge weighed 79.7 grams (0.176 pounds), and the load at failure was 34.3 pounds. The structural efficiency was 195.6, which was the lowest of all the design teams. The maximum structural efficiency was 604.6, and the range was 409. The median structural efficiency was 355.2, the mean was 354.1, and the geometric mean was 331.4. A more detailed analysis can be found under Table 7.

Forensic Analysis. Immediately after the initial load of 34.3 pounds was placed on the bridge, the struts and floor beams wobbled and the whole bridge collapsed. All 8 strut and floor beam Popsicle sticks fell off at the joints. The seventh and eighth diagonal joints for the left side of the bridge (LD 7 and LD 8) also came apart. It was determined that since the struts and floor beams were glued to the bridge on the same day of the load test, the bridge collapsed because the glue did not have sufficient time to dry. This would explain why the sides of the bridge were still mostly intact after the bridge collapsed. The collapsed Howe bridge can be seen in Figure 4.

Results. As seen in Figure 7, the prototype Howe bridge was not structurally efficient compared to the other Howe bridges.

Warren Truss.

Prototype Bridge. The prototype bridge was constructed out of Popsicle sticks, white Elmer's glue, and a small amount of water that was added to the Elmer's glue. A small amount of water was added to the Elmer's glue to help increase the number of polymers in each drop of glue used to construct the bridge. Q-tips were used in the application of glue to the joints and connected members. Binder clips were used to hold the Popsicle sticks together while the glue dried. The Warren Truss bridge used a total of 52 Popsicle sticks.

Load Testing. The bridge weighed 75.5 grams (0.166 pounds), and the load at failure was 55.6 pounds. The structural efficiency was 334.7, which was slightly above the average for the EDSGN100 design teams. The maximum structural efficiency was 494.9, and the range was 291.8. The median structural efficiency was 355.2, the mean was 329.8, and the geometric mean was 317.2. A more detailed analysis can be found under Table 8.

Forensic Analysis. The Warren truss bridge failed because of inefficient gluing, inefficient strut placement, and the crookedness of the bridge when it was constructed. The Warren truss bridge failed at Joints 3, 4, 5 and the left-upper joint. The Warren bridge failed by toppling over sideways and coming apart at the struts.

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)	Carbon Steel Solid Bar	(378.0 kg) x ($4.30 per kg) x (2 Trusses) =	$3,250.61
	Carbon Steel Hollow Tube	(2492.4 kg) x ($6.30 per kg) x (2 Trusses) =	$31,403.77
	High-Strength Low-Alloy Steel Solid Bar	(2329.9 kg) x ($5.60 per kg) x (2 Trusses) =	$26,094.66
	Quenched & Tempered Steel Hollow Tube	(2646.5 kg) x ($7.70 per kg) x (2 Trusses) =	$40,756.85
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses) =	$20,000.00
Product Cost (P)		($1,000.00 per product) x (12 products)	$12,000.00
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	$101,505.88 + $20,000.00 + $12,000.00 + $77,400.00 =	$210,905.88

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

Dennis H. Mahan Memorial Bridge										
Project ID: 00002A-										
Designed By: Armadillo										
#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	QTS	Hollow Tube	220x220x11	5	2314.85	2829.73	OK	0	4237.06	OK
2	CS	Solid Bar	45x45	3	0	59.36	OK	458.5	480.94	OK
3	CS	Solid Bar	60x60	5	0	67.54	OK	633.28	855	OK
4	CS	Hollow Tube	160x160x8	7.21	481.5	538.75	OK	0	1155.2	OK
5	CS	Hollow Tube	100x100x5	6	0	124.45	OK	328.42	451.25	OK
6	CS	Hollow Tube	120x120x6	8.06	117.1	142.93	OK	344.87	649.8	OK
7	CS	Hollow Tube	120x120x6	7	0	189.6	OK	609.75	649.8	OK
8	CS	Hollow Tube	160x160x8	8.06	409.48	451.28	OK	73.05	1155.2	OK
9	CS	Hollow Tube	120x120x6	7	0	189.6	OK	621.09	649.8	OK
10	CS	Hollow Tube	160x160x8	8.06	372.98	451.28	OK	109.55	1155.2	OK
11	QTS	Hollow Tube	200x200x10	4	2100	2530.55	OK	0	3501.7	OK

12	CS	Hollow Tube	120x120x6	7	0	189.6	OK	578.06	649.8	OK
13	CS	Hollow Tube	120x120x6	8.06	99.04	142.93	OK	424.14	649.8	OK
14	QTS	Hollow Tube	200x200x10	4.12	2196.46	2488.09	OK	0	3501.7	OK
15	CS	Hollow Tube	160x160x8	7.21	458.41	538.75	OK	70.84	1155.2	OK
16	CS	Solid Bar	60x60	5	0	67.54	OK	614.07	855	OK
17	CS	Hollow Tube	140x140x7	6.4	295.44	403.86	OK	243.06	884.45	OK
18	CS	Solid Bar	45x45	3	0	59.36	OK	447.83	480.94	OK
19	QTS	Hollow Tube	220x220x11	5	2261.49	2829.73	OK	0	4237.06	OK
20	HSS	Solid Bar	80x80	4	0	333.51	OK	1809.19	2097.6	OK
21	HSS	Solid Bar	80x80	4	0	333.51	OK	1925.79	2097.6	OK
22	HSS	Solid Bar	90x90	4	0	534.22	OK	2130.88	2654.77	OK
23	CS	Hollow Tube	90x90x4	6	54.4	73.82	OK	312.57	326.8	OK
24	QTS	Hollow Tube	190x190x9	4.12	1985.06	2071.38	OK	0	3002.25	OK
25	QTS	Hollow Tube	200x200x10	4.47	2022.74	2364.93	OK	0	3501.7	OK
26	QTS	Hollow Tube	200x200x10	4	2111.81	2530.55	OK	0	3501.7	OK
27	QTS	Hollow Tube	200x200x10	4.12	2224.88	2488.09	OK	0	3501.7	OK
28	QT	Hollow	190x190x9	4.12	2035.94	2071.38	OK	0	3002.2	OK

	S	Tube							5	
29	QTS	Hollow Tube	200x200x10	4.47	2070.47	2364.93	OK	0	3501.7	OK
30	HSS	Solid Bar	80x80	4	0	333.51	OK	1851.88	2097.6	OK
31	HSS	Solid Bar	80x80	4	0	333.51	OK	1975.16	2097.6	OK
32	HSS	Solid Bar	90x90	4	0	534.22	OK	2158.45	2654.77	OK
33	HSS	Solid Bar	90x90	4	0	534.22	OK	2111.81	2654.77	OK
34	HSS	Solid Bar	90x90	4	0	534.22	OK	2195.27	2654.77	OK
35	HSS	Solid Bar	90x90	4	0	534.22	OK	2195.27	2654.77	OK
36	HSS	Solid Bar	90x90	4	0	534.22	OK	2100	2654.77	OK
37	CS	Hollow Tube	140x140x7	6.4	309.11	403.86	OK	208.04	884.45	OK

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

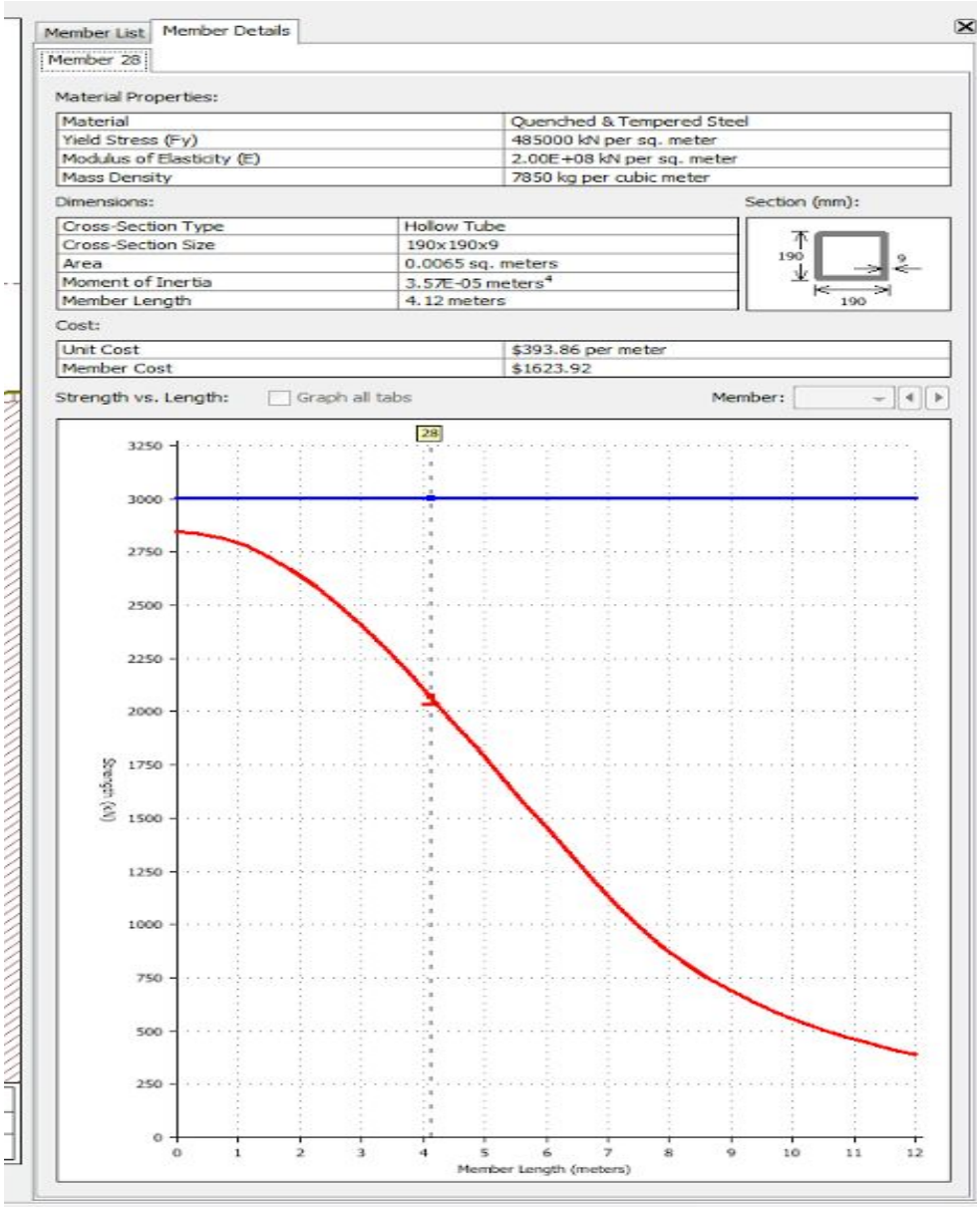


Table 4:
Warren Truss Bridge
Cost Calculations Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(5763.5 kg) x ($4.30 per kg) x (2 Trusses) =	$49,565.78
	Carbon Steel Hollow Tube	(2197.9 kg) x ($6.30 per kg) x (2 Trusses) =	$27,693.63
	High-Strength Low-Alloy Steel Solid Bar	(5508.6 kg) x ($5.60 per kg) x (2 Trusses) =	$61,696.41
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	2 - 80x80 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
	4 - 90x90 mm High-Strength Low-Alloy Steel Bar	(1,000.00 per Product) =	$1,000.00
	4 - 100x100 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 120x120x6 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 130x130x6 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 140x140 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00

	10 - 140x140x7 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	7 - 140x140 mm High-Strength Low-Alloy Steel Bar	($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	$138,955.81 + $21,000.00 + $9,000.00 + $77,400.00 =	$246,355.81

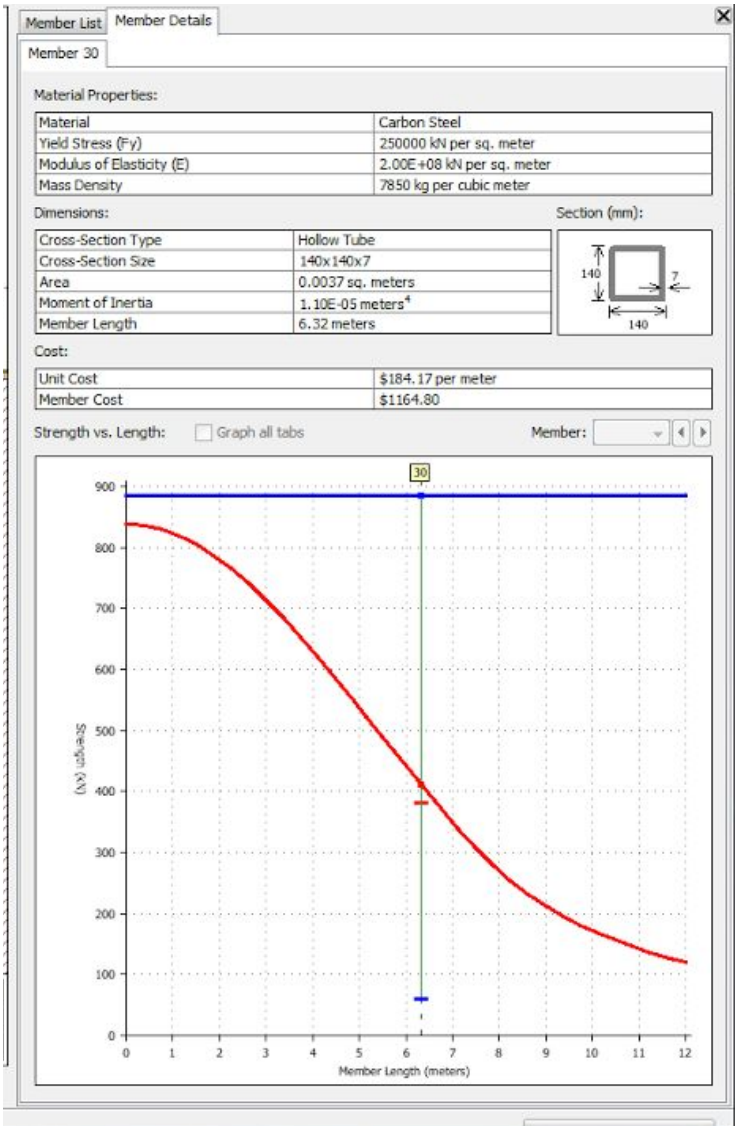
Table 5:
Warren Truss Bridge
Load Test Results Report from Bridge Designer 2015

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	140x140	3.61	1712.38	2900.89	OK	0	4655	OK
2	CS	Solid Bar	90x90	3.61	0	657.51	OK	1213.46	1923.75	OK
3	CS	Solid Bar	80x80	4	0	333.51	OK	949.86	1520	OK
4	CS	Solid Bar	100x100	4	0	814.24	OK	1946.77	2375	OK
5	CS	Solid Bar	90x90	3.61	0	657.51	OK	1186.08	1923.75	OK
6	CS	Solid Bar	80x80	4	0	333.51	OK	928.6	1520	OK
7	CS	Solid Bar	100x100	4	0	814.24	OK	1926.29	2375	OK
8	CS	Solid Bar	100x100	4	0	814.24	OK	2287.49	2375	OK
9	HSS	Solid Bar	90x90	4	0	534.22	OK	2317.22	2654.77	OK
10	HSS	Solid Bar	90x90	4	0	534.22	OK	2517.23	2654.77	OK
11	HSS	Solid Bar	90x90	4	0	534.22	OK	2506.6	2654.77	OK
12	HSS	Solid Bar	90x90	4	0	534.22	OK	2303.57	2654.77	OK
13	CS	Solid Bar	100x100	4	0	814.24	OK	2287.49	2375	OK

14	CS	Solid Bar	140x140	3.61	1674.06	2900.89	OK	0	4655	OK
15	CS	Solid Bar	140x140	4.12	2307.94	2550.11	OK	0	4655	OK
16	HSS	Solid Bar	140x140	4.12	2473.35	2857.89	OK	0	6423.9	OK
17	HSS	Solid Bar	140x140	4	2508.84	2987.82	OK	0	6423.9	OK
18	HSS	Solid Bar	140x140	4	2607.23	2987.82	OK	0	6423.9	OK
19	HSS	Solid Bar	140x140	4	2495.19	2987.82	OK	0	6423.9	OK
20	HSS	Solid Bar	140x140	4.12	2442.64	2857.89	OK	0	6423.9	OK
21	CS	Solid Bar	140x140	4.12	2251.64	2550.11	OK	0	4655	OK
22	CS	Solid Bar	140x140	4.12	1672.91	2550.11	OK	0	4655	OK
23	CS	Solid Bar	140x140	4.12	1635.35	2550.11	OK	0	4655	OK
24	CS	Hollow Tube	140x140 x7	4.47	0	586.91	OK	653.51	884.45	OK
25	HSS	Solid Bar	140x140	4.47	857.88	2501	OK	0	6423.9	OK
26	CS	Hollow Tube	140x140 x7	5.39	381.17	500.03	OK	41.23	884.45	OK
27	CS	Hollow Tube	140x140 x7	5.39	44	500.03	OK	301.6	884.45	OK
28	CS	Hollow Tube	130x130 x6	6.32	57.96	295.06	OK	363.13	706.8	OK
2	CS	Hollow	140x140	6.32	0	411.11	OK	649.	884.45	OK

9		Tube	x7					13		
30	CS	Hollow Tube	140x140 x7	6.32	381.78	411.11	OK	59.84	884.45	OK
31	CS	Hollow Tube	120x120 x6	6.32	70.66	232.26	OK	370.95	649.8	OK
32	CS	Hollow Tube	120x120 x6	6.32	104.27	232.26	OK	337.34	649.8	OK
33	CS	Hollow Tube	140x140 x7	6.32	348.16	411.11	OK	93.45	884.45	OK
34	CS	Hollow Tube	140x140 x7	6.32	0	411.11	OK	615.52	884.45	OK
35	CS	Hollow Tube	130x130 x6	6.32	42.68	295.06	OK	439.52	706.8	OK
36	CS	Hollow Tube	140x140 x7	5.39	104.16	500.03	OK	285.99	884.45	OK
37	CS	Hollow Tube	140x140 x7	5.39	362.09	500.03	OK	114.76	884.45	OK
38	CS	Hollow Tube	140x140 x7	4.47	0	586.91	OK	633.7	884.45	OK
39	HSS	Solid Bar	140x140	4.47	832.42	2501	OK	0	6423.9	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 30

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	140x140x7
Area	0.0037 sq. meters
Moment of Inertia	1.10E-05 meters^4
Member Length	6.32 meters

Section (mm):

Cost:

Unit Cost	$184.17 per meter
Member Cost	$1164.80

Strength vs. Length: Graph all tabs Member:

Table 7

HOWE Truss Bridge
Load Test Results

Design Team No.	Actual Bridge Weight (grams)	Actual Bridge Weight (lbs.)	LOAD at Failure (lbs)	Structural Efficiency
1	84.5	0.186	49.4	265.7
2	75.3	0.166	34.0	205.2
3	81.8	0.180	108.8	604.6
4	78.1	0.172	77.9	453.4
5	81.4	0.179	58.3	325.6
6	85.2	0.187	72.1	384.7
7	79.7	0.176	34.3	195.6
8	80.0	0.176	70.0	397.7
			Minimum	195.6
			Maximum	604.6
			Range	409
			Mean	354.1
			Median	355.2
			Geometric Mean	331.4

Table 8:
Warren Truss Bridge Load Testing Results

WARREN Truss Bridge

Design Team No.	Actual Bridge Weight (grams)	Actual Bridge Weight (lbs)	LOAD at Failure (lbs)	Structural Efficiency
1	85.2	0.187	39	208.1
2	80.3	0.177	55.1	311.9
3	83.4	0.183	90.8	494.9
4	73.2	0.161	32.7	203.1
5	85.3	0.188	60.8	324.0
6	83.8	0.184	70.4	381.9
7	75.5	0.166	55.6	334.7
8	81.9	0.180	68.4	379.6
			Minimum	203.1
			Maximum	494.9
			Range	291.8
			Mean	329.8
			Median	329.4
			Geometric Mean	317.2

FIGURES

Figure 1. Howe Truss Bridge Model from Bridge Designer 2015

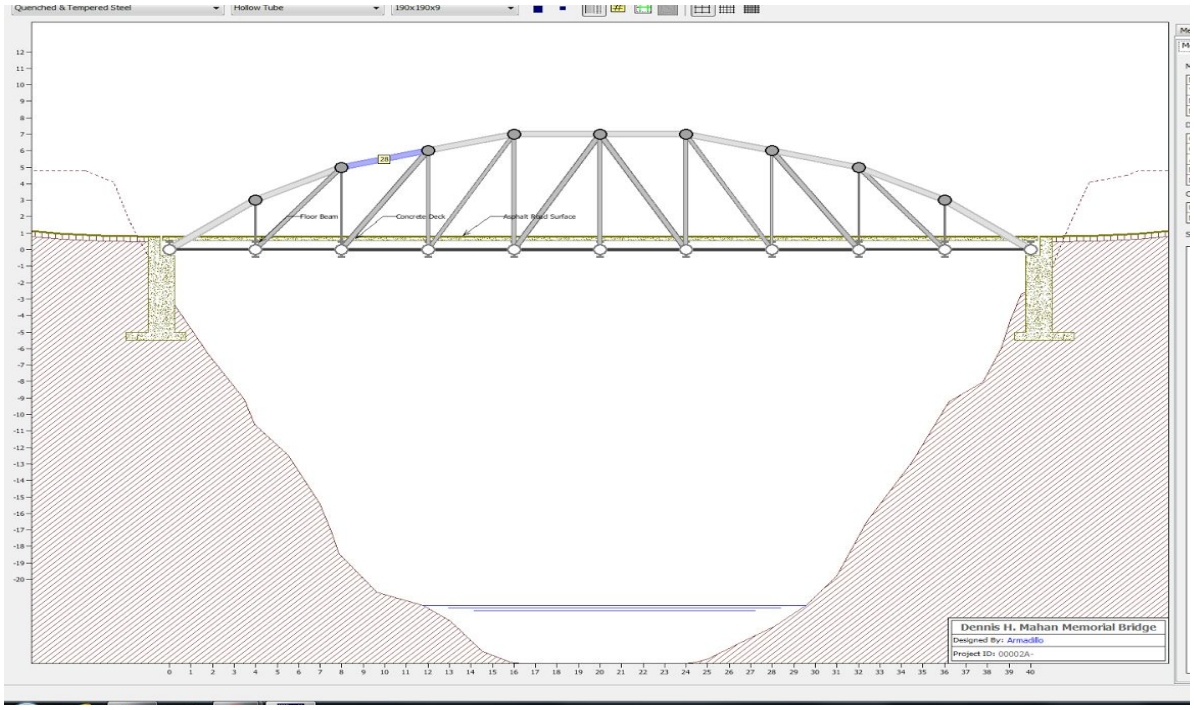


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

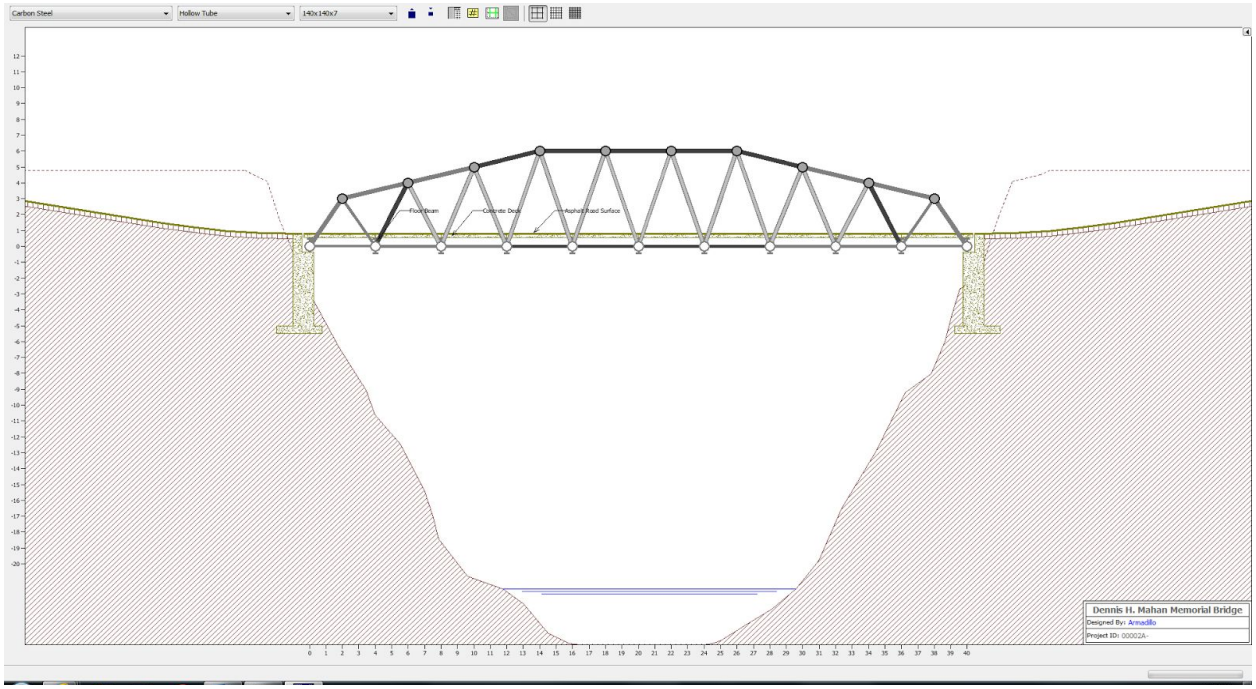


Figure 3.
Howe Truss Bridge Prototype before Load Testing

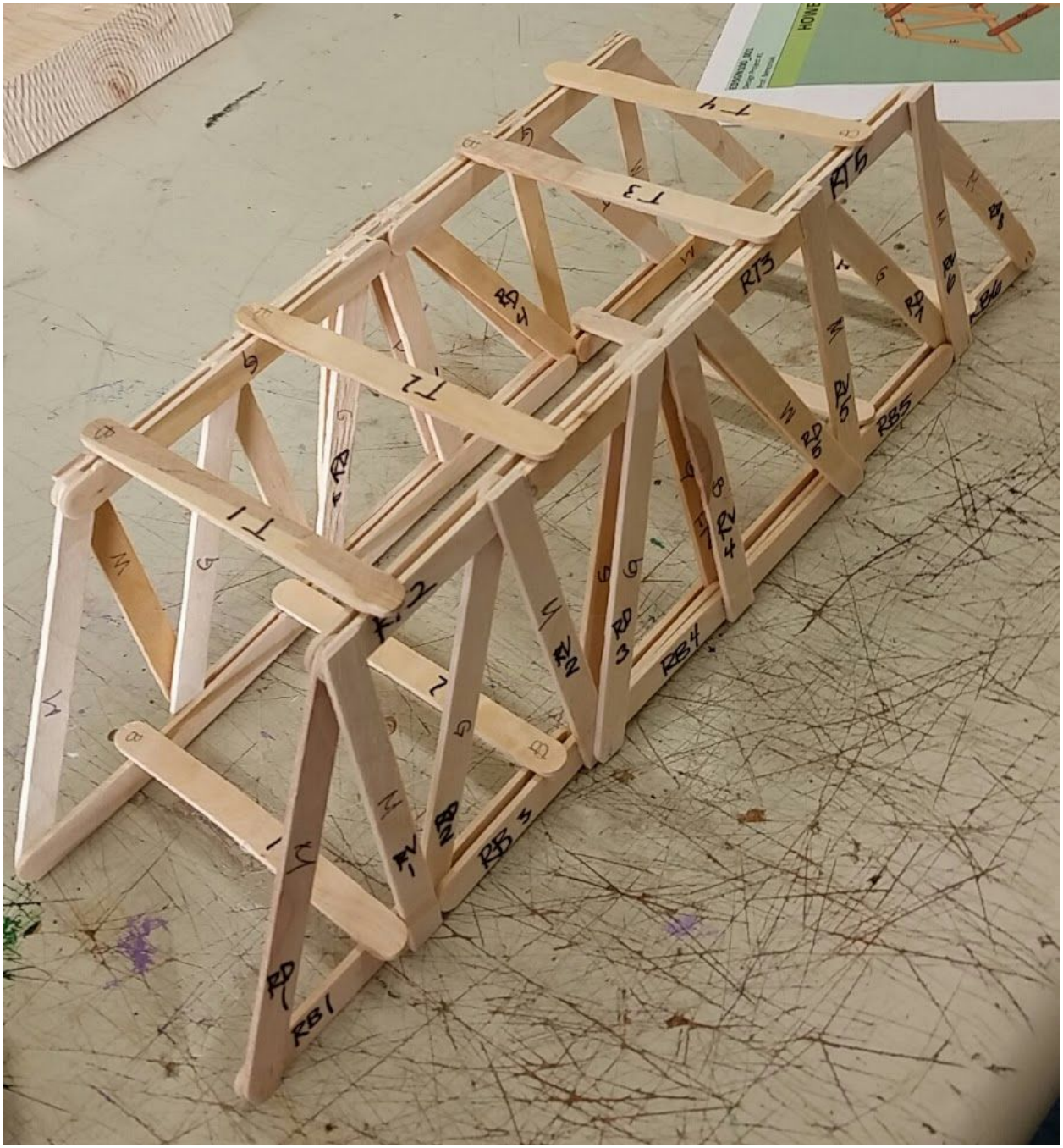


Figure 4:
Howe Truss Bridge Prototype Failure after Load Testing

Figure 5:
Warren Truss Bridge Prototype before Load Testing

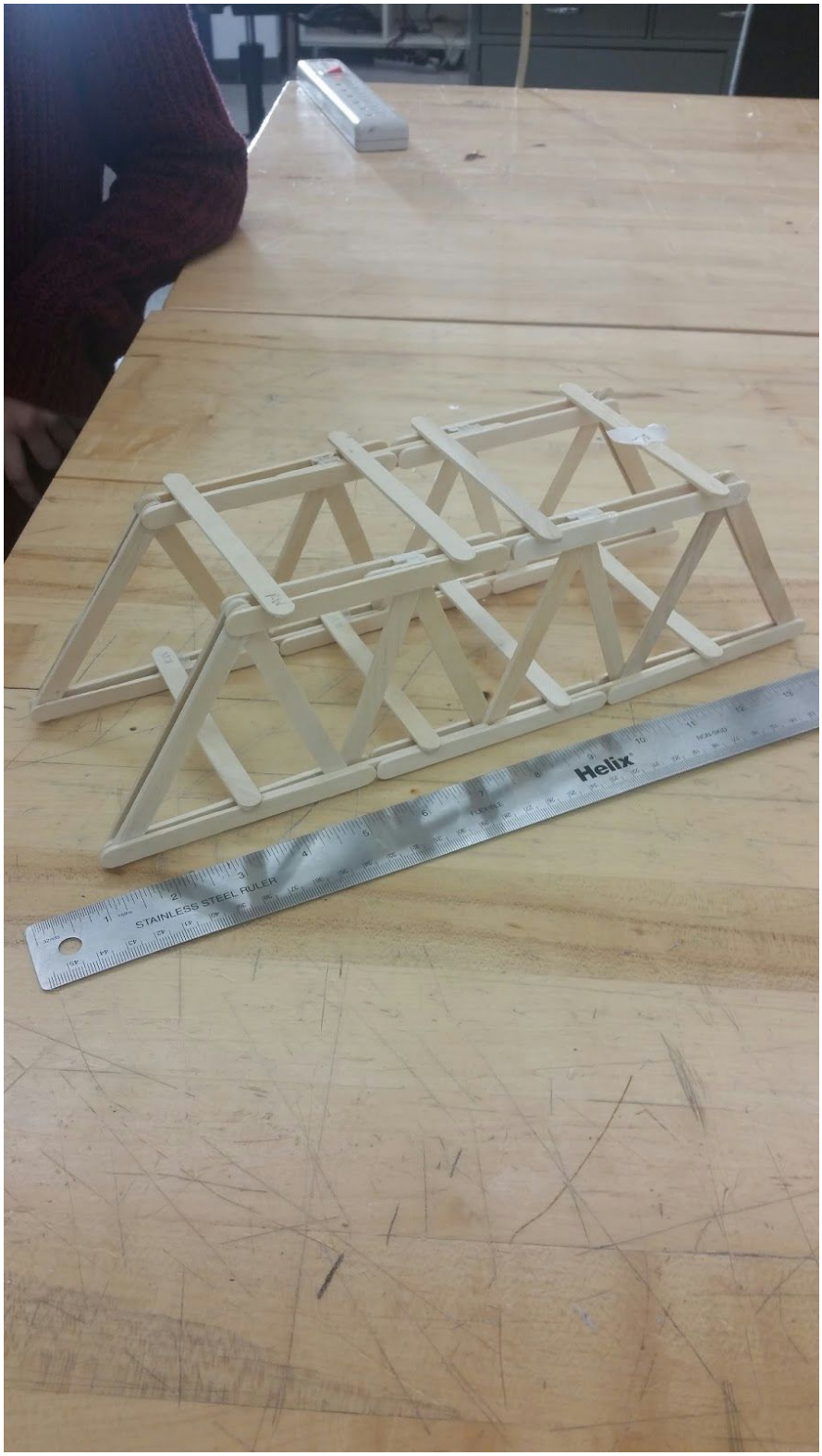


Figure 6:
Warren Truss Bridge Prototype Failure after Load Testing

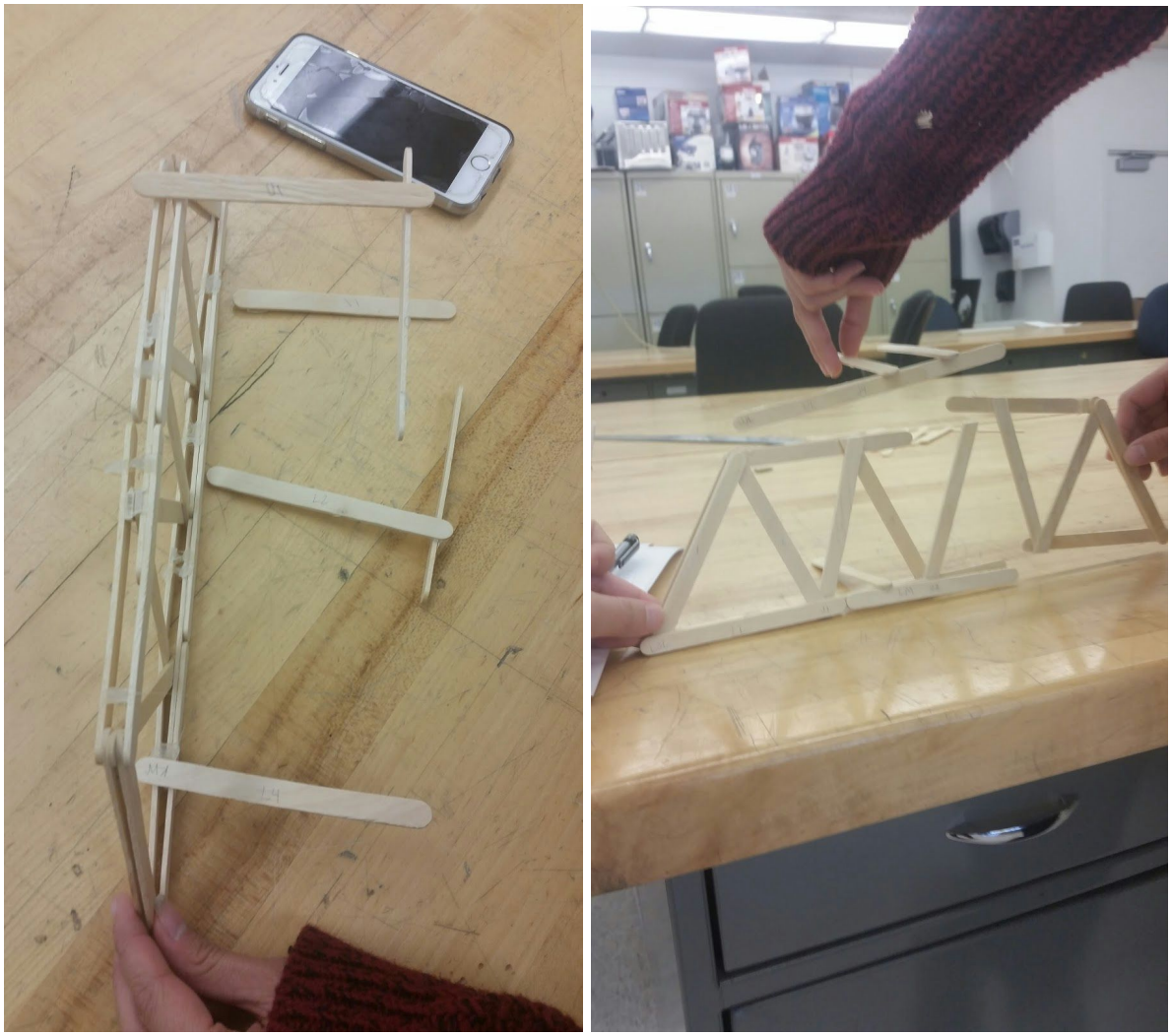


Figure 7:
Howe Truss Bridge Structural Efficiencies

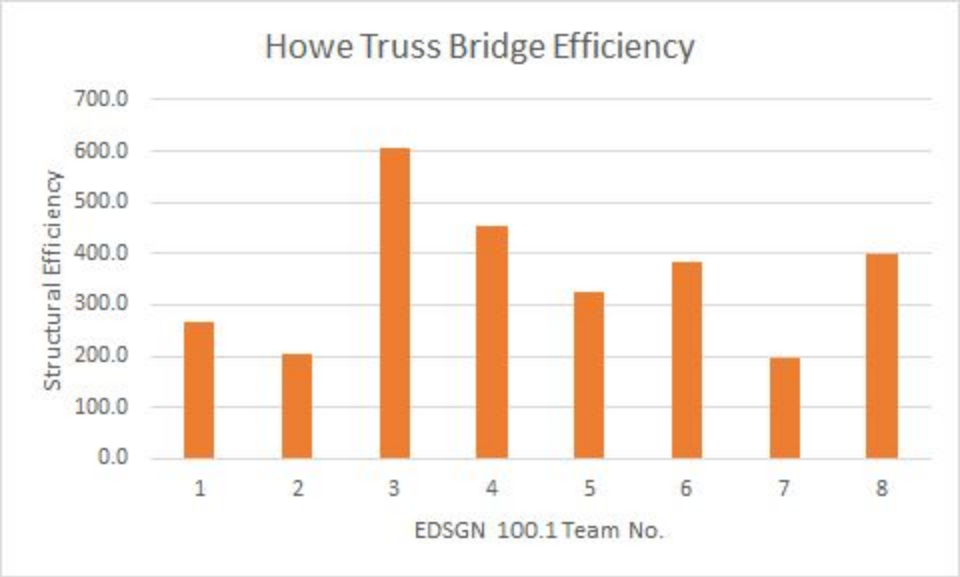
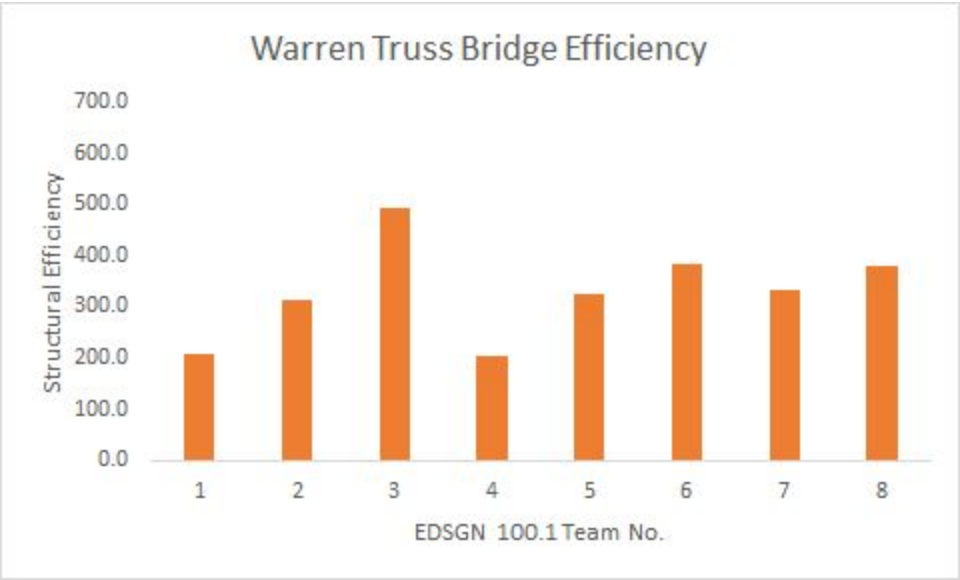



Figure 8.
Warren Truss Bridge Structural Efficiencies