School of Engineering Design, Technology and Professional Programs

213 Hammond Building

University Park, PA 16802-2701

April 3, 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 January 30, 2015.

Statement of Problem.

The bridge located over Spring Creek along Puddintown Road in College Township in Pennsylvania Department of Transportation (PennDOT) Engineering District 2-0 was destroyed by a severe flood. The bridge is functioning as a heavily traveled local road and is vital transportation for the Mount Nittany Medical Center located in State College, PA. The destruction leads to more than 10 miles re-route and obstructing local transportation and potential risk in terms of safety. The damage also hinders the functioning of the Mount Nittany Medical Center.

Objective.

An emergency project was initiated by Pennsylvania Department of Transportation (PennDOT) Engineering District 2-0 to expedite the design of a new bridge to replace the damaged bridge over Spring Creek.

Design Criteria.

The bridge should have standard abutments, no piers; the deck material shall be medium strength concrete (0.23 meters thick); there should be no cable anchorages, and the bridge is designed for the load of two AASHTO H20-44 trucks (225kN) with one in each traffic lane. The bridge deck elevation is set to be 20 meters and the deck span shall be 40 meters.
The type of steel is selected to be carbon steel for both Howe and Warren Truss Bridge, the steel cross section is combined by both bar and tube according to the different forces applied to the steel. The sizes of the steel vary accordingly.

Technical Approach.

Phase 1: Economic Efficiency.

The cost is determined using the Engineering Encounters Bridge Design 2015 software based on the requirement, constraints and performance.
The costs of both Howe and Warren truss bridge are kept as low as possible while both bridges are capable to support its own weight and the weight of two AASHTO H20-44 trucks.

Phase 2: Structural Efficiency.

The prototype bridges of Howe and Warren truss bridge are designed, built and load tested in the lab to catastrophic failure. The structural efficiency is then calculated by dividing the load the bridge supports at failure by the weight of the prototype bridge, and then the more effective bridge at dissipating the force of a load is determined and reported.

Results.

Phase 1: Economic Efficiency.

In terms of the lower cost, since both bridges have the same output as supporting the two AASHTO H20-44 trucks, and the Howe truss bridge has lower cost at $236,904.51 compared to the Warren bridge at, as indicated in Attachment 1. The Howe truss bridge has greater economic efficiency.

Phase 2: Structural Efficiency.

As stated in attachment 2, the Howe through truss bridges tested in the lab can support the load range from 187 lbs to 541 lbs with a range width of 354 lbs and mean load 334 lbs, while the Warren through truss bridges can support the load range from 175 lbs and 443 lbs with a range of 267 lbs wide and mean load 290 lbs. Thus, in general the Howe through truss bridges have higher structural efficiency

since the minimum, maximum and mean load of the Howe truss bridges are all higher than those of the Warren bridge, and both of the bridges were made of the same materials.

Best Solution.

The best solution to the problem should be the building of a Howe bridge over the Spring Creek. From the economy efficiency analysis and the data from Table 1 to 3 and Table 4 to 6, the cost of the Howe bridge is more than $3000 lower than the cost of Warren truss bridge at supporting the same amount of load. From the structural efficiency analysis, the Howe truss bridges have higher efficiency in average than the Warren bridges making from the same materials, thus the building of the Howe bridges has greater structural performance with 44 lbs more capable load while the economic performance is better than those of Warren bridges since it is more than $3000 cheaper. A design of Howe through truss bridge would be the best solution.

Conclusions and Recommendations.

In comparison between the Howe truss bridges and Warren truss bridges, a design of a Warren through truss bridge is recommended to replace the bridge destroyed by the flood. To finalize the design for the replacement, an investigation of the local condition is recommended for the next step. The investigation should include the condition of the base of the bridge, such as the structure and the component of the ground, which will affect greatly in terms of the bridge structural efficiency and building cost. Also, the situation of the flood should also be investigated so reinforcement can be made to the bridge to encounter another possible flood.

Respectfully,

Zhenyuan Yuan
Electrical Engineering Student
EDSGN100 Section 002
Design Team 8
Design Team Donut Shooter
College of Engineering
Penn State University

Yechen Wang
Electrical Engineering Student
EDSGN100 Section002
Design Team 8
Design Team Donut Shooter
College of Engineering
Penn State University

Garrett Skinner
Nuclear Engineering Student
EDSGN100 Section002
Design Team 8
Design Team Donut Shooter
College of Engineering
Penn State University

ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss.

The cost details for Howe Truss bridge design can be viewed in the table 1 to table 3 in the lists of the tables and figures reports. The lowest cost for the Howe truss is $236,904.51 in total as indicated in Table 1. The load test result reported in Table 2 shows that all the bridge members are very close to their supporting limit by more than 80 percent and some are a couple percent off by 100 percent. This indicates the materials used for the bridge are about the limit and little adjustment can be made to reduce the cost further as long as it can still support the two passing truck.

Warren Truss.

The cost details for Warren Truss bridge design can be viewed in the table 4 to table 6 in the lists of the tables and figures reports. The lowest cost for the Howe truss is $239,617.85 in total as indicated in Table 1. The load test result reported in Table 2 shows that all the bridge members are very close to their supporting limit by more than 80 percent and some are a couple percentages off by 100 percent. This indicates the materials used for the bridge are about the limit and little adjustment can be made to reduce the cost further as long as it can still support the two passing truck.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss

Prototype Bridge. We used popsicle sticks and latex to build our Howe Truss bridge. Finally, 60 sticks are used and the dimensions of the bridge is 4 ½ inches in width, 4 inches in height and 13 ½ inches in length with a weight of 78.3 grams. (Figure 3)

Load Testing. Our team has done a good job in Howe truss. Our Howe Truss bridge structural efficiency is 481, which is 147 higher than the average. The minimum, maximum and range of structural efficiency values from all EDSGN100 design teams are 187, 541 and 354. (Table 7)

Forensic Analysis. Our Howe Truss bridge failed due to the break of struts and floor beams. The connections between those members and top/bottom cords are weak so when force is applied, the connections cannot afford the load and finally the bridge bended to one side and failed. (Figure 4)

Results. The average of the structural efficiencies of the Howe truss bridge is 334. The maximum is 541 and the minimum is 187. (Figure 7 and Table 7)

Warren Truss

Prototype Bridge. 60 total popclies were used to the construct the bridge. 26 on each side panel and 4 on both the top and bottom braces. Height 4 1/8" width 4" Length 13 1/8" weight 80.5 g (Figure 5). The bridge was constructed to be stronger in the center because thats where it was believed most of the load would received by the bridge.

Load Testing. The structural efficiently of the Warren bridge was below average, it was 241 about half of the max value of 443 (Table 8). That was because of the lack of the side panels and the lateral bracing being perpendicular. The side panels were caving in. This was done by having the clips when the glue was drying on each side of the bridge on slightly different.

Forensic Analysis. The bridge failed because of a lack of support beams. Which was made into the design so that we could generate enough load to fail the bridge. Also, the side panels were not perpendicular to the top cords. Causing the bridge to already to caved in to the load without much stress. As shown in the picture after load testing the side panel stayed completely intact, only the lack of lateral cross bracing was the problem (figure 6).

Results. As displayed in the graph and table below the results are varied quite a bit depending on design. The average was 290 and the max was 443 more results can be seen in (Table 8).

Howe Truss Bridge
Table 1: Bridge Designer 2015 Cost Calculation Report Table 2: Bridge Designer 2015 Load Test Report Table 3: Bridge Designer 2015 Member Detail Graph Table 7: EXCEL table providing the EDSGN 100 design team numbers versus truss bridge weight (grams), truss bridge weight (lbs), load at failure (lbs) and the calculated structural efficiency calculations for all eight Howe truss bridges
Figure 1: Bridge Designer 2015 image(s) of the Howe truss bridge design Figure 3: Photograph of the prototype Howe truss bridge before load testing Figure 4: Photograph of the prototype Howe truss bridge after failure Figure 7: EXCEL clustered column chart (graph) comparing Structural Efficiencies calculated in Table 7

Warren Truss Bridge
Table4 : Bridge Designer 2015 Cost Calculation Report Table 5: Bridge Designer 2015 Load Test Report Table 6: Bridge Designer 2015 Member Detail Graph Table 8: EXCEL table providing the EDSGN 100 design team numbers versus truss bridge weight (grams), truss bridge weight (lbs), load at failure (lbs) and the calculated structural efficiency calculations for all eight Warren truss bridges
Figure 2: Bridge Designer 2015 image(s) of the Howe truss bridge design Figure 5: Photograph of the prototype Howe truss bridge before load testing Figure 6: Photograph of the prototype Howe truss bridge after failure Figure 8: EXCEL clustered column chart (graph) comparing Structural Efficiencies calculated in Table 7

TABLES

Table 1
Howe 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	(3284.4 kg) x ($4.30 per kg) x (2 Trusses) =	$28,246.18
	Carbon Steel Hollow Tube	(7877.6 kg) x ($6.30 per kg) x (2 Trusses) =	$99,258.32
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses) =	$20,000.00
Product Cost (P)	2 - 90x90 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 100x100 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 110x110 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	3 - 120x120x6 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	3 - 140x140x7 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 150x150x7 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	1 - 160x160x8 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 180x180x9 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 190x190x9 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 240x240x12 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 260x260x13 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 280x280x14 mm Carbon 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**	**$127,504.51 + $20,000.00 + $12,000.00 + $77,400.00 =**	**$236,904.51**

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

					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	0.98
2	CS	Bar	90	4.00	153.96	0.00	0.95
3	CS	Bar	100	4.00	138.56	0.00	0.94
4	CS	Bar	100	4.00	138.56	0.00	0.94
5	CS	Bar	110	4.00	125.97	0.00	0.87
6	CS	Bar	110	4.00	125.97	0.00	0.87
7	CS	Bar	100	4.00	138.56	0.00	0.92
8	CS	Bar	100	4.00	138.56	0.00	0.91
9	CS	Bar	110	4.00	125.97	0.00	0.87
10	CS	Bar	110	4.00	125.97	0.00	0.85
11	CS	Tube	180	7.21	103.15	0.94	0.00
12	CS	Tube	180	7.21	103.15	0.89	0.00
13	CS	Tube	150	7.21	123.37	0.00	0.93
14	CS	Tube	150	7.21	123.37	0.00	0.99
15	CS	Tube	190	5.66	76.46	0.91	0.00
16	CS	Tube	190	5.66	76.46	0.89	0.00
17	CS	Tube	140	6.00	110.35	0.79	0.00
18	CS	Tube	140	6.00	110.35	0.92	0.00
19	CS	Tube	160	3.00	48.28	0.00	0.81
20	CS	Tube	150	3.00	51.33	0.00	0.96
21	CS	Tube	260	5.00	49.52	0.92	0.00
22	CS	Tube	260	5.00	49.52	0.90	0.00
23	CS	Tube	240	4.12	44.23	0.87	0.00
24	CS	Tube	280	4.47	41.13	0.91	0.00
25	CS	Tube	260	4.00	39.61	0.82	0.00
26	CS	Tube	260	4.12	40.83	0.97	0.00
27	CS	Tube	260	4.12	40.83	0.97	0.00
28	CS	Tube	260	4.00	39.61	0.81	0.00
29	CS	Tube	280	4.47	41.13	0.89	0.00
30	CS	Tube	240	4.12	44.23	0.85	0.00
31	CS	Tube	120	7.00	150.20	0.00	0.96
32	CS	Tube	120	4.00	85.83	0.77	0.00
33	CS	Tube	120	4.00	85.83	0.77	0.00
34	CS	Tube	150	6.00	102.65	0.00	0.92
35	CS	Tube	150	6.00	102.65	0.00	0.89
36	CS	Tube	140	8.06	148.28	0.00	0.85
37	CS	Tube	150	8.06	137.94	0.00	0.87

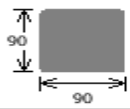
Table 3
Howe Truss Bridge
Member Details Report from Bridge Designer 2015
Member with the Highest Compression (or Tension) Force/Strength Ratio

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	90x90
Area	0.0081 sq. meters
Moment of Inertia	5.47E-06 meters^4
Member Length	--

Section (mm):



Cost:

Unit Cost	$273.42 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member:

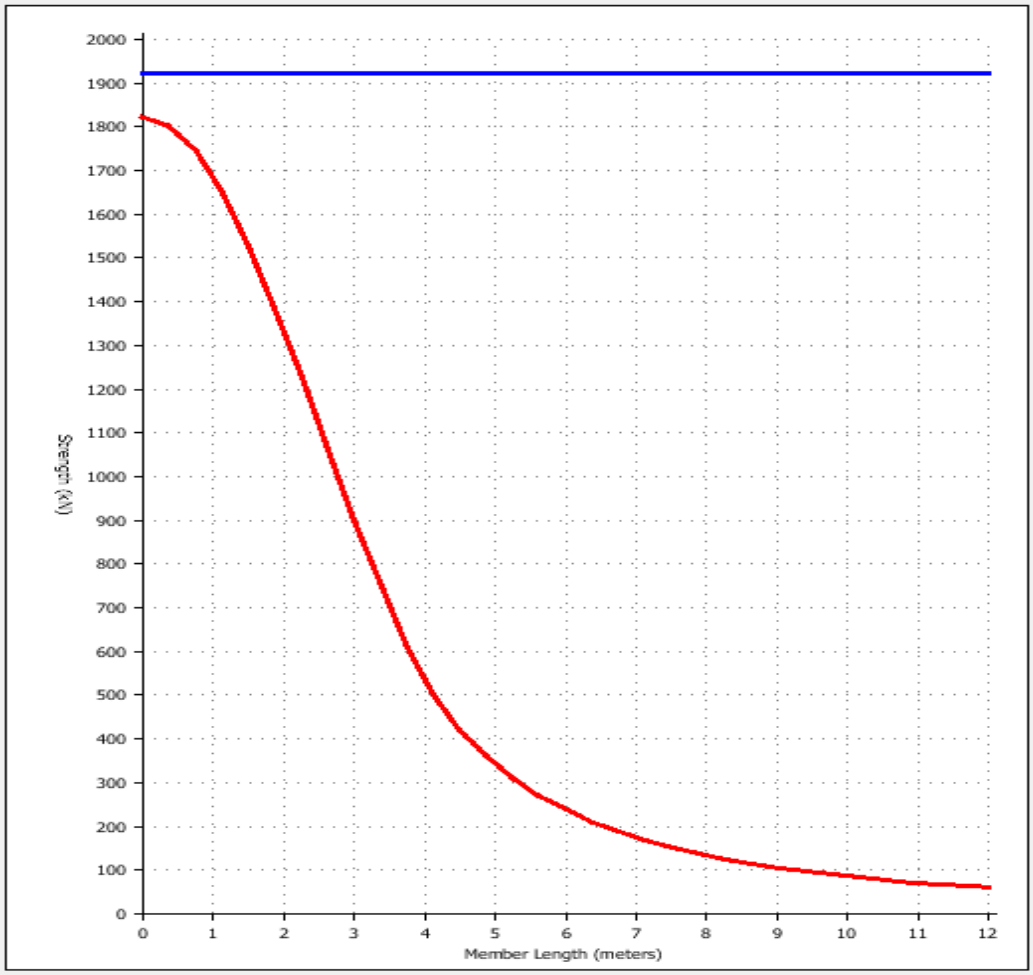


Table 4
Warren Truss Bridge
Cost Calculation Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(5179.5 kg) x ($4.30 per kg) x (2 Trusses) =	$44,543.51
	Carbon Steel Hollow Tube	(6561.5 kg) x ($6.30 per kg) x (2 Trusses) =	$82,674.34
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	4 - 55x55 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 65x65 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
	3 - 90x90 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	3 - 110x110 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 130x130 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 130x130x6 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 160x160x8 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 180x180x9 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 200x200x10 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 220x220x11 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 260x260x13 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 300x300x15 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	3 - 320x320x16 mm Carbon 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**	**$127,217.85 + $21,000.00 + $14,000.00 + $77,400.00 =**	**$239,617.85**

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

Member List | Member Details

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Load Test Results: Compression Force/Strength	Load Test Results: Tension Force/Strength
1	CS	Tube	220	4.47	52.34	0.88	0.00
2	CS	Bar	110	4.00	125.97	0.00	0.67
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	0.94
6	CS	Bar	130	4.00	106.59	0.00	0.94
7	CS	Bar	130	4.00	106.59	0.00	0.87
8	CS	Bar	110	4.00	125.97	0.00	0.99
9	CS	Bar	90	4.00	153.96	0.00	1.00
10	CS	Tube	220	4.47	52.34	0.86	0.00
11	CS	Bar	90	4.47	172.13	0.00	0.80
12	CS	Tube	200	4.47	57.58	0.87	0.00
13	CS	Bar	75	4.47	206.56	0.00	0.93
14	CS	Tube	180	4.47	63.97	0.86	0.00
15	CS	Bar	65	4.47	238.34	0.00	0.95
16	CS	Tube	160	4.47	71.97	0.80	0.00
17	CS	Bar	55	4.47	281.67	0.00	0.91
18	CS	Tube	130	4.47	88.24	0.83	0.14
19	CS	Tube	130	4.47	88.24	0.24	0.51
20	CS	Tube	130	4.47	88.24	0.17	0.56
21	CS	Tube	130	4.47	88.24	0.91	0.09
22	CS	Bar	55	4.47	281.67	0.00	0.96
23	CS	Tube	160	4.47	71.97	0.84	0.00
24	CS	Bar	65	4.47	238.34	0.00	0.99
25	CS	Tube	180	4.47	63.97	0.89	0.00
26	CS	Bar	75	4.47	206.56	0.00	0.96
27	CS	Tube	200	4.47	57.58	0.90	0.00
28	CS	Bar	90	4.47	172.13	0.00	0.82
29	CS	Tube	200	4.00	51.50	0.95	0.00
30	CS	Tube	260	4.00	39.61	0.94	0.00
31	CS	Tube	300	4.00	34.33	0.91	0.00
32	CS	Tube	320	4.00	32.19	0.91	0.00
33	CS	Tube	320	4.00	32.19	0.94	0.00
34	CS	Tube	320	4.00	32.19	0.90	0.00
35	CS	Tube	300	4.00	34.33	0.90	0.00
36	CS	Tube	260	4.00	39.61	0.92	0.00
37	CS	Tube	200	4.00	51.50	0.93	0.00
38	CS	Bar	55	4.00	251.93	0.00	0.99
39	CS	Bar	55	4.00	251.93	0.00	0.96

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

Current Material

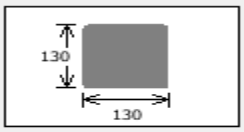
Material Properties:

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:

Cross-Section Type	Solid Bar
Cross-Section Size	130x130
Area	0.0169 sq. meters
Moment of Inertia	2.38E-05 meters^4
Member Length	--

Section (mm):



Cost:

Unit Cost	$570.46 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member:

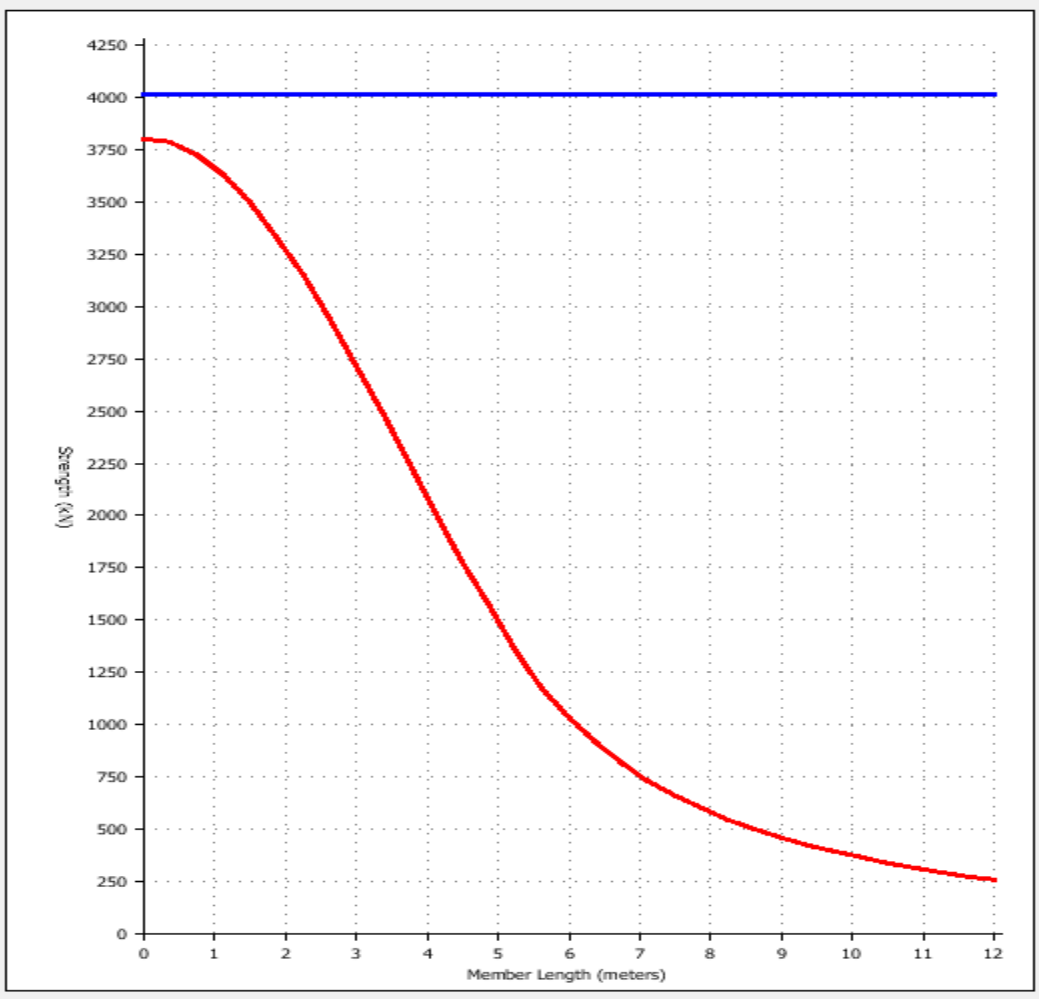


Table 7 Howe Truss Bridge Load Testing Results

HOWE Truss Bridge				
Design Team No.	Actual Bridge Weight (grams)	Bridge Weight (lbs.)	LOAD at Failure (lbs)	Structural Efficiency
1	80	0.1764	95.4	541
2	68.8	0.1517	34.7	229
3	72.9	0.1607	73.8	459
4	75.6	0.1667	55.8	335
5	82.4	0.1817	33.9	187
6	69	0.1521	34	224
7	72.6	0.1601	34.9	218
8	78.3	0.1726	83.1	481
		Minimum	187	
		Maximum	541	
		Range	354	
		Mean	334	

Table 8 Warren Truss Bridge Load Testing Results

WARREN Truss Bridge				
Design Team No.	Actual Bridge Weight (grams)	Bridge Weight (lbs.)	LOAD at Failure (lbs)	Structural Efficiency
1	81.1	0.1788	57.8	323
2	82.0	0.1808	80	443
3	74.8	0.1649	34.7	210
4	78.3	0.1726	57.7	334
5	86.6	0.1909	33.5	175
6	85.4	0.1883	33.3	177
7	77.6	0.1711	71.5	418
8	80.5	0.1775	42.7	241
		Minimum	175	
		Maximum	443	
		Range	267	
		Mean	290	

FIGURES

Figure 1. Howe Truss Bridge Model from Bridge Designer 2015

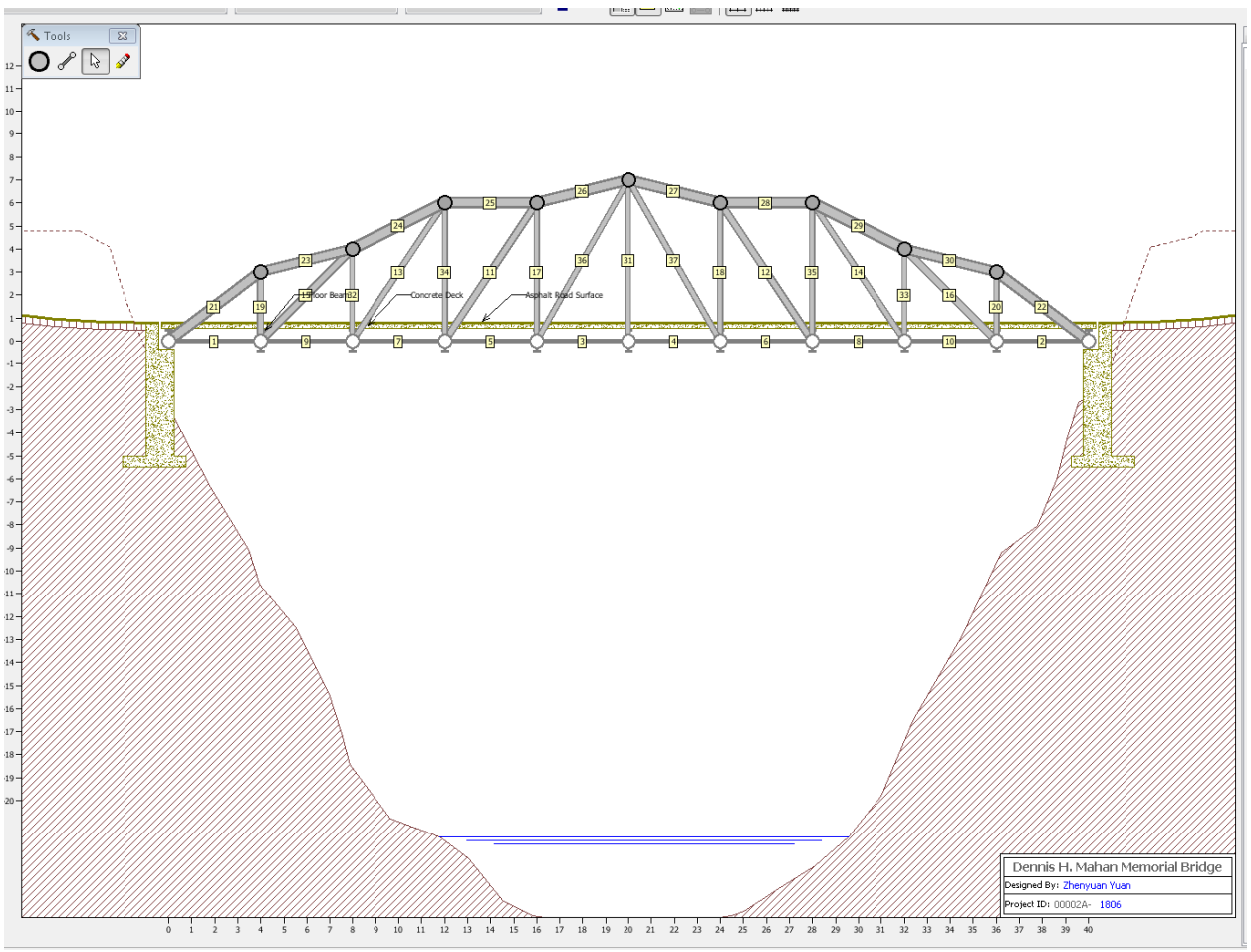


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

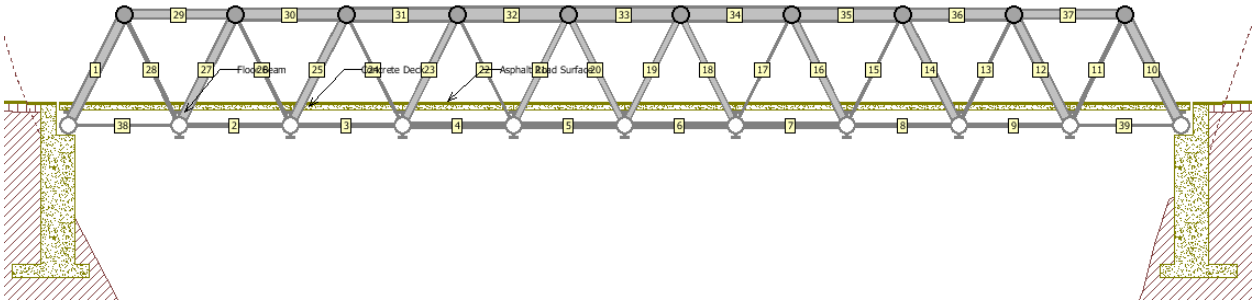


Figure 3. Howe Truss Bridge Prototype before Load Testing

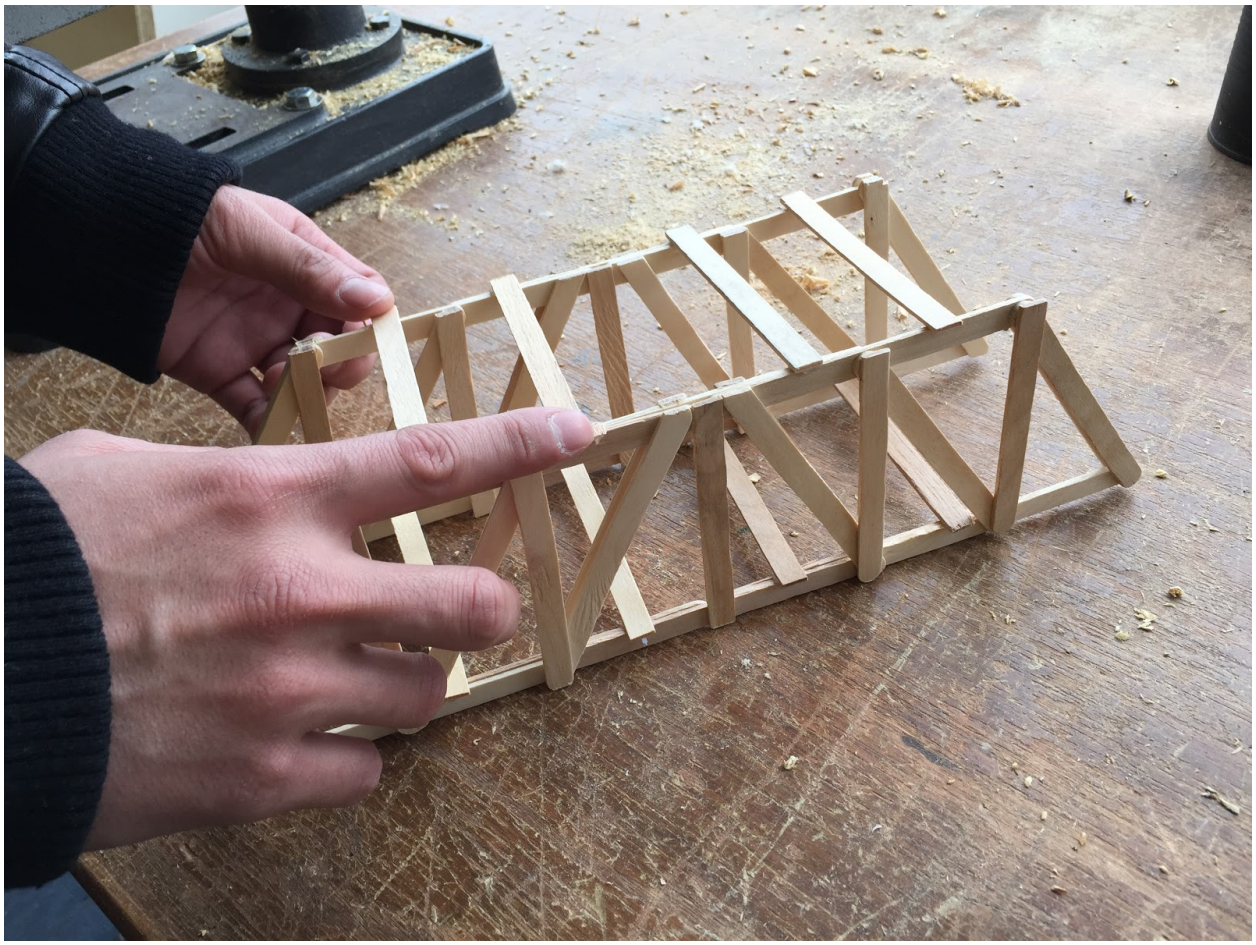


Figure 4. Howe Truss Bridge Prototype Failure after Load Testing

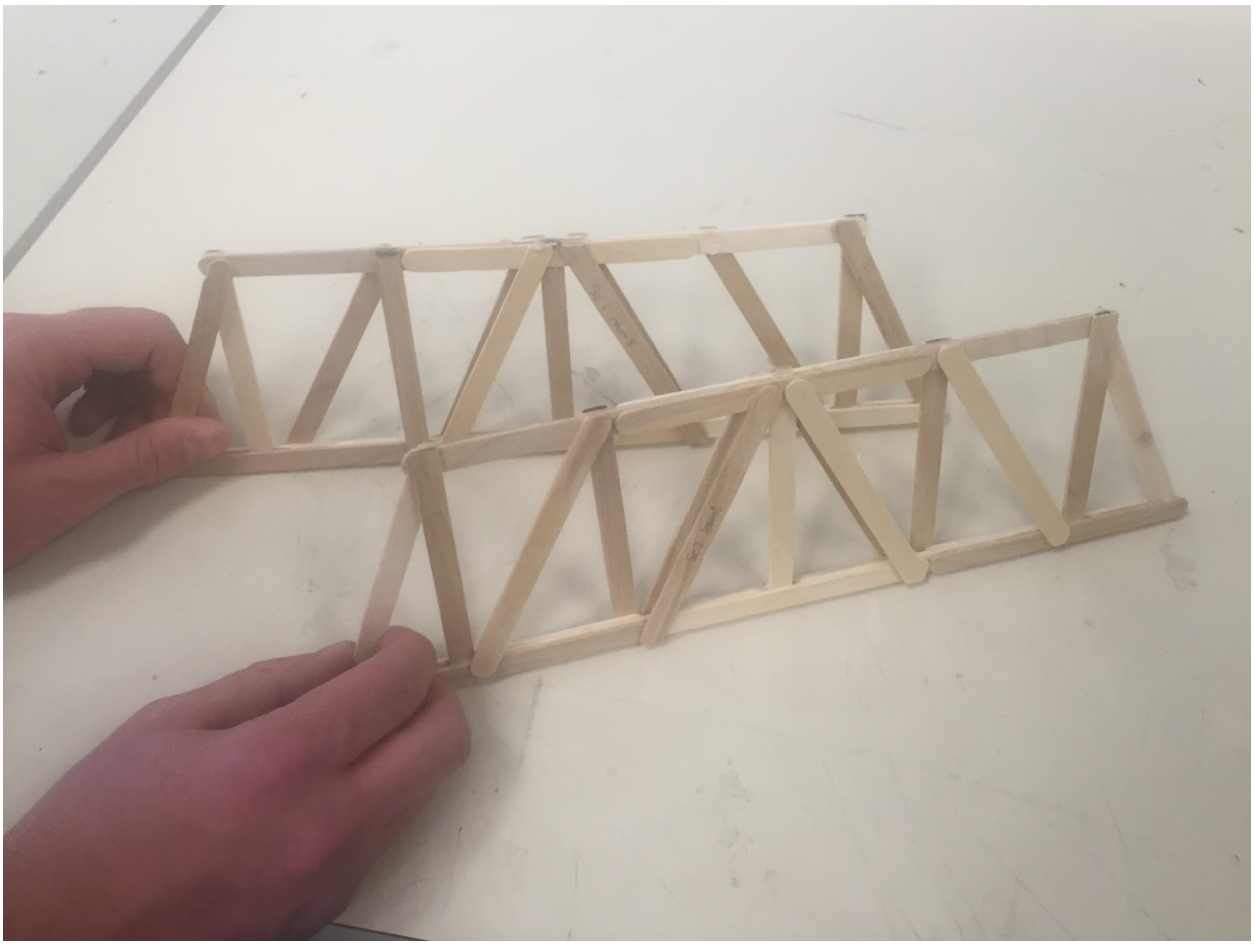


Figure 5. Warren Truss Bridge Prototype before Load Testing

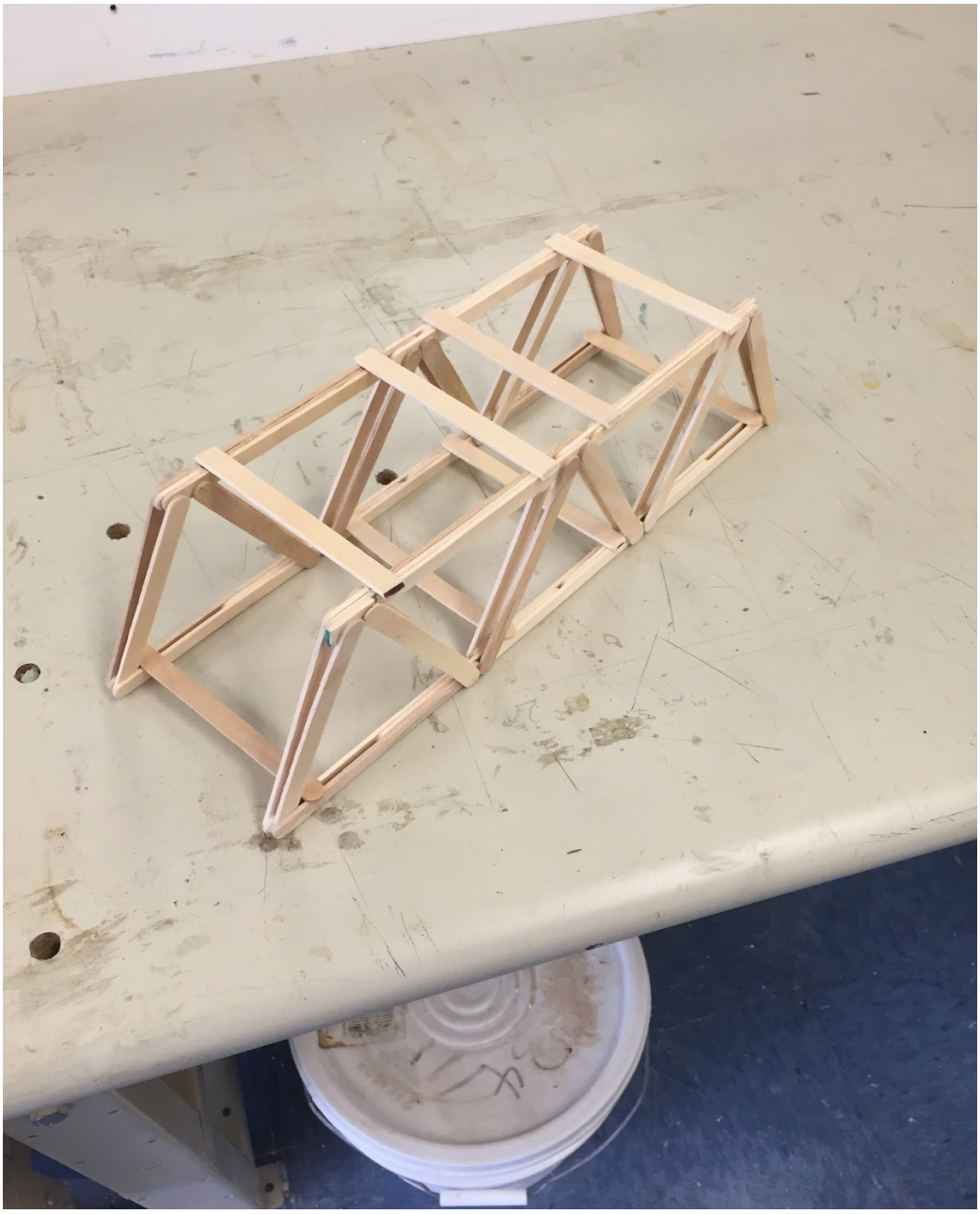


Figure 6. Warren Truss Bridge Prototype Failure after Load Testing

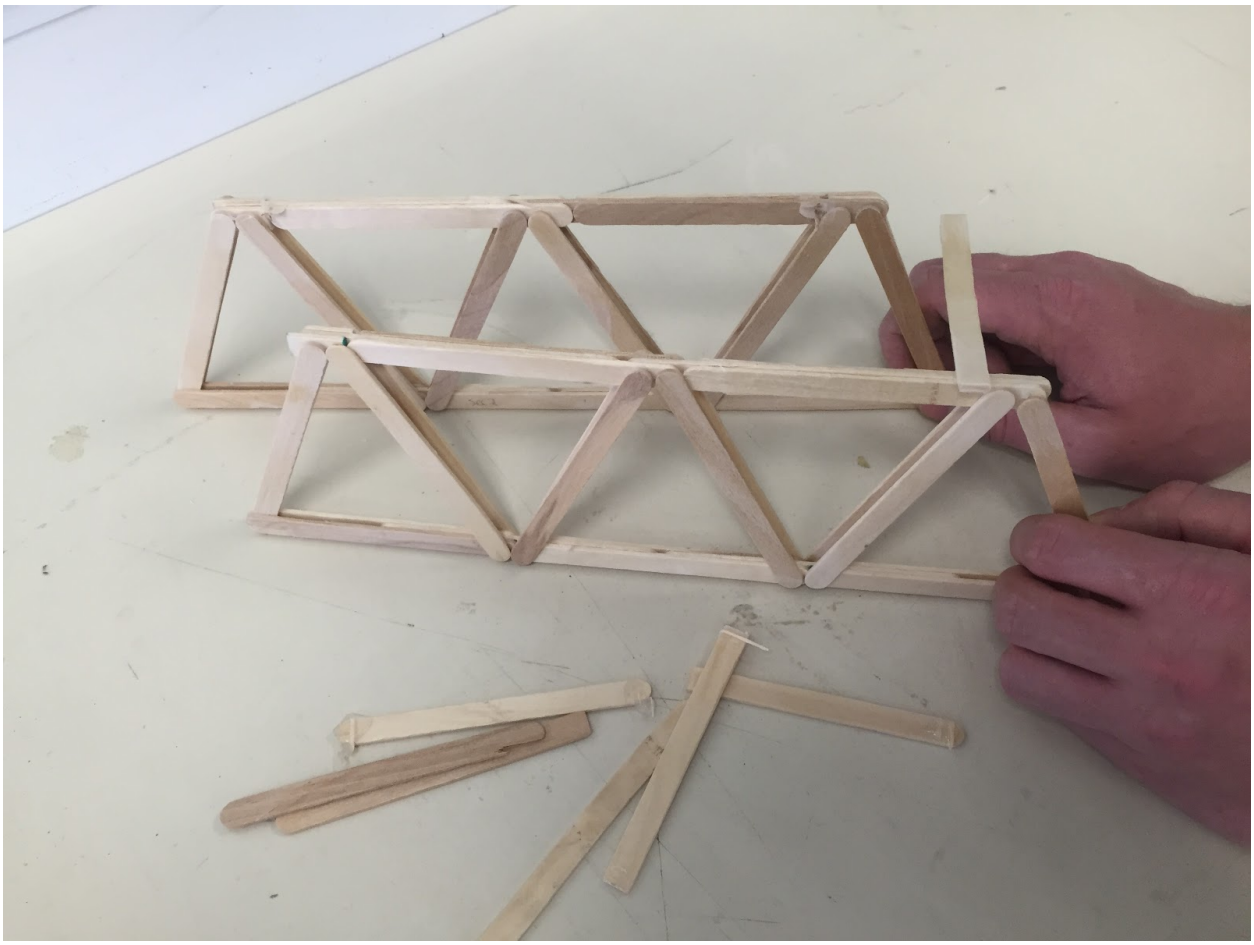


Figure 7. Howe Truss Bridge Structural Efficiencies

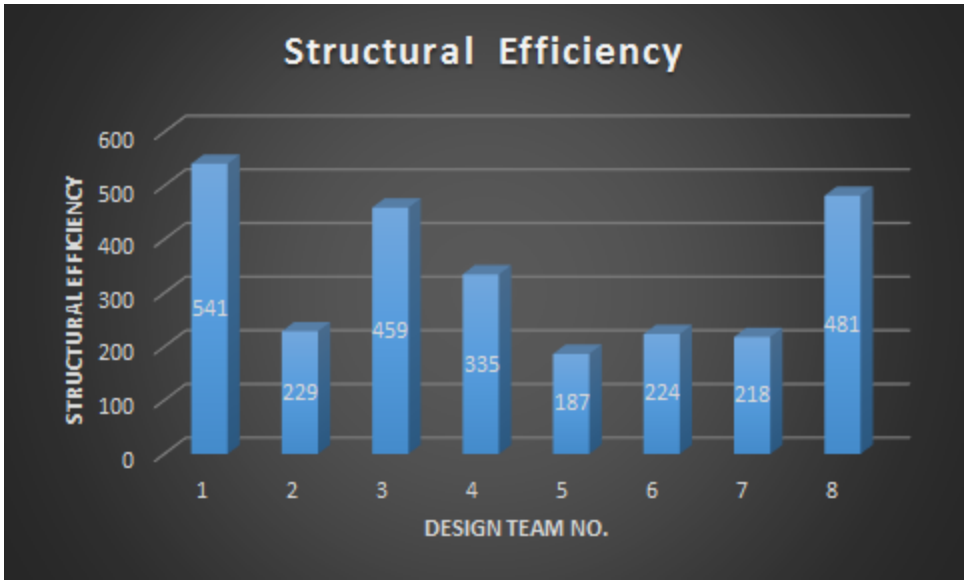
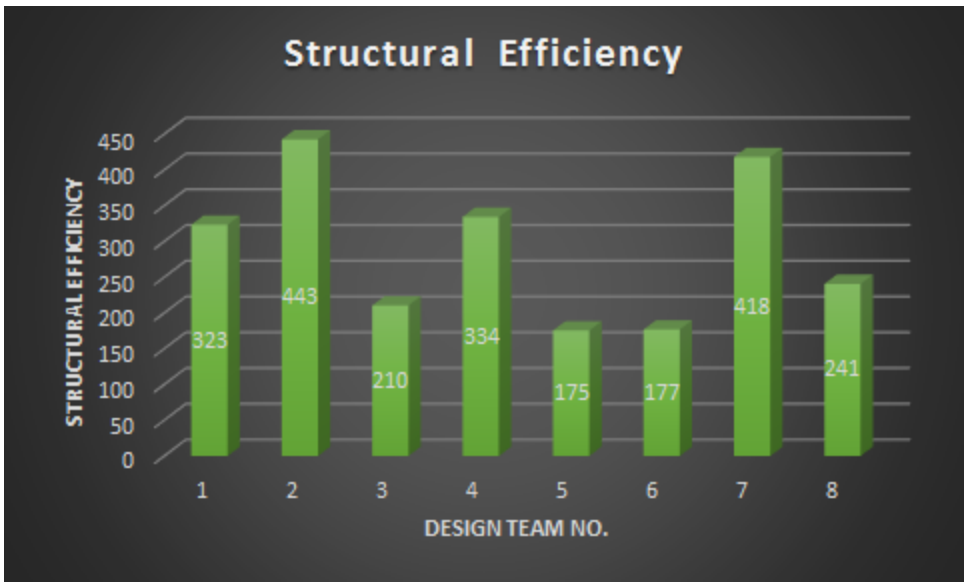



Figure 8. Warren Truss Bridge Structural Efficiencies