PENNSTATE

School of Engineering Design, Technology and Professional Programs
213 Hammond Building

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 100-year flood has recently destroyed a bridge over Spring Creek that services much traffic to Mount Nittany Medical Center. Traffic has been routed 10 miles out of the way to the hospital and is very inconvenient for emergency and general traffic.

Objective. Design a new vehicle bridge to span Spring Creek and replace the one that was destroyed by flood.

Design Criteria. The bridge must include: standard abutments, no piers (one span), 0.23 meter thick medium strength concrete for the deck material, no cable anchorages, strong enough to hold two AASHTO H20-44 trucks (225kN) with one in each lane, deck elevation is 20 meters, deck span is 40 meters, and a Warren through truss and Howe through truss bridge shall be analyzed for use. Member and cross section materials shall be decided by the design team.

Technical Approach.

Phase 1: Economic Efficiency. Using the Engineering Encounters Bridge Design 2015 (EEBD 2015), a Warren and Howe through truss bridge will be built to the lowest cost while performing to the standards of holding its own weight plus the weight of the live trucks.

Phase 2: Structural Efficiency. . A prototype for each bridge shall be built and tested to catastrophic failure. The Structural Efficiency shall be measured by dividing the weight of the load supported by the bridge by the actual weight of the bridge.

Results.

Phase 1: Economic Efficiency. Cost was reduced to its lowest point by using similar material of similar size. The Howe bridge was constructed out of only QTS tubes to reduced the cost greatly. The Warren bridge used two different materials, but it was made solely out of tubes as well.

Phase 2: Structural Efficiency. The structural efficiency for the Howe truss bridge was 282.46, using the formula: load held divided by weight of the bridge. The structural efficiency of the Warren truss was 307.88.

Best Solution. The Warren bridge is a more economically efficient and more structurally efficient bridge based on the tables of cost and the prototype. The Howe bridge cost $229,839.09 to build, while the Warren cost $223,400.49. When looking at the average, maximum, and minimum structural efficiency for the two bridges (shown in tables 7 and 8), the Warren is still the better choice. It beats the Howe in every category. The Warren bridge is the bridge of choice. As shown in figures 4 and 6, the failure of the Howe versus the Warren was much worse. The Howe bridge was completely torn apart, while the Warren had a few members and joints come apart.

Conclusions and Recommendations. The bridge that should replace the destroyed bridge should be a Warren through truss bridge because of its structural stability and low cost. The structural efficiency of this bridge was 308.29 compared to 282.46 produced by the Howe. The materials to build this bridge should be gathered and construction should start immediately. The online blueprint could be used directly to start the building of this bridge.

Respectfully,

Dan Mihalko
Engineering Student
EDSGN 100 Section 002
Design Team 3
Design Team Purple Cobras
College of Engineering
Penn State University

Ian Hutchinson
Engineering Student
EDSGN 100 Section 002
Design Team 3
Design Team Purple Cobras
College of Engineering
Penn State University

Azrina Zulkefli
Engineering Student
EDSGN 100 Section 002
Design Team 3
Design Team Purple Cobras
College of Engineering
Penn State University

Douglas Jorgensen
Engineering Student
EDSGN 100 Section 002
Design Team 3
Design Team Purple Cobras
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. WPBD 2013 results must include: (i) a tabulated cost calculation report as Table 1; (ii) a tabulated load test report as Table 2, (iii) a tabulated member detail report as Table 3 (NOTE: identify the structural member, by member number, with the highest compressive or tension force/strength ratio and provide a "member details" image, as a properly cropped *Prt Scrn* image, for only that member), and (iv) a EEBD 2015 image(s) of the Howe Truss bridge design as Figure 1.> The cost of our Howe bridge was $229,839.09. Materials of similar size were used to further reduced the cost of the bridge. Tabulated cost calculation report is presented as Table 1 and tabulated load test report is presented as Table 2. The member with the highest compressive or tension force/strength ratio is member 9 and the member details is presented as Table 3. An image of the bridge design is presented as Figure 1.

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. EEBD 2015 results must include: (i) a tabulated cost calculation report as Table 4; (ii) a tabulated load test report as Table 5, (iii) a tabulated member detail report as Table 6 (NOTE: identify the structural member, by member number, with the highest compressive or tension force/strength ratio and provide a "member details" image, as a properly cropped *Prt Scrn* image, for only that member), and (iv) a EEBD 2015 image(s) of the warren truss bridge design as Figure 2.> The cost of our warren bridge was $223,400.49. Materials of similar size were used to further reduced the cost of the bridge. Tabulated cost calculation report is presented as Table 4 and tabulated load test report is presented as Table 5. The member with the highest compressive or tension force/strength ratio is member 3 and the member details is presented as Table 6. An image of the bridge design is presented as Figure 2.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss. The structural efficiency was calculated by dividing the load the bridge supports at failure by the weight of the prototype bridge. SE= 59.6/.211 = 282.46

Prototype Bridge. The materials used in the Howe truss bridge were 40 Popsicle sticks held together with white glue. The glue was set to cure for weeks so that the bridge would have greater strength. The floor beams and top braces were attached with hot glue. A photograph can be seen in Figure 3.

Load Testing. The average structural efficiency for Howe bridge from all EDSGN 100 teams is 368.9. Our structural efficiency, which is 282.46, runs a little lower than the average value. The minimum structural efficiency from other team is 221.19 while the maximum value is 584.81. The range of the structural efficiency obtained is about 363.82. The load at our bridge failure result is 59.6. The Load at bridge failure results, bridge weights and calculation of structural efficiencies for all Howe truss bridges are presented as Table 7.

Forensic Analysis. During load testing, the **Joints** throughout the Howe Truss Bridge all seemed to give way, causing a catastrophic structural failure. While the **Top and Bottom Chords** and **End Posts** remained intact, along with most of the **Verticals** and **Diagonals**, The **Verticals** attached to **Joint 2** and **Joint 4** were broken. Weakness in the **Joints**, either due to lack of glue or uneven placement, could not maintain the structure with the given weight and lead to the **Joints** being lifted off either the **Top or Bottom Chords**.

Results. Shown in Figure 8 is the Howe Truss bridge structural efficiencies for each design team's bridge. The Results are as follows: design team one had the highest structural efficiency of about 600. The next highest was design team eight with a rating of 500 structural efficiency. Next was design team six with slightly higher than 400 and design team seven with slightly lower than 400. Team five followed scoring slightly over 300 and team three was next with slightly below 300. Design team two had a rating of about 250 while design team four had the least structurally sound design with a rating of slightly higher than 200.

Warren Truss. The structural efficiency was calculated by dividing the load the bridge supports at failure by the weight of the prototype bridge. SE= 50.8/.165 = 307.88

Prototype Bridge. The materials used in the warren bridge were 54 Popsicle sticks held together with white glue. The glue was set to cure for weeks so that the bridge would have greater strength. The floor beams and top braces were attached with hot glue. A photograph can be seen in Figure 5.

Load Testing. The average structural efficiency for warren bridge from all EDSGN100 teams is 359.14. Our structural efficiency, which is 308.29, runs a little lower than the average value. The minimum structural efficiency from other team is 199.86 while the maximum value is 586.53. The range of the structural efficiency obtained is about 380.67 The load at our bridge failure result is 50.8.The Load at bridge failure results, bridge weights and calculation of structural efficiencies for all Warren truss bridges are presented as Table 8.

Forensic Analysis. During load testing, **Base Member 2,** along with **Joints 2 and 6** gave under the weight and caused for structural failure. Of these failures, however. **Base Member 2** is the most significant, having cleanly broken in two due to weakness from the glue inside the member. **Joints 2 and 6**, however, remain intact, and had simply separated from their locations between **Top Member 4/Member 5** and **Base Member 1/Member 2** respectively. It is possible that this is a result of **Base Member 2's** failure.

Results. Shown in Figure 8 is the Warren Truss bridge structural efficiencies for each design team's bridge. The Results are as follows: design team one had the most structurally sound design with a rating of almost 600. Following team one, design team eight had the second best rating of nearly 500. Team six and seven practically tied and had the next highest rating of almost 400. Teams three and five with a rating of about 300 followed. The least structurally sound designs were from team four, with a rating of slightly higher than 200, and team two, with a rating of slightly below 200.

TABLES

Table 1
Howe Truss Bridge

Cost Calculation Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Quenched & Tempered Steel Hollow Tube	(8145.4 kg) x ($7.70 per kg) x (2 Trusses) =	$125,439.09
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses) =	$20,000.00
Product Cost (P)	5 - 110x110x5 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	7 - 140x140x7 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 160x160x8 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	7 - 180x180x9 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 200x200x10 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 220x220x11 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 240x240x12 mm Quenched & Tempered 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**	**$125,439.09 + $20,000.00 + $7,000.00 + $77,400.00 =**	**$229,839.09**

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

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	QTS	Tube	180	4.00	57.22	1391.25	1923.61	OK	0.00	2836.38	OK
2	QTS	Tube	220	4.00	46.82	2472.49	3209.27	OK	0.00	4237.06	OK
3	QTS	Tube	240	4.00	42.91	3241.89	3958.27	OK	0.00	5042.45	OK
4	QTS	Tube	240	4.00	42.91	3699.31	3958.27	OK	0.00	5042.45	OK
5	QTS	Tube	240	4.00	42.91	3678.61	3958.27	OK	0.00	5042.45	OK
6	QTS	Tube	240	4.00	42.91	3200.48	3958.27	OK	0.00	5042.45	OK
7	QTS	Tube	200	4.00	51.50	2410.70	2530.55	OK	0.00	3501.70	OK
8	QTS	Tube	180	4.00	57.22	1359.46	1923.61	OK	0.00	2836.38	OK
9	QTS	Tube	200	5.66	72.83	1922.57	1930.33	OK	0.00	3501.70	OK
10	QTS	Tube	140	4.00	73.57	0.00	935.47	OK	1359.46	1715.83	OK
11	QTS	Tube	180	4.00	57.22	0.00	1923.61	OK	2410.70	2836.38	OK
12	QTS	Tube	200	4.00	51.50	0.00	2530.55	OK	3200.48	3501.70	OK
13	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3678.61	4237.06	OK
14	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3844.77	4237.06	OK
15	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3844.77	4237.06	OK
16	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3699.31	4237.06	OK
17	QTS	Tube	200	4.00	51.50	0.00	2530.55	OK	3241.89	3501.70	OK
18	QTS	Tube	180	4.00	57.22	0.00	1923.61	OK	2472.49	2836.38	OK
19	QTS	Tube	140	4.00	73.57	0.00	935.47	OK	1391.25	1715.83	OK
20	QTS	Tube	220	5.66	66.21	1967.52	2565.85	OK	0.00	4237.06	OK
21	QTS	Tube	140	4.00	73.57	0.00	935.47	OK	1386.49	1715.83	OK
22	QTS	Tube	200	5.66	72.83	1603.16	1930.33	OK	0.00	3501.70	OK
23	QTS	Tube	140	4.00	73.57	0.00	935.47	OK	1127.41	1715.83	OK
24	QTS	Tube	180	5.66	80.92	1236.22	1377.06	OK	0.00	2836.38	OK
25	QTS	Tube	110	4.00	93.21	0.00	377.57	OK	867.71	967.57	OK
26	QTS	Tube	160	5.66	91.03	869.07	911.02	OK	0.00	2241.09	OK
27	QTS	Tube	110	4.00	93.21	0.00	377.57	OK	608.11	967.57	OK
28	QTS	Tube	140	5.66	104.04	501.95	537.86	OK	90.53	1715.83	OK
29	QTS	Tube	110	4.00	93.21	0.00	377.57	OK	620.99	967.57	OK
30	QTS	Tube	140	5.66	104.04	457.18	537.86	OK	135.31	1715.83	OK
31	QTS	Tube	110	4.00	93.21	0.00	377.57	OK	576.45	967.57	OK
32	QTS	Tube	160	5.66	91.03	824.30	911.02	OK	0.00	2241.09	OK
33	QTS	Tube	110	4.00	93.21	0.00	377.57	OK	836.05	967.57	OK
34	QTS	Tube	180	5.66	80.92	1190.98	1377.06	OK	0.00	2836.38	OK
35	QTS	Tube	140	4.00	73.57	0.00	935.47	OK	1095.41	1715.83	OK
36	QTS	Tube	200	5.66	72.83	1557.45	1930.33	OK	0.00	3501.70	OK
37	QTS	Tube	180	4.00	57.22	0.00	1923.61	OK	1354.67	2836.38	OK

Table 3
Howe Truss Bridge

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

Member 9

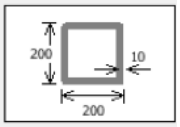
Material Properties:

Material	Quenched & Tempered Steel
Yield Stress (Fy)	485000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

Dimensions:

Cross-Section Type	Hollow Tube
Cross-Section Size	200x200x10
Area	0.0076 sq. meters
Moment of Inertia	4.59E-05 meters^4
Member Length	5.66 meters

Section (mm):



Cost:

Unit Cost	$459.38 per meter
Member Cost	$2598.66

Strength vs. Length: Graph all tabs Member:

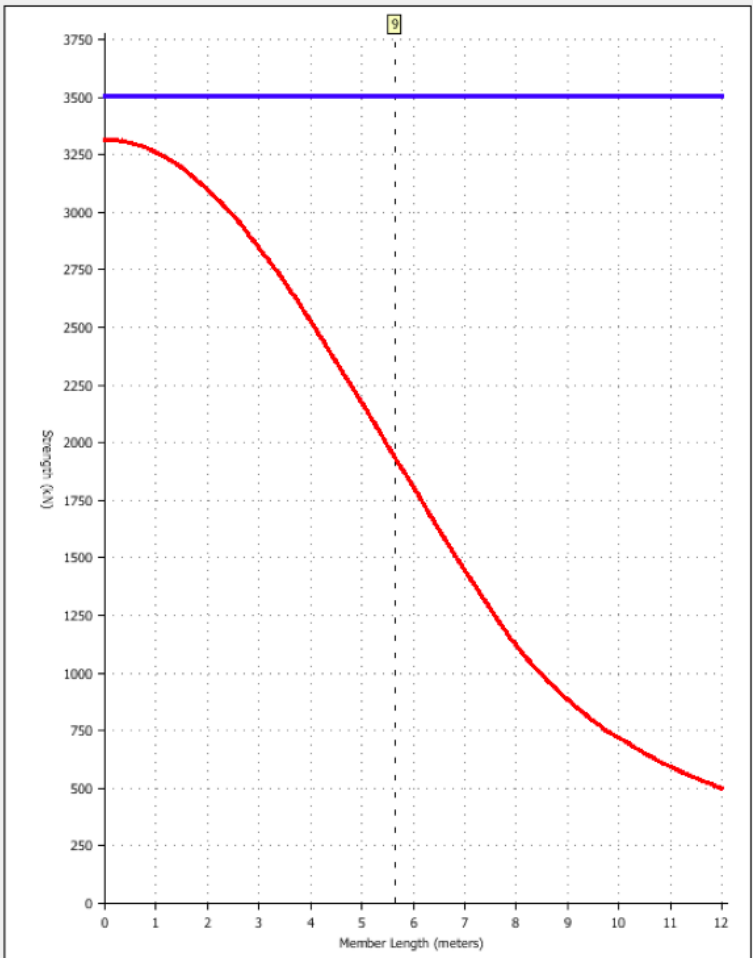


Table 4

Warren Truss Bridge
Cost Calculation Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	High-Strength Low-Alloy Steel Hollow Tube	(3958.8 kg) x ($7.00 per kg) x (2 Trusses) =	$55,423.43
	Quenched & Tempered Steel Hollow Tube	(3933.6 kg) x ($7.70 per kg) x (2 Trusses) =	$60,577.06
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	2 - 90x90x4 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 120x120x6 mm High-Strength Low-Alloy Steel Tube	($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
	5 - 160x160x8 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	10 - 190x190x9 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	3 - 190x190x9 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 200x200x10 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	5 - 220x220x11 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 240x240x12 mm Quenched & Tempered 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**	**$116,000.49 + $21,000.00 + $9,000.00 + $77,400.00 =**	**$223,400.49**

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

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	HSS	Tube	120	4.00	85.83	0.00	497.55	OK	695.59	896.72	OK
2	HSS	Tube	190	4.00	54.07	0.00	1636.25	OK	1903.63	2135.62	OK
3	QTS	Tube	190	4.00	54.07	0.00	2110.37	OK	2800.36	3002.25	OK
4	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3385.48	4237.06	OK
5	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3684.20	4237.06	OK
6	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3699.79	4237.06	OK
7	QTS	Tube	220	4.00	46.82	0.00	3209.27	OK	3404.91	4237.06	OK
8	QTS	Tube	190	4.00	54.07	0.00	2110.37	OK	2798.96	3002.25	OK
9	HSS	Tube	190	4.00	54.07	0.00	1636.25	OK	1881.96	2135.62	OK
10	HSS	Tube	120	4.00	85.83	0.00	497.55	OK	679.25	896.72	OK
11	HSS	Tube	190	4.00	54.07	1356.31	1636.25	OK	0.00	2135.62	OK
12	QTS	Tube	200	4.00	51.50	2404.83	2530.55	OK	0.00	3501.70	OK
13	QTS	Tube	220	4.00	46.82	3192.56	3209.27	OK	0.00	4237.06	OK
14	QTS	Tube	240	4.00	42.91	3669.11	3958.27	OK	0.00	5042.45	OK
15	QTS	Tube	240	4.00	42.91	3834.78	3958.27	OK	0.00	5042.45	OK
16	QTS	Tube	240	4.00	42.91	3690.30	3958.27	OK	0.00	5042.45	OK
17	QTS	Tube	240	4.00	42.91	3234.75	3958.27	OK	0.00	5042.45	OK
18	QTS	Tube	200	4.00	51.50	2467.66	2530.55	OK	0.00	3501.70	OK
19	HSS	Tube	190	4.00	54.07	1388.99	1636.25	OK	0.00	2135.62	OK
20	QTS	Tube	190	4.47	60.45	1555.39	1958.65	OK	0.00	3002.25	OK
21	HSS	Tube	190	4.47	60.45	0.00	1551.67	OK	1550.49	2135.62	OK
22	HSS	Tube	190	4.47	60.45	1267.87	1551.67	OK	0.00	2135.62	OK
23	HSS	Tube	190	4.47	60.45	0.00	1551.67	OK	1261.21	2135.62	OK
24	HSS	Tube	160	4.47	71.97	978.15	1036.79	OK	0.00	1594.18	OK
25	HSS	Tube	160	4.47	71.97	0.00	1036.79	OK	971.31	1594.18	OK
26	HSS	Tube	140	4.47	82.25	688.35	707.46	OK	0.00	1220.54	OK
27	HSS	Tube	120	4.47	95.96	0.00	435.27	OK	681.59	896.72	OK
28	HSS	Tube	120	4.47	95.96	398.82	435.27	OK	69.58	896.72	OK
29	HSS	Tube	90	4.47	127.24	75.74	132.87	OK	392.66	450.98	OK
30	HSS	Tube	90	4.47	127.24	110.60	132.87	OK	357.80	450.98	OK
31	HSS	Tube	120	4.47	95.96	363.96	435.27	OK	104.44	896.72	OK
32	HSS	Tube	120	4.47	95.96	0.00	435.27	OK	646.73	896.72	OK
33	HSS	Tube	140	4.47	82.25	653.09	707.46	OK	0.00	1220.54	OK
34	HSS	Tube	160	4.47	71.97	0.00	1036.79	OK	936.04	1594.18	OK
35	HSS	Tube	160	4.47	71.97	942.47	1036.79	OK	0.00	1594.18	OK
36	HSS	Tube	160	4.47	71.97	0.00	1036.79	OK	1225.10	1594.18	OK
37	HSS	Tube	190	4.47	60.45	1231.34	1551.67	OK	0.00	2135.62	OK
38	HSS	Tube	190	4.47	60.45	0.00	1551.67	OK	1513.95	2135.62	OK
39	HSS	Tube	190	4.47	60.45	1518.85	1551.67	OK	0.00	2135.62	OK

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

Member 3

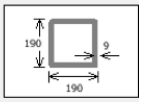
Material Properties:

Material	Quenched & Tempered Steel
Yield Stress (Fy)	485000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

Dimensions:

Cross-Section Type	Hollow Tube
Cross-Section Size	190x190x9
Area	0.0065 sq. meters
Moment of Inertia	3.57E-05 meters^4
Member Length	4.00 meters

Section (mm):



Cost:

Unit Cost	$393.86 per meter
Member Cost	$1575.44

Strength vs. Length: Graph all tabs Member:

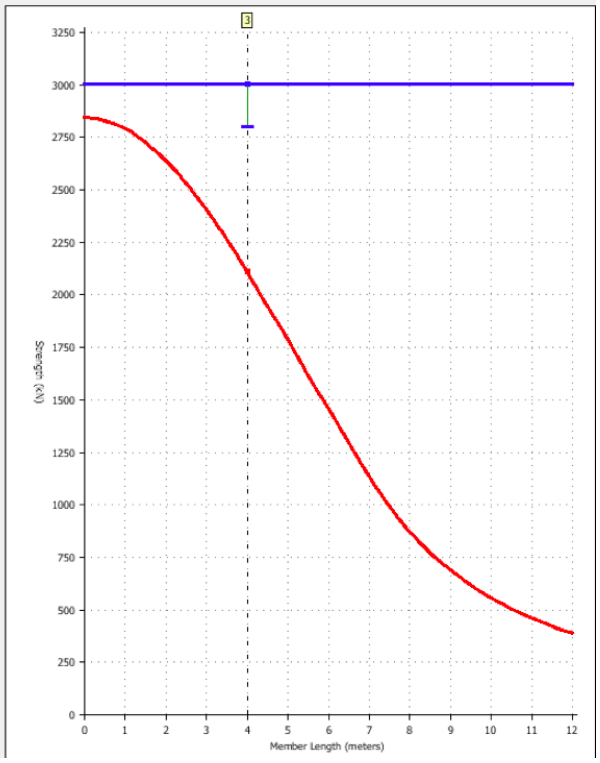


Table 7
Howe Truss Bridge
Load Testing Results

Design Team	Howe Weight (g)	Weight (lbs)	Failure Load (lbs)	Structural Efficiency
1	81.3	0.179	104.6	584.81
2	64.3	0.141	33.9	239.64
3	95.8	0.211	59.6	282.46
4	78.5	0.173	38.2	221.19
5	79.4	0.175	55.4	317.15
6	80.4	0.177	75.8	428.54
7	84.7	0.186	70.9	380.49
8	82.6	0.182	90.3	496.92

Average	368.9
Max	584.81
Min	221.19

Table 8
Warren Truss Bridge
Load Testing Results

Design Team	Warren Weight (g)	Weight (lbs)	Failure Load (lbs)	Structural Efficiency
1	81.9	0.180	104.6	580.53
2	77.1	0.170	33.9	199.86
3	74.9	0.165	50.8	308.29
4	75.7	0.167	38.2	229.37
5	80.9	0.178	55.4	311.27
6	90.1	0.198	75.8	382.40
7	87	0.191	70.9	370.43
8	83.6	0.184	90.3	490.97

Average	359.14
Max	580.53
Min	199.86

FIGURES

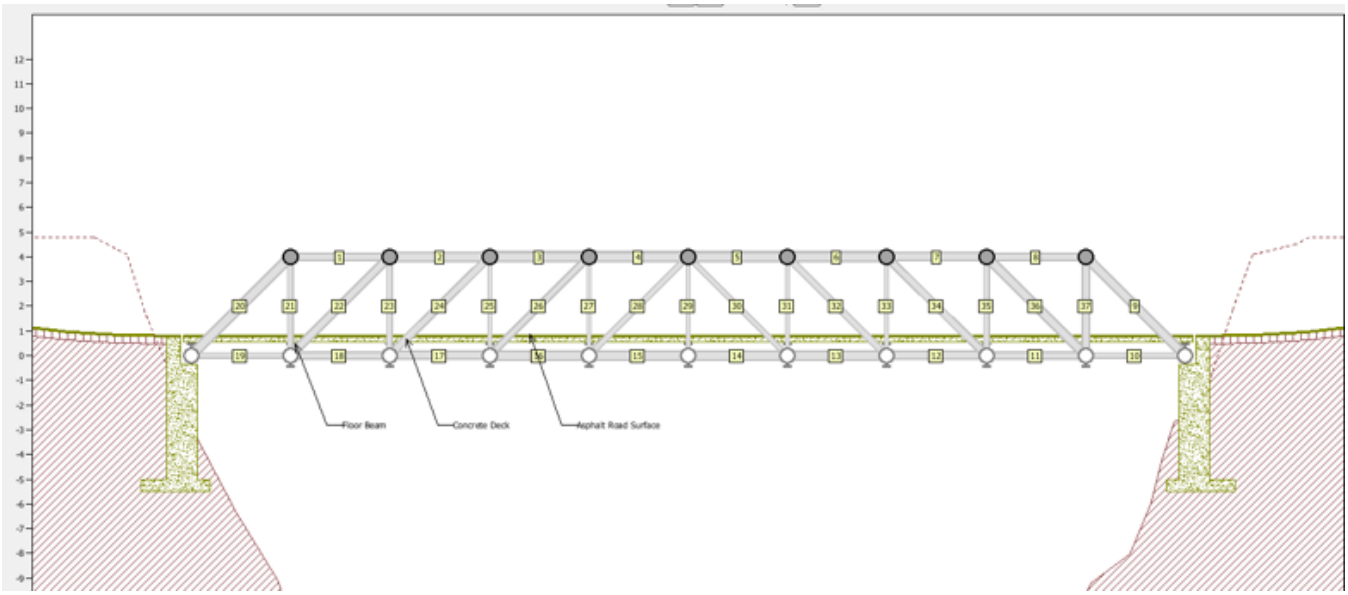


Figure 1. Howe Truss Bridge Model from Bridge Designer 2015

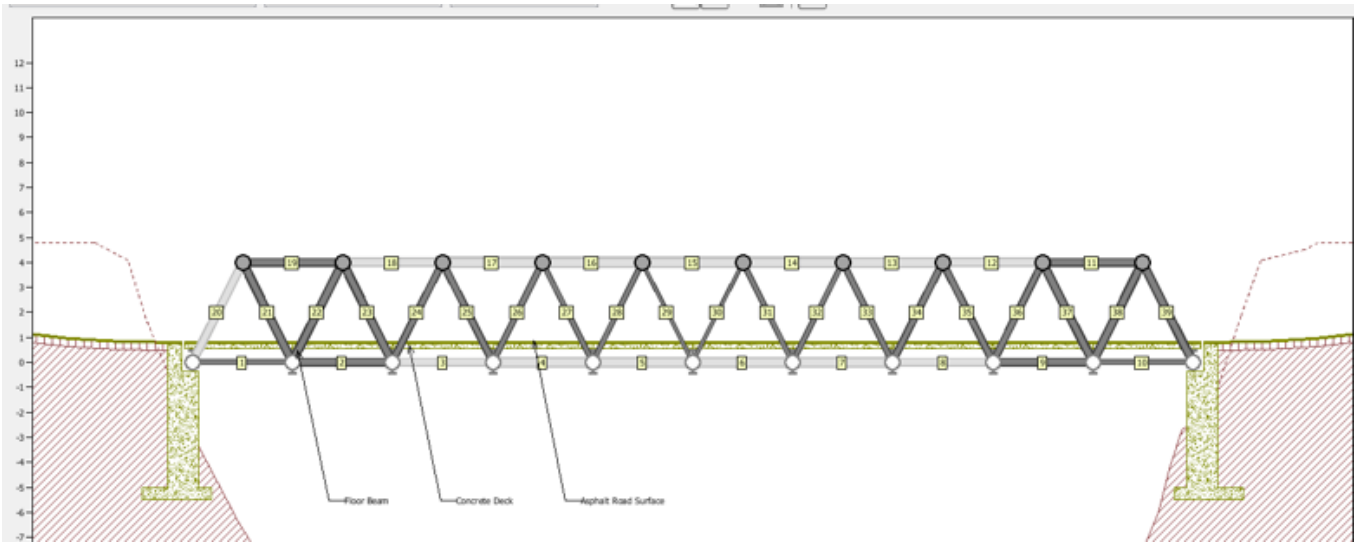


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

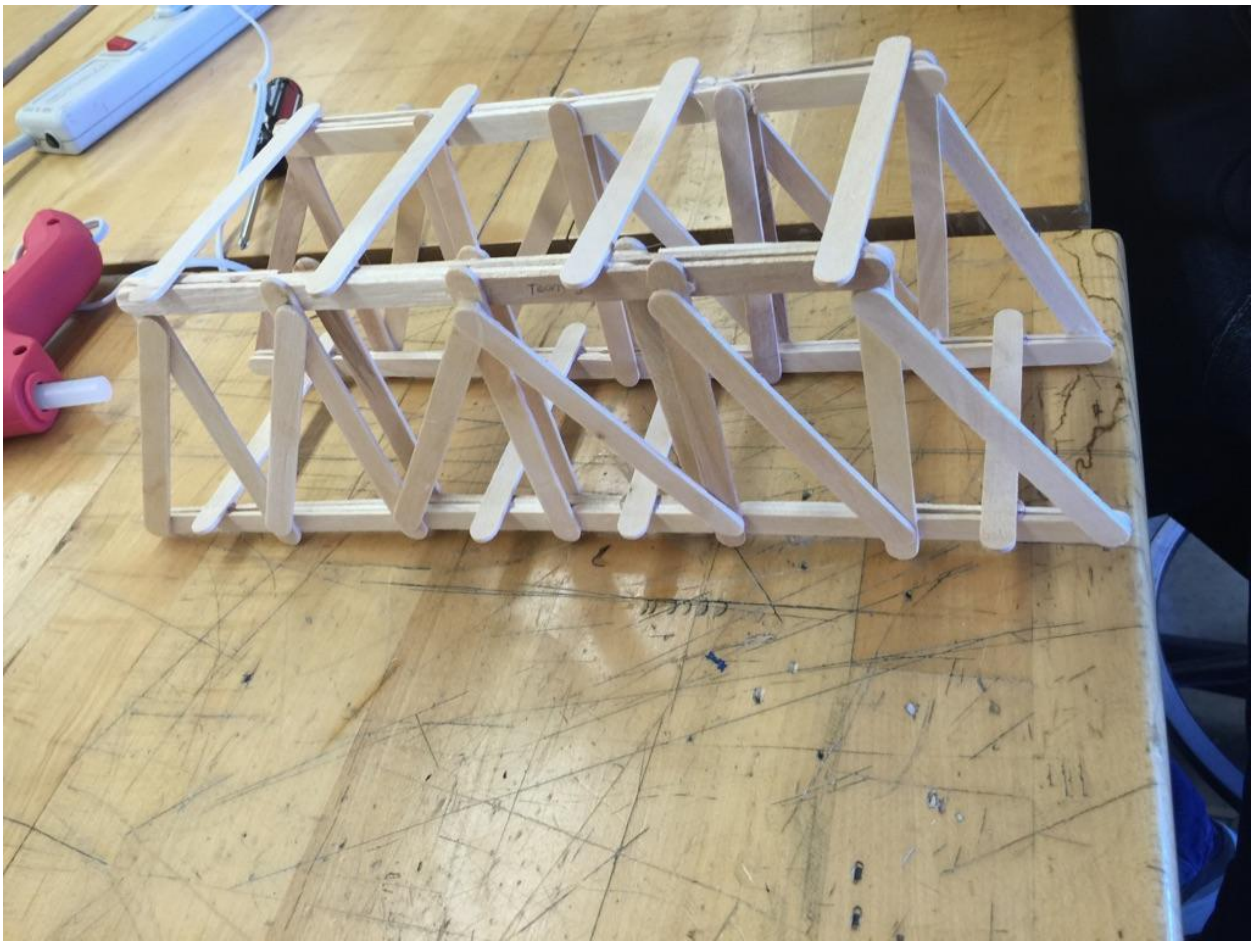


Figure 3. Howe Truss Bridge Prototype before Load Testing

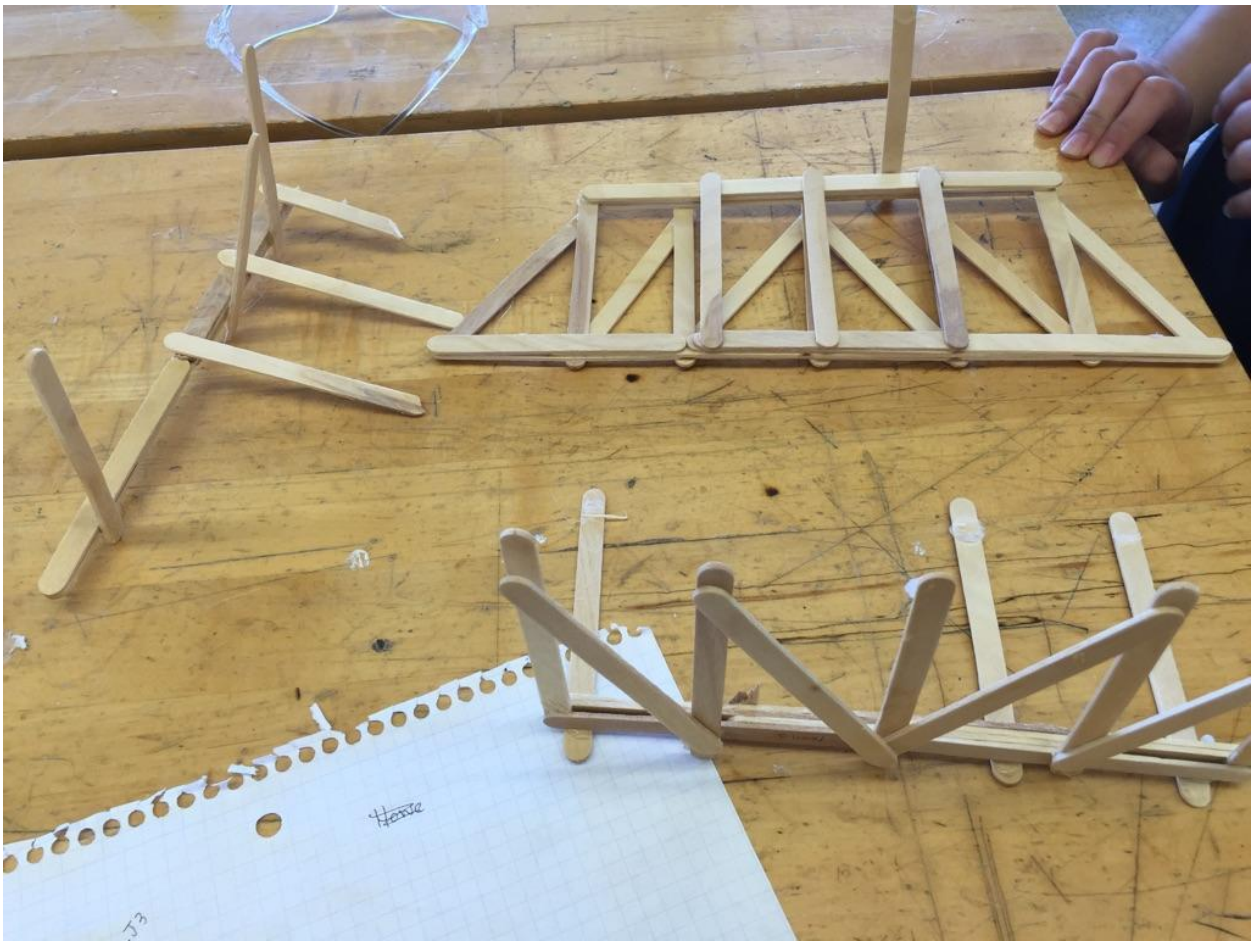


Figure 4. Howe Truss Bridge Prototype Failure after Load Testing

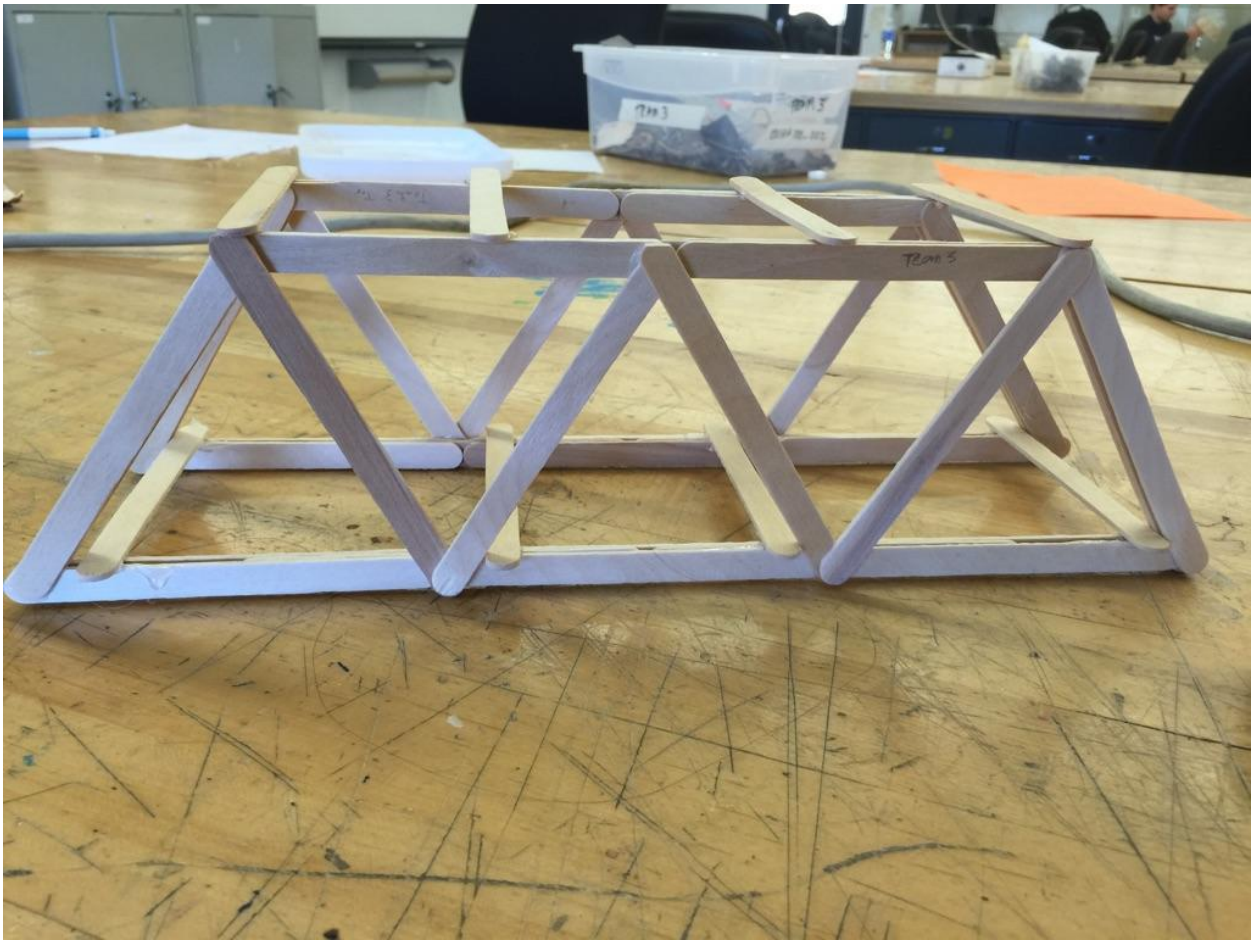


Figure 5. Warren Truss Bridge Prototype before Load Testing

Figure 6. Warren Truss Bridge Prototype Failure after Load Testing

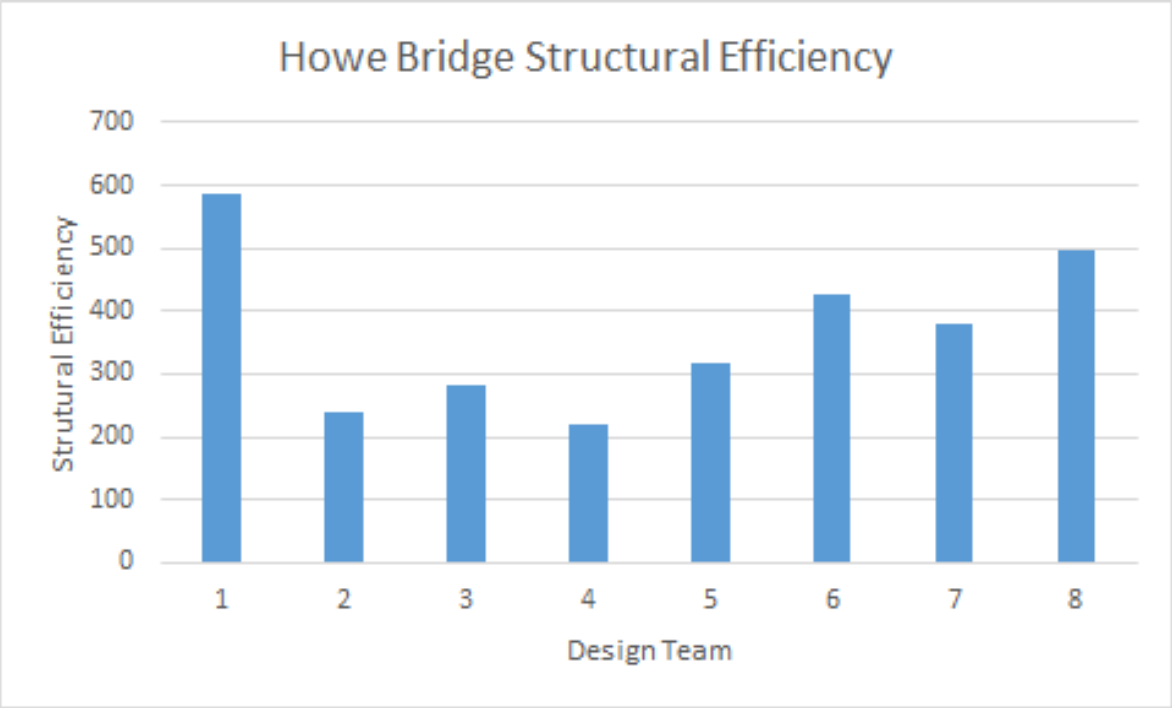


Figure 7. Howe Truss Bridge Structural Efficiencies

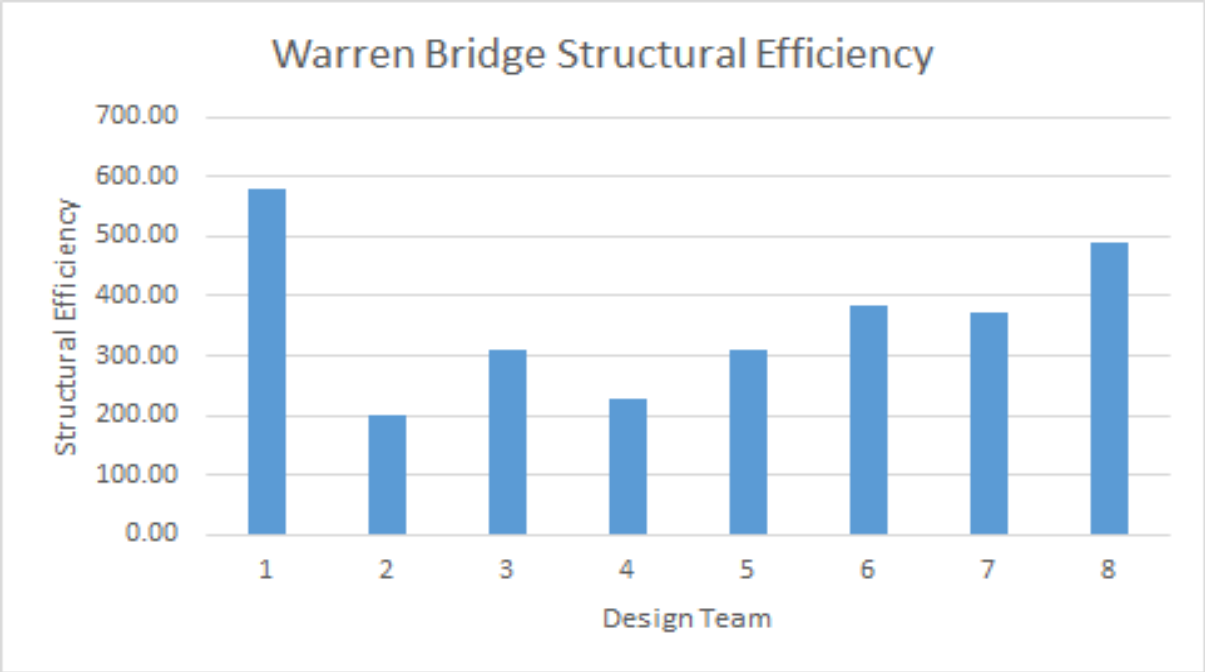


Figure 8. Warren Truss Bridge Structural Efficiencies