PENNSTATE

School of Engineering Design, Technology and Professional Programs
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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 vital bridge located in Pennsylvania Department of Transportation (PennDOT) Engineering District 2-0 for vehicle access to the Mount Nittany Medical Center located in State College, PA has been completely destroyed by a recent 100-year flood event. All traffic now must be re-route more than 10 miles around the destroyed bridge. State College's traffic flow, local commerce, as well as residential safety have been influenced.

Objective.
To design a replacement vehicle bridge over Spring Creek as an emergency project.

Design Criteria.
PennDOT established design criteria for the bridge to include (for both Warren through truss bridge and Howe through truss bridge): 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. Steel member type, steel cross section type, and steel member size can be selected by the design team.

Technical Approach.

Phase 1: Economic Efficiency.

Economic efficiency can be determined by Engineering Encounters Bridge Design 2015 (EEBD 2015) software based on the requirements, constraints, and performance criteria specified herein.While the bridge can support the dead load (its own weight) and the live load (weight of a standard truck loading), the cost needs to be as low as possible.

Phase 2: Structural Efficiency.

A prototype bridge shall be designed and built for both Warren through truss bridge and Howe through truss bridge. Each prototype bridge is required to accomplish load test for the catastrophic failure in the lab. Structural efficiency (SE) is calculated by the load of bridge support at failure divided by the weight of the prototype bridge.

The prototype bridges are constructed using standard (4-1/2 x 3/8 x 1/12 inch) wooden (white birch) Popsicle (craft) sticks, Elmer's white glue, and hot glue (only to attach beams between the two adjacent truss sections). For each bridge, a maximum of 60 Popsicle sticks is allowed to be used.

All of the prototype bridges are accurately weighed prior to the loading test. The load at failure is measured and recorded in order to be analyzed later. A forensic engineering investigation to determine the cause of bridge failure including why did it fail; where did it fail; and how did it fail is performed by the design team for each bridge. The location of failure is determined by the structural members and joints labeled prior to the load test.

Results.

Phase 1: Economic Efficiency.

The cost of Howe Truss Bridge is $289,957.55 while the cost of Warren Truss Bridge is $272,664.59 the cost of Howe Truss Bridge is slightly higher/lower than the Warren Truss Bridge.

Phase 2: Structural Efficiency.

According to the load test in the lab, the load at failure of Howe Truss Bridge is 65.4, and the structural efficiency is 378.0. However, the load at failure of Warren Truss Bridge is 38.2, and the structural efficiency is 228.7. Apparently the structural efficiency of Howe Truss Bridge is much higher than the structural efficiency of Warren Truss Bridge.

Best Solution.

Comparing and contrasting the economic efficiency and structural efficiency of Howe Truss Bridge and Warren Truss Bridge, the best solution of the problem is to build a Howe Truss Bridge. The reasons are as follows:

1. Even though the total cost of Warren Truss Bridge is lower than the total cost of Howe Truss Bridge, but the difference of cost is only $272,664.59. Considering other factors such as Structural Efficiency, a slightly higher cost would not be a problem.
2. The Structural Efficiency of Howe Truss Bridge is 378.0, while the mean of Structural Efficiency of all eight teams is 370, which means it is above average. The maximum Howe Structural Efficiency is 570, the minimum is 238, and the range is 332 (Table 7). However, the Structural Efficiency of Warren Truss Bridge is 228.7, while the mean of Structural Efficiency of all eight team is 358, which is 100 less than the average value. The maximum Warren Structural Efficiency is 581, the minimum is 201, and the range is 358 (Table 8).
Since the difference between economic efficiencies is much smaller than the difference between structural efficiencies, Howe Truss Bridge is the best solution.

Conclusions and Recommendations.

Based on both the Economic Efficiency factor and Structural Efficiency factor, a Howe Truss Bridge shall be built to replace the bridge destroyed by the recent extreme flood event. Some suggestions to advance the project include: make the structure to be asymmetric, as a result the bridge would be more stable; strengthen the solid bar and hollow tube on the sides of the bridge, which would significantly increase the strength of the bridge.

Respectfully,

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Phase 1: Economic Efficiency

Howe Truss.

The total cost of the Howe Truss Bridge is $289,957.55, including material cost, connection cost, product cost, and site cost. For material cost, 14057.8kg of Carbon Steel Solid Bar and 4655.6kg of Carbon Steel Hollow Tube were used for each of the Howe trusses. The price of Carbon Steel Solid Bar is $4.30 per kg, and the price of Carbon Steel Hollow Tube is $6.30 per kg; as a result, the total material cost is (14057.8 kg) x ($4.30 per kg) x (2 Trusses) + (4655.6 kg) x ($6.30 per kg) x (2 Trusses) = $179,557.55. The connection cost is (20 Joints) x (500.0 per joint) x (2 Trusses) = $20,000. Product cost is calculated based on 13 different materials used on the truss bridges: 3 - 70x70 mm Carbon Steel Bar, 4 - 80x80 mm Carbon Steel Bar, 4 - 100x100 mm Carbon Steel Bar, 2 - 140x140 mm Carbon Steel Bar, 2 - 150x150 mm Carbon Steel Bar, 2 - 150x150x7 mm Carbon Steel Tube, 6 - 160x160 mm Carbon Steel Bar, 4 - 180x180 mm Carbon Steel Bar, 1 - 180x180x9 mm Carbon Steel Tube, 1 - 200x200x10 mm Carbon Steel Tube, 4 - 220x220x11 mm Carbon Steel Tube, 2 - 240x240x12 mm Carbon Steel Tube, 2 - 280x280x14 mm Carbon Steel Tube. The total product cost is equal to $13,000. Site cost is consist of three parts: Deck Cost, Excavation Cost, and Abutment Cost, which is (10 4-meter panels) x ($4,700.00 per panel) + (19,900 cubic meters) x ($1.00 per cubic meter) + (2 standard abutments) x ($5,250.00 per abutment) = $77,400. Adding all of the terms together, the total cost of the Howe Truss Bridge is $289,957.55.

Warren Truss.

The total cost of the Warren Truss Bridge is $289,957.55, including material cost, connection cost, product cost, and site cost. For material cost, 6651 kg of Carbon Steel Bar, 1579.4 kg of Carbon Steel Hollow tube, 5501 kg of High strength low alloy steel solid bar, 964.1 kg high strength low alloy steel hollow tube, and 522.9 kg of quenched & tempered steel hollow tube were used for each side of the Warren Truss Bridge. The price of Carbon Steel Bar is $4.30 per kg The price of Carbon Steel Hollow tube is $6.30 per kg. The price of High strength low alloy steel solid bar is $5.60 per kg. The price of high strength low alloy steel hollow tube is $7.00 per kg. The price of quenched & tempered steel hollow tube is $7.70; as a result if you multiply the (price per kg)*(kg of the material)*(2 trusses) you will get a total of $160,264.58. The connection cost is calculated by multiplying (21 joints)*($500.00 per joint)*(2 Trusses); the total for the connection cost is $21,000.00. The product cost is calculated based on 14 different materials used on the Warren truss bridge. Each material has a cost of $1000.00 so the total product cost is at $14,000. Site cost is calculated with the Deck Cost + Excavation Cost + Abutment Cost which equals $77,400. Adding all of the terms together, the total cost of the Warren Truss Bridge is $272,664.59.

Phase 2: Structural Efficiency

Howe Truss.

Prototype Bridge. We used standard (4-1/2 x 3/8 x 1/12 inch) wooden (white birch) Popsicle (craft) sticks and Elmer's white glue only to build the bridge. Hot glue is used to attach struts/floor beams between the two adjacent truss sections. The structure is based on the Howe Truss. There are totally 58 popsicle sticks used in our Howe bridge and the dimension is two-popsicle stick-length on the top and three-popsicle- stick- length on the bottom for each side. (See Figure 3)

Load Testing. From the data collected from all design teams, we could see our bridge can load more than what we estimated and it failed until 65.4. The average load failure value is 65.9, which is quite similar to our load at failure. The minimum load value is 33.8 and the maximum load is 99.7, which means the range is from 33.8 to 99.7 lbs. The minimum efficiency value is 238.0 and the maximum efficiency value is 569.7. Range of efficiency is 238.0 to 569.7. It seems a relation between the weight of bridge and the structural efficiency. One of the teams weighed more than our bridges but load less than us, but most of the bridge weighed more can load more. (See Table 7)

Forensic Analysis. Howe bridge load much more than our Warren bridge. It loads 65.4 until failure. The first broken part is on the top where only use single stick. We double the top chord and bottom cord to make sure that it can support itself and as much load as possible, but we only have single diagonal which need to be doubled. Another problem could be that the top chord and bottom chord are little tilted, so our bridge could not stand stably. When our group member Will slowly filled the bucket with sand, the bridge was wobble and it first inclined and then got collapse completely as the load increased to 65.4.

Results. See Figure 7 and Table 7

Warren Truss.

Prototype Bridge. We used standard (4-1/2 x 3/8 x 1/12 inch) wooden (white birch) Popsicle (craft) sticks and Elmer's white glue only to build the bridge. Hot glue is used to attach struts/floor beams between the two adjacent truss sections. The structure is based on the Warren Truss. There are totally 54 popsicle sticks used in our Warren bridge and the dimension is two

and a half-popsicle stick-length on the top and three-popsicle- stick- length on the bottom for each side. (See figure 5)

Load Testing. From the data collected from all design teams, we could see our bridge can load quite similar to what we estimated and it failed until 38.2. The average load failure value is 65.0, which is much higher than our load at failure. The minimum load value is 33.9 and the maximum load is 104.6, which means the range is from 33.9 to 104.6 lbs. The minimum efficiency value is 200.6 and the maximum efficiency value is 581.1. Range of efficiency is 200.6 to 581.1. It seems a relation between the weight of bridge and the structural efficiency. Most of the bridge weighed more can load more. (See Table 8)

Forensic Analysis. Our Warren bridge load much less than that of other teams . It loads 38.2 until failure. The first broken part is on the top where only use single stick. Except the top and bottom chord, we only have single diagonal which need to be doubled. For Warren structure, the diagonal is weaker and all the team that made high load Warren bridge doubled their diagonal sticks. Another problem could be that the top chord and bottom chord are tilted, so our bridge could not stand stably. When our group member Will slowly filled the bucket with sand, the bridge was wobble and it first inclined and then got collapse completely as the load increased to 38.2.

Results. Figure 8 and 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	(14057.8 kg) x ($4.30 per kg) x (2 Trusses) =	$120,896.91
	Carbon Steel Hollow Tube	(4655.6 kg) x ($6.30 per kg) x (2 Trusses) =	$58,660.64
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses) =	$20, 000.00
Product Cost (P)	3 - 70x70 mm Carbon Steel Bar	(%s per Product)=	$1,000.00
	4 - 80x80 mm Carbon Steel Bar	(%s per Product) =	$1,000.00

	4 - 100x100 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 140x140 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 150x150 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 150x150x7 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	6 - 160x160 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	4 - 180x180 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	1 - 180x180x9 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	1 - 200x200x10 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 220x220x11 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	2 - 240x240x12 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	2 - 280x280x14 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =	$47,000.00
	Excavation Cost	(19,900 cubic meters) x ($1.00 per cubic meter) =	$19,900.00
	Abutment Cost	(2 standard abutments) x ($5,250.00 per abutment) =	$10,500.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	M + C + P + S	$179,557.55 + $20,000.00 + $13,000.00 + $77,400.00 =	$289,957.55

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

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Hollow Tube	200x200x10	5.66	906.04	1293.53	OK	0.00	1805.00	OK
2	CS	Solid Bar	140x140	4.00	0.00	2633.62	OK	2596.32	4655.00	OK
3	CS	Solid Bar	160x160	4.00	0.00	3881.59	OK	3409.73	6080.00	OK
4	CS	Solid Bar	160x160	4.00	0.00	3881.59	OK	3893.29	6080.00	OK
5	CS	Solid Bar	160x160	4.00	0.00	3881.59	OK	4047.10	6080.00	OK
6	CS	Solid Bar	160x160	4.00	0.00	3881.59	OK	4047.10	6080.00	OK
7	CS	Solid Bar	160x160	4.00	0.00	3881.59	OK	3872.21	6080.00	OK

8	CS	Solid Bar	160x160	4.00	0.00	3881.59	OK	3368.00	6080.00	OK
9	CS	Solid Bar	140x140	4.00	0.00	2633.62	OK	2534.37	4655.00	OK
10	CS	Hollow Tube	180x180 x9	5.66	861.18	981.36	OK	0.00	1462.05	OK
11	CS	Hollow Tube	220x220 x11	5.66	1252.99	1642.86	OK	0.00	2184.05	OK
12	CS	Hollow Tube	280x280 x14	5.66	2062.16	2906.73	OK	0.00	3537.80	OK
13	CS	Hollow Tube	280x280 x14	5.66	2016.70	2906.73	OK	0.00	3537.80	OK
14	CS	Hollow Tube	150x150 x7	5.66	513.76	550.30	OK	78.72	950.95	OK
15	CS	Hollow Tube	150x150 x7	5.66	469.51	550.30	OK	122.98	950.95	OK
16	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1449.80	2375.00	OK
17	CS	Solid Bar	80x80	4.00	0.00	333.51	OK	1179.39	1520.00	OK
18	CS	Solid Bar	80x80	4.00	0.00	333.51	OK	902.70	1520.00	OK
19	CS	Solid Bar	80x80	4.00	0.00	333.51	OK	870.55	1520.00	OK
20	CS	Solid Bar	80x80	4.00	0.00	333.51	OK	1147.25	1520.00	OK
21	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1417.66	2375.00	OK
22	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1458.17	2375.00	OK
23	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1426.03	2375.00	OK
24	CS	Solid Bar	70x70	4.00	0.00	195.50	OK	623.94	1163.75	OK
25	CS	Solid Bar	70x70	4.00	0.00	195.50	OK	628.39	1163.75	OK
26	CS	Solid Bar	70x70	4.00	0.00	195.50	OK	592.65	1163.75	OK
27	CS	Hollow Tube	220x220 x11	5.66	1298.45	1642.86	OK	0.00	2184.05	OK
28	CS	Hollow Tube	220x220 x11	4.00	1458.17	1843.70	OK	0.00	2184.05	OK

29	CS	Hollow Tube	220x220 x11	4.00	1426.03	1843.70	OK	0.00	2184.05	OK
30	CS	Solid Bar	150x150	4.00	2596.32	3230.99	OK	0.00	5343.75	OK
31	CS	Solid Bar	150x150	4.00	2534.37	3230.99	OK	0.00	5343.75	OK
32	CS	Solid Bar	180x180	4.00	3409.73	5336.92	OK	0.00	7695.00	OK
33	CS	Solid Bar	180x180	4.00	3893.29	5336.92	OK	0.00	7695.00	OK
34	CS	Solid Bar	180x180	4.00	3872.21	5336.92	OK	0.00	7695.00	OK
35	CS	Solid Bar	180x180	4.00	3368.00	5336.92	OK	0.00	7695.00	OK
36	CS	Hollow Tube	240x240 x12	5.66	1683.66	2028.51	OK	0.00	2599.20	OK
37	CS	Hollow Tube	240x240 x12	5.66	1638.20	2028.51	OK	0.00	2599.20	OK

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

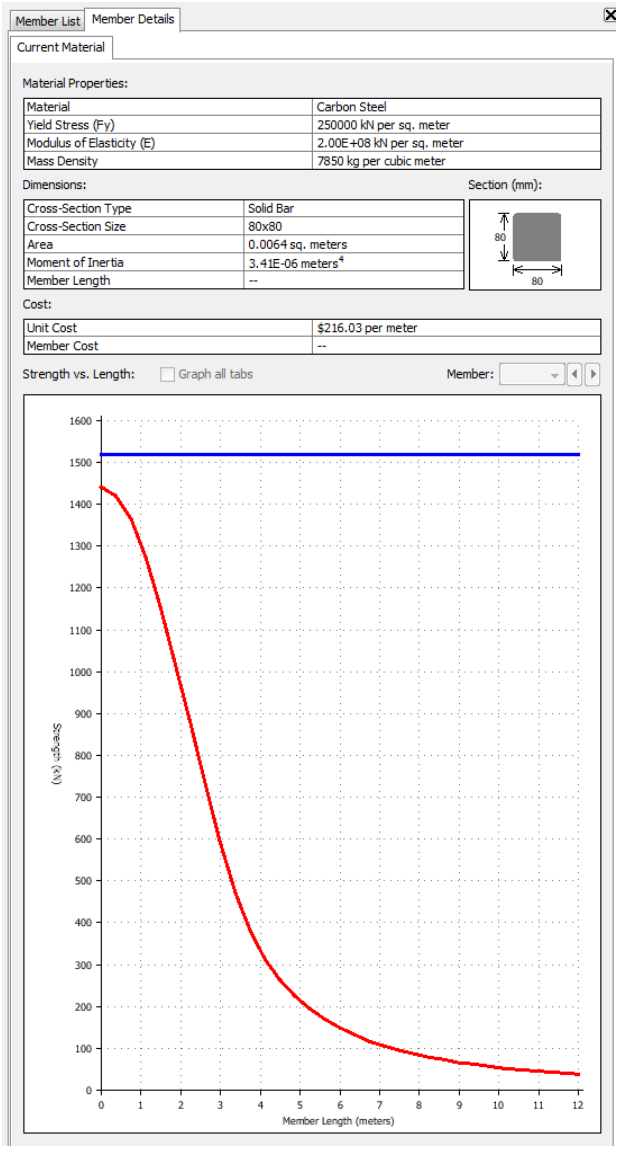


Table 4
Warren Truss Bridge
Cost Calculation Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(6651 kg)*($4.30 per kg)*(2 Trusses)	= $57,198.75
	Carbon Steel Hollow tube	(1579.4 kg)*($6.30 kg)*(2 Trusses)	= $19,900.69
	High-Strength low-alloy steel solid bar	(5501 kg)*($5.60 per kg)*(2 Trusses)	= $61,614.34
	High-Strength low-alloy steel hollow tube	(964.1 kg)*($7.00 per kg)*(2 Trusses)	= $13,497.48
	Quenched & Tempered steel hollow tube	(522.9 kg)*($7.70 per kg)*(2 Trusses)	= $8,053.32
Connection Cost (C)		(21 joints)*(500.0 per joint)*(2 Trusses)	= $21,000.00
Product Cost (P)	2 -120x120 mm Carbon Steel Bar	($1000.00 Per Product)	= $1,000.00
	2 -120x120x6 mm Carbon Tube	($1000.00 Per Product)	= $1,000.00
	2 - 130x130 Carbon Steel Bar	($1000.00 Per Product)	= $1,000.00
	2 - 130x130x6 Carbon Steel Tube	($1000.00 Per Product)	= $1,000.00
	2 - 130x130 mm High-Strength Low-Alloy Steel Bar	($1000.00 Per Product)	= $1,000.00
	7 - 140x140 mm Carbon Steel Bar	($1000.00 Per Product)	= $1,000.00
	4 - 140x140x7 mm Carbon Steel Tube	($1000.00 Per Product)	= $1,000.00
	1 - 140x140mm High-Strength Low-Alloy Steel Bar	($1000.00 Per Product)	= $1,000.00
	4 - 140x140x7 mm Quenched & Tempered Steel Tube	($1000.00 Per Product)	= $1,000.00
	2 - 150x150 mm High-Strength Low-Alloy Steel Bar	($1000.00 Per Product)	= $1,000.00
	4 - 160x160x8 mm Carbon Steel Tube	($1000.00 Per Product)	= $1,000.00

	3 - 160x160 mm High-Strength Low-Alloy Steel Bar	($1000.00 Per Product)	= $1,000.00
	2 - 180x180x9 mm High-Strength Low-Alloy Steel Tube	($1000.00 Per Product)	= $1,000.00
	2 - 220x220x11 mm High-Strength Low-Alloy Steel Tube	($1000.00 Per Product)	= $1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels)*(4,700.00 Per Panel)	= $47,000.00
	Excavation Cost	(19,900 Cubic Meters)*($1.00 per cubic meter)	= $19,900.00
	Abutment Cost	(2 standard abutment)*($5,250.00 per abutment)	= $10,500.00
	Pier Cost	No Pier	= $0.00
	Cable Anchorage	No Anchorage	= $0.00
Total Cost	M + C + P + S	$160,264.59 + $21,000.00 + $14,000.00 + $77,400.00	= $272,664.59

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/Strength	Tension Force/Strength
1	CS	Tube	130	4.47	88.24	0.92	0.08
2	CS	Tube	140	4.47	82.25	0.00	0.79
3	CS	Tube	120	4.47	95.96	0.29	0.55
4	CS	Tube	140	4.47	82.25	0.00	0.75
5	CS	Tube	130	4.47	88.24	0.84	0.13
6	CS	Tube	120	4.47	95.96	0.19	0.61
7	CS	Bar	130	4.47	119.17	0.89	0.00
8	CS	Bar	130	4.47	119.17	0.87	0.00
9	CS	Bar	140	4.47	110.66	0.57	0.00
10	CS	Bar	120	4.47	129.10	0.75	0.00
11	CS	Tube	160	4.47	71.97	0.85	0.00
12	CS	Tube	160	4.47	71.97	0.81	0.00
13	CS	Bar	120	4.47	129.10	0.72	0.00
14	CS	Bar	140	4.47	110.66	0.55	0.00
15	HSS	Bar	130	4.00	106.59	0.62	0.00
16	HSS	Bar	140	4.00	98.97	0.85	0.00
17	CS	Bar	140	4.00	98.97	0.94	0.00
18	HSS	Bar	130	4.00	106.59	0.61	0.00
19	CS	Tube	160	4.47	71.97	0.00	0.86
20	CS	Tube	160	4.47	71.97	0.00	0.83
21	HSS	Bar	150	4.00	92.38	0.89	0.00
22	HSS	Bar	160	4.00	86.60	0.83	0.00
23	HSS	Bar	160	4.00	86.60	0.86	0.00
24	HSS	Bar	160	4.00	86.60	0.82	0.00
25	HSS	Bar	150	4.00	92.38	0.88	0.00
26	QTS	Tube	140	4.47	82.25	0.00	0.93
27	QTS	Tube	140	4.47	82.25	0.00	0.76
28	QTS	Tube	140	4.47	82.25	0.00	0.74
29	QTS	Tube	140	4.47	82.25	0.00	0.91
30	CS	Tube	140	4.00	73.57	0.00	0.81
31	CS	Tube	140	4.00	73.57	0.00	0.79
32	HSS	Tube	180	4.00	57.22	0.00	0.97
33	HSS	Tube	220	4.00	46.82	0.00	0.96
34	CS	Bar	140	4.00	98.97	0.00	0.75
35	CS	Bar	140	4.00	98.97	0.00	0.82
36	CS	Bar	140	4.00	98.97	0.00	0.82
37	CS	Bar	140	4.00	98.97	0.00	0.76
38	HSS	Tube	180	4.00	57.22	0.00	0.96
39	HSS	Tube	220	4.00	46.82	0.00	0.96

Table 6
Warren Truss Bridge
Member Details Report from Bridge Designer 2015

Member with the Highest Tension Force/Strength Ratio

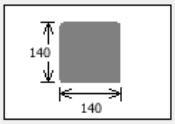
Material Properties:

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	140x140
Area	0.0196 sq. meters
Moment of Inertia	3.20E-05 meters^4
Member Length	--

Section (mm):



Cost:

Unit Cost	$661.60 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member:

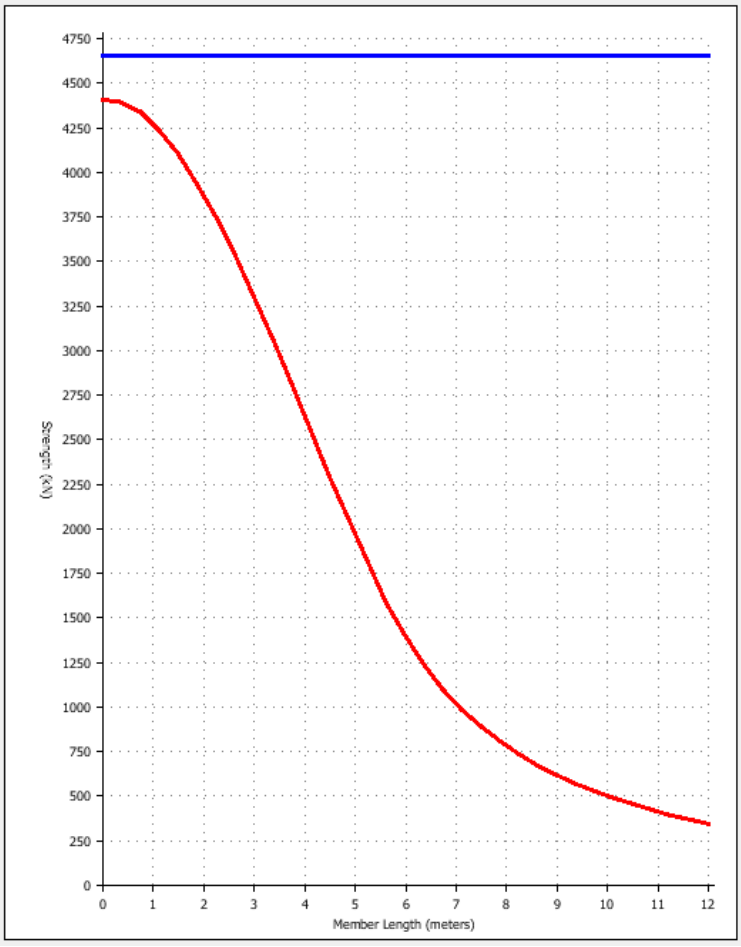


Table 7
Howe Truss Bridge
Load Testing Results

EDSGN100 Design Team#	Howe Truss Bridge Weight (grams)	Bridge Weight (lbs.)	Load at Failure (lbs.)	Structural Efficiency
1	81.3	0.179	69.7	389.4
2	64.3	0.142	33.8	238.0
3	95.8	0.211	59.6	282.5
4	78.5	0.173	65.4	378.0
5	79.4	0.175	99.7	569.7
6	80.4	0.177	84.2	475.7
7	84.7	0.187	71.0	379.7
8	82.6	0.182	44.3	243.4

Minimum	**238**
Maximum	**570**
Range	**332**
Mean	**370**

Table 8
Warren Truss Bridge
Load Testing Results

EDSGN100 Design Team#	Howe Truss Bridge Weight	Bridge Weight (lbs.)	Load at Failure (lbs.)	Structural Efficiency

	(grams)			
1	81.9	0.180	104.6	581.1
2	77.1	0.169	33.9	200.6
3	74.9	0.165	50.8	307.9
4	75.7	0.167	38.2	228.7
5	80.9	0.178	55.4	311.2
6	90.1	0.199	75.8	380.9
7	87.0	0.192	70.9	369.3
8	83.6	0.184	90.3	480.8

Minimum	**201**
Maximum	**581**
Range	**381**
Mean	**358**

FIGURES

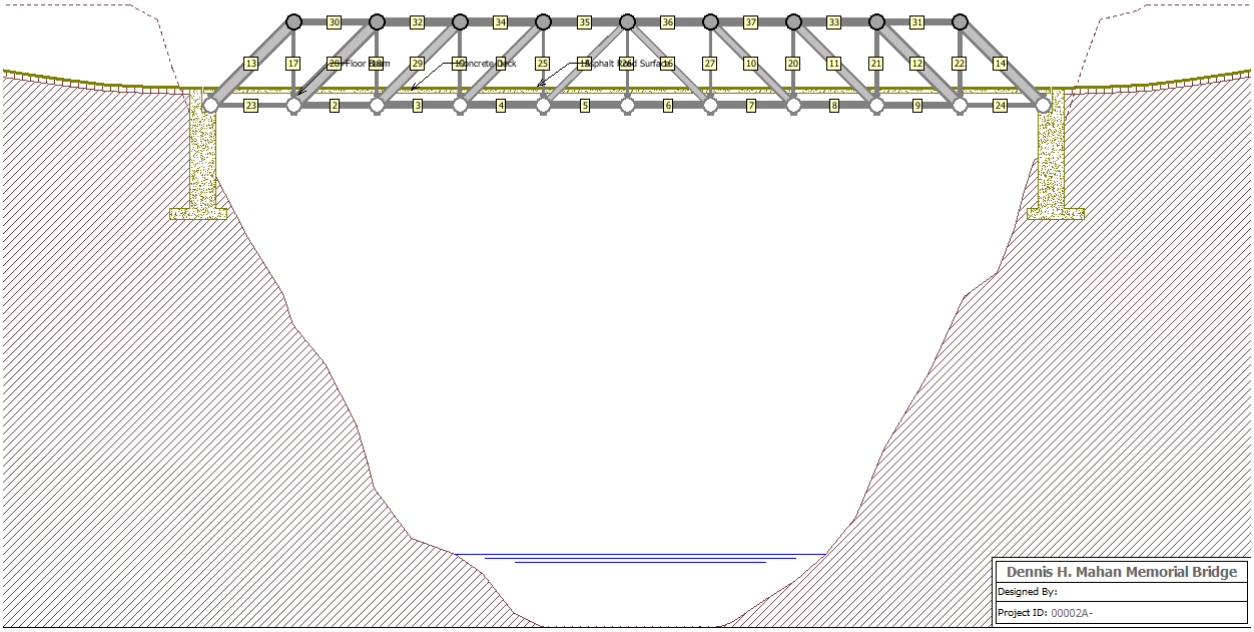


Figure 1. Howe Bridge Model from Bridge Designer 2015

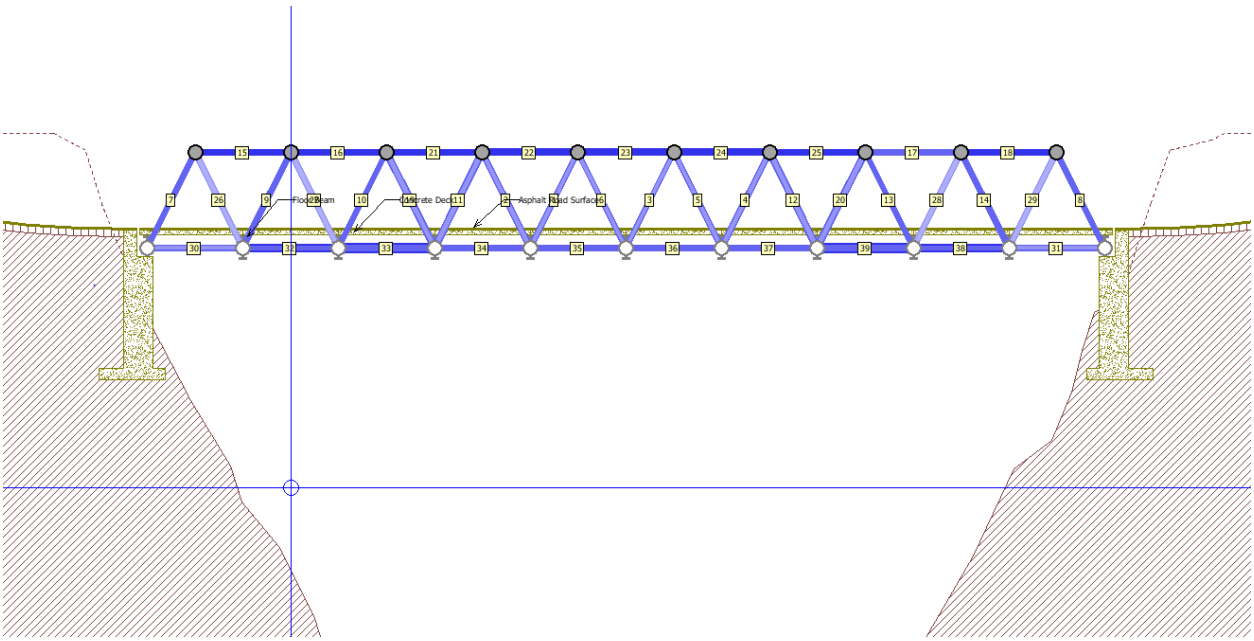


Figure 2. Warren Bridge Model from Bridge Designer 2015

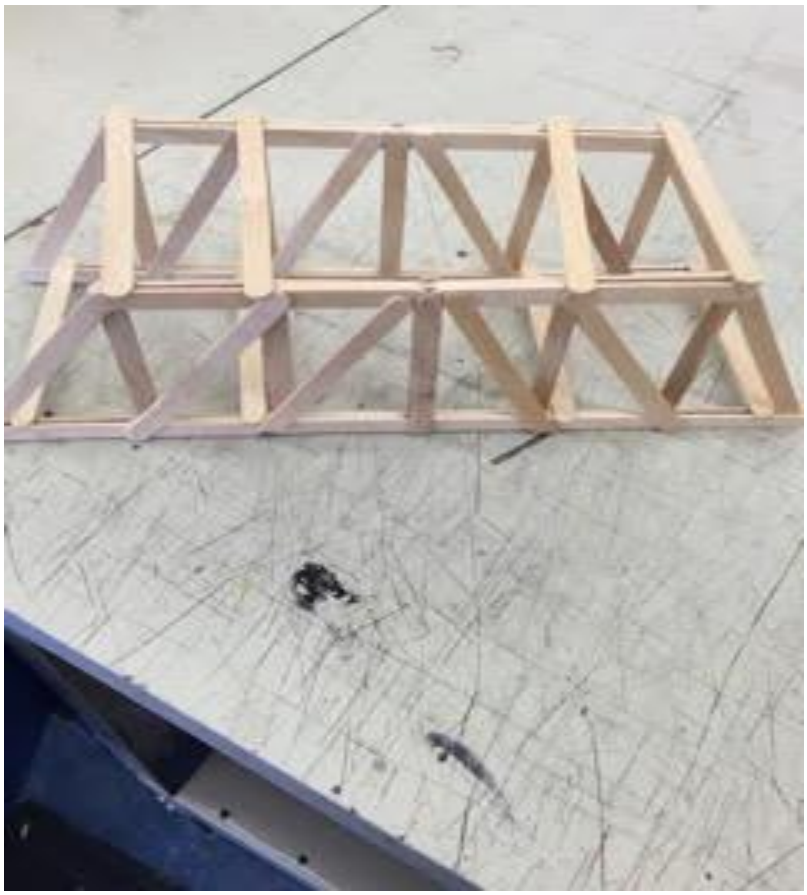


Figure 3. Howe Bridge Phototype Before Load Testing

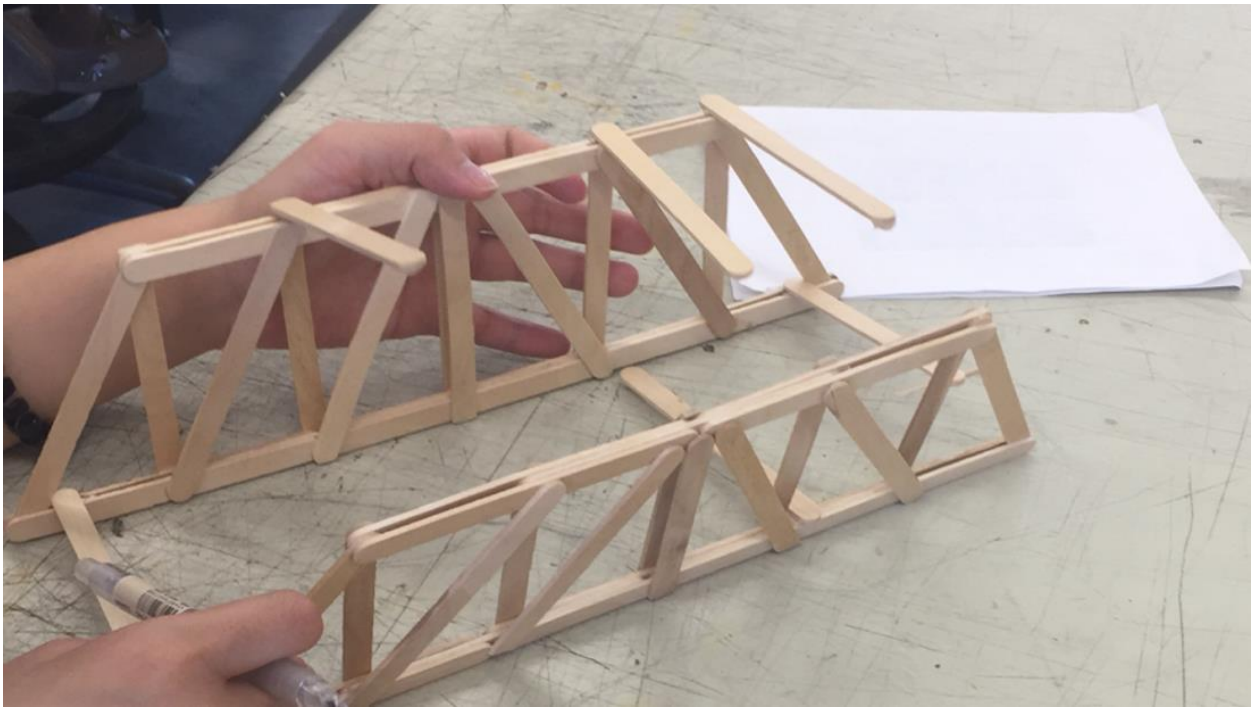


Figure 4. Howe Truss Bridge Prototype After Load Testing

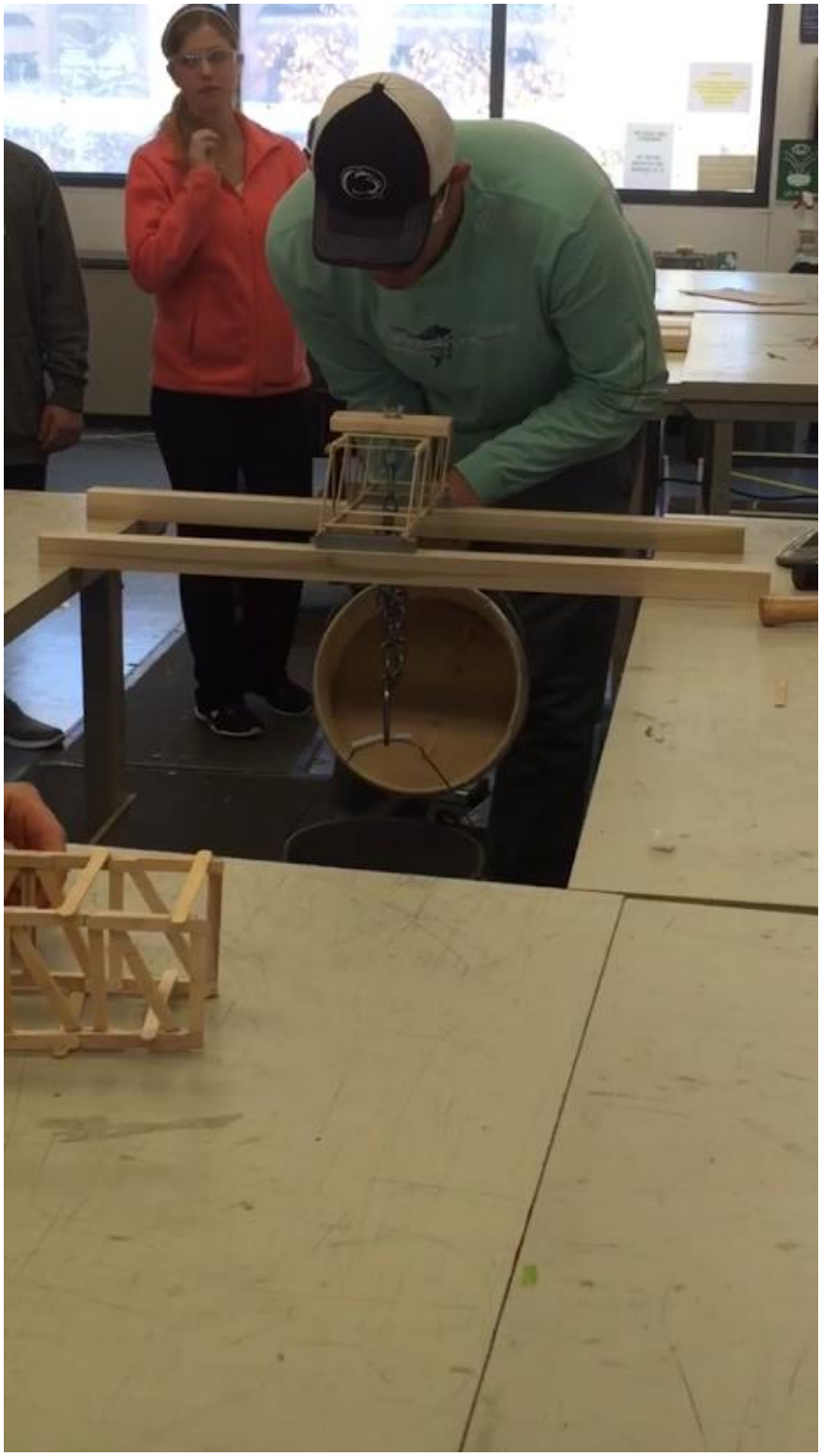


Figure 5. Warren Truss Bridge Prototype Before Load Testing

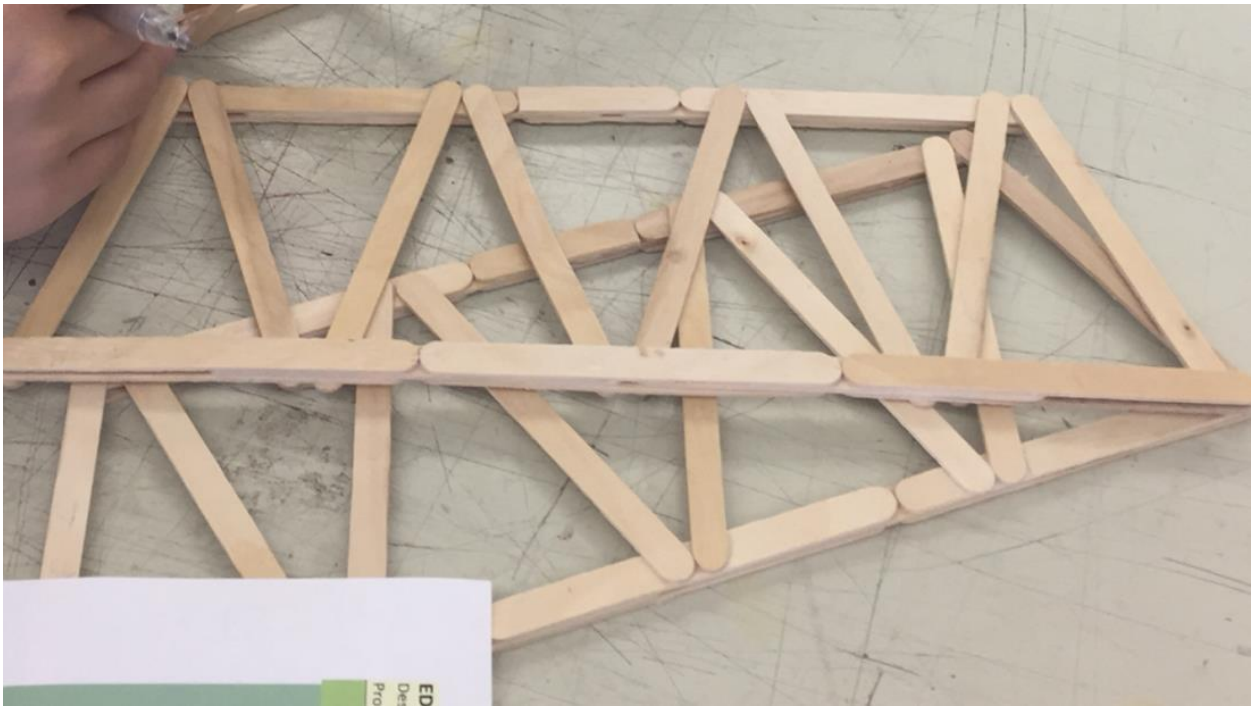


Figure 6. Warren Truss Bridge Prototype After Load Testing

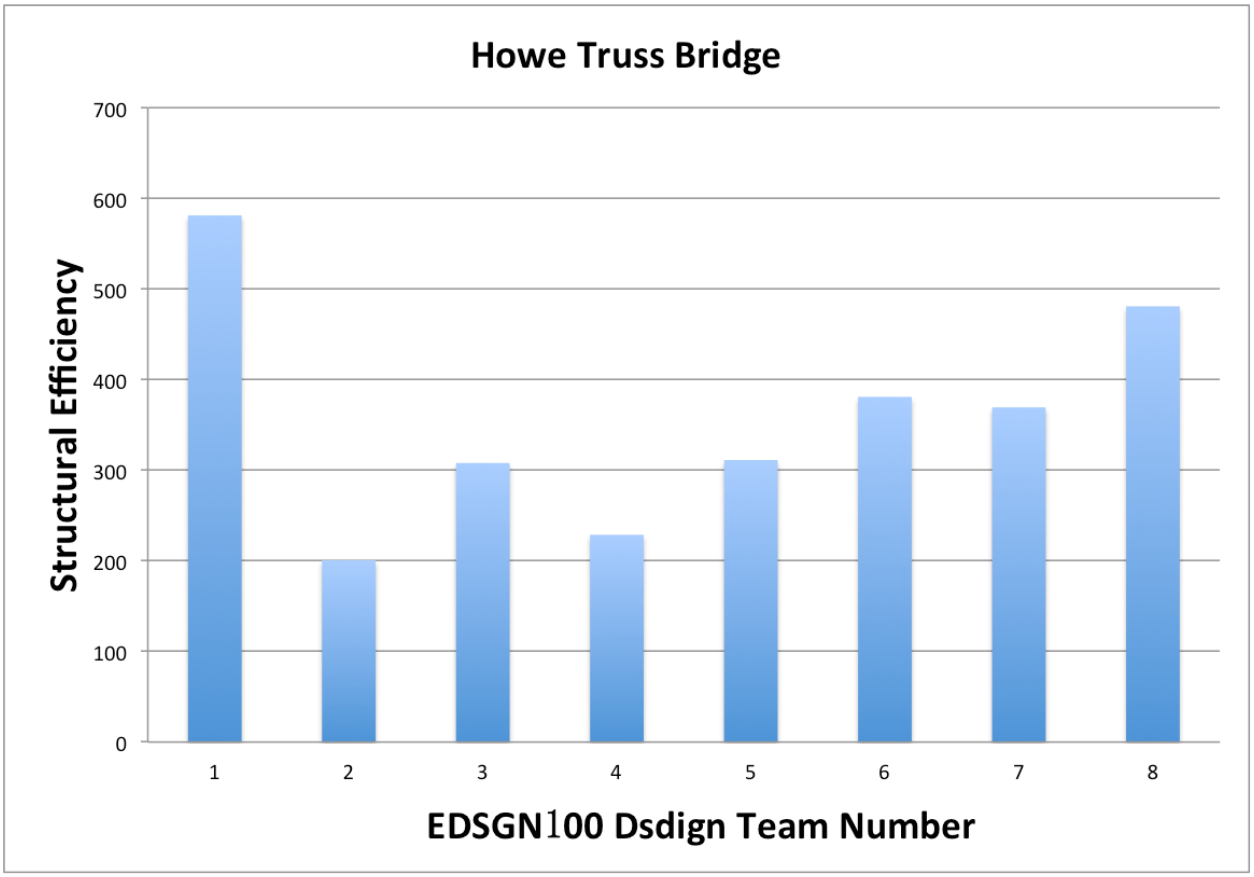


Figure 7. Howe Truss Bridge Structural Efficiencies

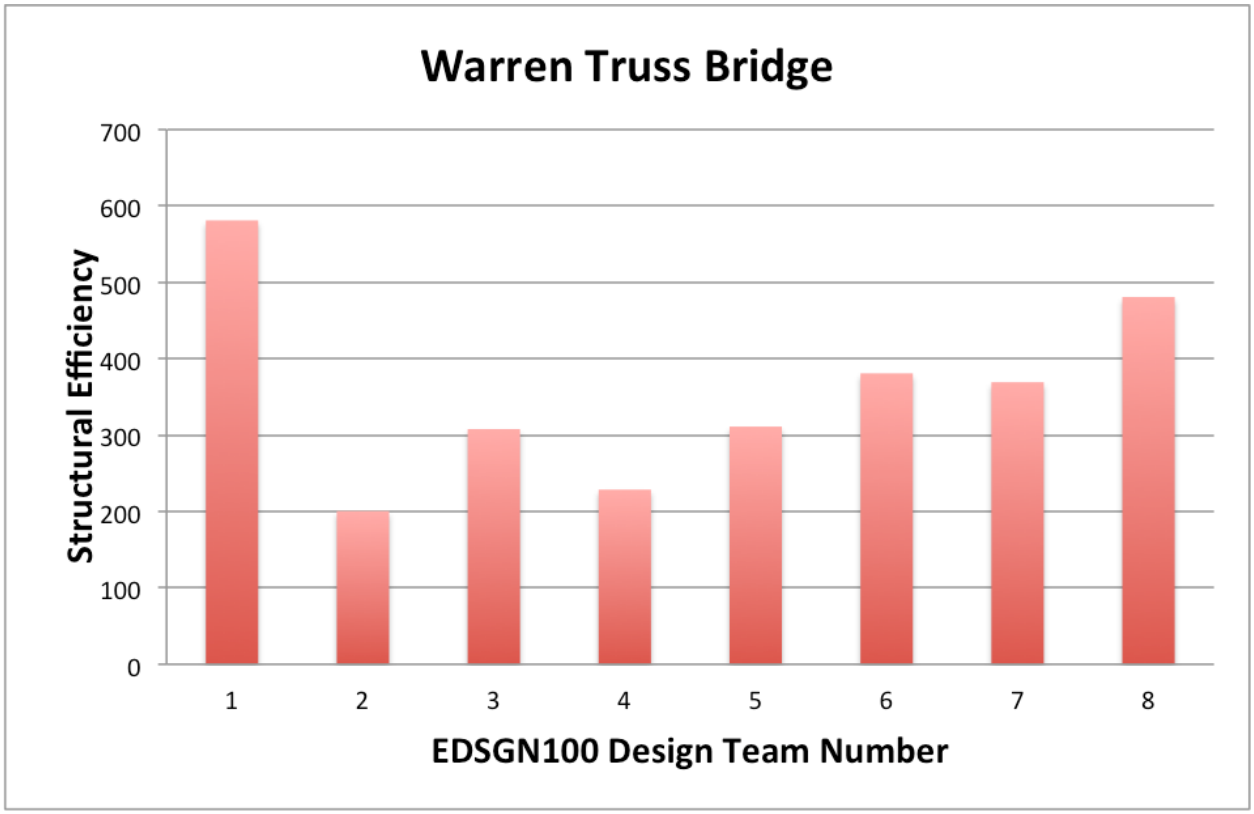


Figure 8. Warren Truss Bridge Structural Efficiencies