PENNSTATE

School of Engineering Design, Technology and Professional Programs
213 Hammond Building
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April 1, 2016

Kevin R. Kline, PE, District Executive
Penn D Engineering District 2-0
1924 Daisy Street - P.O. Box 342
Clearfield County, PA 16830

Dear Mr. Kline:

Reference. Penn DOT 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 100-year flood event has completely destroyed a structurally deficient vehicle bridge located over Spring Creek along Puddintown Road in College Township, Centre County, PA. The damaged bridge also severely restricts general regional vehicle access to the Mount Nittany Medical Center.

Objective. Pennsylvania Department of Transportation of (Penn DOT) 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. Penn DOT 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. Every other features are to be determined by the individual design team.

Technical Approach.

Phase 1: Economic Efficiency. Economic efficiency (cost) shall be determined using the Engineering Encounters Bridge Design 2015 (EEBD 2015) software based on the requirements, constraints, and performance criteria specified herein. The design objective is to use EEBD 2015 to perform a systematic and iterative analysis to design a stable Warren and Howe through truss bridge that has been optimized to keep the cost of the replacement bridge as low as possible; as well as to ensure that the replacement bridge can 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 shall be designed and built for both a standard Warren through truss bridge and a standard Howe through truss bridge by each design team. Structural efficiency is the ability of the truss bridge to safely dissipate live loads. Structural Efficiency (SE) is calculated by dividing the load the bridge supports at catastrophic failure by the weight of the prototype bridge. The design objective is to determine and report which prototype through truss bridge design is more effective at dissipating the force of a load, a Howe through truss bridge or the Warren through truss bridge. A prototype bridge for both one Howe through truss bridge and one Warren through truss bridge shall be constructed by each EDSGN100 design team using standard (4-1/2 x 3/8 x 1/12 inch) wooden (white birch) Popsicle (craft) sticks and Elmer's white glue only. Hot glue may only be used to attach no more than eight (8) 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 shall be provided by Penn DOT District 2-0. When a structure fails, there is invariably an investigation to find out why it failed. After loading and bridge failure, each design team must perform a forensic engineering investigation to determine the cause of bridge failure. The forensic investigation shall include: why did it fail; where did it fail; and how did it fail. Both trusses shall be suitably and uniquely marked and these markings shall be used in identifying the location and type of failure. A recommendation of how to improve the design or construction of the prototype bridges shall also be provided.

Results.

Phase 1: Economic Efficiency. The Economic Efficiency of the both the Howe and Warren Truss are in affordable range and can be implemented into project without much costs adjustments. For further details reference Table 1 and Table 4.

Phase 2: Structural Efficiency. The Structural Efficiency of both the Howe and Warren Truss Bridges are below the average and thus after some adjustments the bridges can be implemented into a project. For further details reference Table 7 and Table 8.

Best Solution. The "Best Solution" shall appropriately consider the following:

(i) The Economic Efficiency The Howe Truss Bridge was cheaper to build

(ii) The Structural Efficiency the Warren Truss Bridge was better structurally efficient because the Geometric Mean and the arithmetic Mean of Warren Truss Bridge was better than the Howe Truss Bridge.

(iii) The Design Efficiency, The Design Efficiency for both the Warren and Howe Truss Bridge were similar. For further information reference Table 7 and Table 8.

(iv) The Constructability the details about the constructability can be found in Table 1 and Table 3.

The Best solution would be to use Warren Truss Bridge because the warren truss bridge is more efficient and affordable for the project.

Conclusions and Recommendations. Based on the Design Efficiency of both the Howe and Warren Truss Bridges, the Warren Truss Bridge should be recommended to replace the bridge destroyed by the recent flood. The next step is to improve all the flaws found in the bridge and improve it to get better results.

Respectfully,

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ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss. The Carbon Steel was used because it was the cheapest material available. Two different types of Carbon steel were used to increase the efficiency of the tension and compression capabilities of the types. As seen in Table.1, the cost of the Howe Truss Bridge included both hollow tubes and carbon steel bars. Different sizes of the materials were used to decrease costs and increase safety.

As seen in Table 1, the load test was conducted and the results were successful. The compression and tension coefficients above 1.0 would cause a failure in the bridge. As seen in Table 2, all of the coefficients were below but close to 1.0, minimizing the cost and maximizing the efficiency.

As seen in Table 3, the properties of Carbon Steel are much more efficient for the Howe truss bridge. Carbon steel and solid bars makes the bridge more structurally and economically efficient. The shorter members have the most strength.

Warren Truss. The Carbon Steel was used as the base material for the bridge because it was the cheapest and the same time Carbon Steel Hollow Tube produced the highest efficiency for the Tension and the Compression of the bridge. As seen in Table.4, the cost of the Warren Truss Bridge included Carbon Hollow Steel tubes for the material costs. The same material was used throughout the bridge to make the bridge economically efficient.

As seen in Table 4, the load test was conducted and the results were successful. The compression and the tension coefficients above 1.0 would cause a failure in the bridge. As seen in Table 5, all of the coefficients were below but close to 1.0, minimizing the cost and maximizing the efficiency.

As seen in Table 6, the properties of Carbon steel are much more efficient for the warren truss bridge. Carbon Steel and hollow tubes makes the bridge more structurally and economically efficient. The Shorter members have the most strength.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss.

Prototype Bridge. The prototype was built using Popsicle sticks, Elmer's Glue, and a hot glue gun. Elmer's Glue was used to assemble the Top Cord, Bottom Cord, Verticals, Diagonals, and End Posts. The two sides of the prototype were temporarily held together with clips until dry. After a sufficient amount of time had passed, at least one night, the hot glue gun was used to add the Struts and Floor Beams, completing the building process of the prototype. Forty eight Popsicle sticks were used for the construction of the Howe Truss. The dimensions of the final prototype bridge is as follows: Height: 3- 5/8 inches, Width: 4-3/8 inches, Length: 13-1/2 inches.

Load Testing. The Howe Truss Bridge's Structural Efficiency was a lot less compared to the average results for the Howe truss from all other EDSGN100 design teams. The reason for low structural efficiency resulted from the bridge's load at failure being very low. The Load at bridge failure results, bridge weights and calculation of structural efficiencies for all Howe truss bridges can be referenced at Table 7. Also the minimum, maximum and range of structural efficiency values from all EDSGN100 design teams can be found in Table 7.

Forensic Analysis. The Howe Truss Bridge failed when the weight was distributed unevenly. It was built with angles that were not perpendicular, resulting in a slightly slanted physical appearance. With varying pressures on the prototype, the glue holding the Floor Beams and Struts wasn't strong enough to withstand the weight, resulting in the collapse of the bridge at all of the joints using hot glue.

Results. The detailed explanation of the result has been provided in Table 7.

Warren Truss.

Prototype Bridge. The prototype was built using Popsicle sticks, Elmer's Glue, and a hot glue gun. Elmer's Glue was used to assemble the Top Cord, Bottom Cord, Verticals, Diagonals, and End Posts. The two sides of the prototype were temporarily held together with clips until dry. After a sufficient amount of time had passed, at least one night, the hot glue gun was used to add the Struts and Floor Beams, completing the building process of the prototype. Forty four Popsicle sticks were used in the construction of the Warren Truss. The dimensions of the final prototype bridge is as follows: Height: 3-3/4 inches, Width: 3-7/8 inches, Length: 13-3/8 inches.

Load Testing. The Howe Truss Bridge's Structural Efficiency was a lot less compared to the average results for the Howe truss from all other EDSGN100 design teams. The reason for low structural efficiency resulted from the bridge's load at failure being very low. The Load at bridge failure results, bridge weights and calculation of structural efficiencies for all Howe truss

bridges can be referenced at Table 8. Also the minimum, maximum and range of structural efficiency values from all EDSGN100 design teams can be found in Table 8.

Forensic Analysis. The Warren Truss Bridge failed when the weight was distributed unevenly. It was built with angles that were not perpendicular, resulting in a slightly slanted physical appearance. With varying pressures on the prototype, the glue holding the Floor Beams and Struts wasn't strong enough to withstand the weight, resulting in the collapse of the bridge at all of the joints using hot glue.

Results. The detailed explanation of the result has been provided in Table 8.

TABLES

Table 1
Howe Truss Bridge
Cost Calculation Report from Bridge Designer 2016

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(5328.6 kg) x ($4.30 per kg) x (2 Trusses) =	$45,825.79
	Carbon Steel Hollow Tube	(6890.4 kg) x ($6.30 per kg) x (2 Trusses) =	$86,819.16
Connection Cost (C)		(20 Joints) x (400.0 per joint) x (2 Trusses) =	$16,000.00
Product Cost (P)	2 - 40x40 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	3 - 60x60 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	4 - 80x80 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 90x90 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	8 - 120x120 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 120x120x6 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 150x150x7 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 240x240x12 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	2 - 260x260x13 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	6 - 300x300x15 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	(19,400 cubic meters) x ($1.00 per cubic meter) =	$19,400.00
	Abutment Cost	(2 standard abutments) x ($5,500.00 per abutment) =	$11,000.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	M + C + P + S	$132,644.95 + $16,000.00 + $10,000.00 + $77,400.00 =	$236,044.95

Table 2
Howe Truss Bridge
Load Test Results Report from Bridge Designer 2016

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3356.87	3420.00	OK
2	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3302.56	3420.00	OK
3	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3015.33	3420.00	OK
4	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3134.26	3420.00	OK
5	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3134.26	3420.00	OK
6	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	2998.94	3420.00	OK
7	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3261.59	3420.00	OK
8	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3274.94	3420.00	OK
9	CS	Solid Bar	90x90	4.00	0.00	534.22	OK	1846.13	1923.75	OK
10	CS	Hollow Tube	260x260x13	5.00	2307.67	2540.07	OK	0.00	3050.45	OK
11	CS	Solid Bar	80x80	3.00	0.00	592.49	OK	1377.99	1520.00	OK
12	CS	Hollow Tube	240x240x12	5.00	1869.42	2116.37	OK	0.00	2599.20	OK
13	CS	Solid Bar	40x40	3.00	0.00	37.06	OK	294.66	380.00	OK
14	CS	Hollow Tube	120x120x6	5.66	105.65	283.52	OK	537.30	649.80	OK
15	CS	Hollow Tube	150x150x7	6.40	0.00	479.06	OK	822.84	950.95	OK
16	CS	Solid Bar	60x60	5.00	0.00	67.54	OK	582.34	855.00	OK
17	CS	Solid Bar	80x80	4.00	294.41	333.51	OK	46.57	1520.00	OK
18	CS	Hollow Tube	150x150x7	6.40	417.81	479.06	OK	118.70	950.95	OK
19	CS	Solid Bar	60x60	5.00	0.00	67.54	OK	623.65	855.00	OK
20	CS	Hollow Tube	150x150x7	6.40	458.65	479.06	OK	77.87	950.95	OK
21	CS	Solid Bar	60x60	5.00	0.00	67.54	OK	614.22	855.00	OK
22	CS	Hollow Tube	150x150x7	6.40	0.00	479.06	OK	731.03	950.95	OK
23	CS	Solid Bar	80x80	4.00	248.33	333.51	OK	54.54	1520.00	OK

24	CS	Hollow Tube	120x120x6	5.66	120.68	283.52	OK	450.41	649.80	OK
25	CS	Solid Bar	40x40	3.00	0.00	37.06	OK	305.29	380.00	OK
26	CS	Hollow Tube	240x240x12	5.00	1922.56	2116.37	OK	0.00	2599.20	OK
27	CS	Solid Bar	80x80	3.00	0.00	592.49	OK	1409.88	1520.00	OK
28	CS	Hollow Tube	260x260x13	5.00	2360.81	2540.07	OK	0.00	3050.45	OK
29	CS	Hollow Tube	240x240x12	4.00	1888.65	2234.95	OK	0.00	2599.20	OK
30	CS	Hollow Tube	300x300x15	4.12	3460.18	3602.11	OK	0.00	4061.25	OK
31	CS	Hollow Tube	300x300x15	4.12	3404.20	3602.11	OK	0.00	4061.25	OK
32	CS	Hollow Tube	300x300x15	4.00	3015.33	3616.10	OK	0.00	4061.25	OK
33	CS	Hollow Tube	300x300x15	4.00	2998.94	3616.10	OK	0.00	4061.25	OK
34	CS	Hollow Tube	300x300x15	4.12	3361.97	3602.11	OK	0.00	4061.25	OK
35	CS	Hollow Tube	300x300x15	4.12	3375.73	3602.11	OK	0.00	4061.25	OK
36	CS	Hollow Tube	240x240x12	4.00	1846.13	2234.95	OK	0.00	2599.20	OK
37	CS	Solid Bar	90x90	4.00	0.00	534.22	OK	1888.65	1923.75	OK

Table 3
Howe Truss Bridge
Member Details Report from Bridge Designer 2016
Member with the Highest Compression Force/Strength Ratio

Member List | Member Details

Current Material

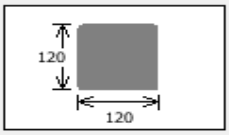
Material Properties:

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	120x120
Area	0.0144 sq. meters
Moment of Inertia	1.73E-05 meters^4
Member Length	--

Section (mm):



Cost:

Unit Cost	$486.07 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member:

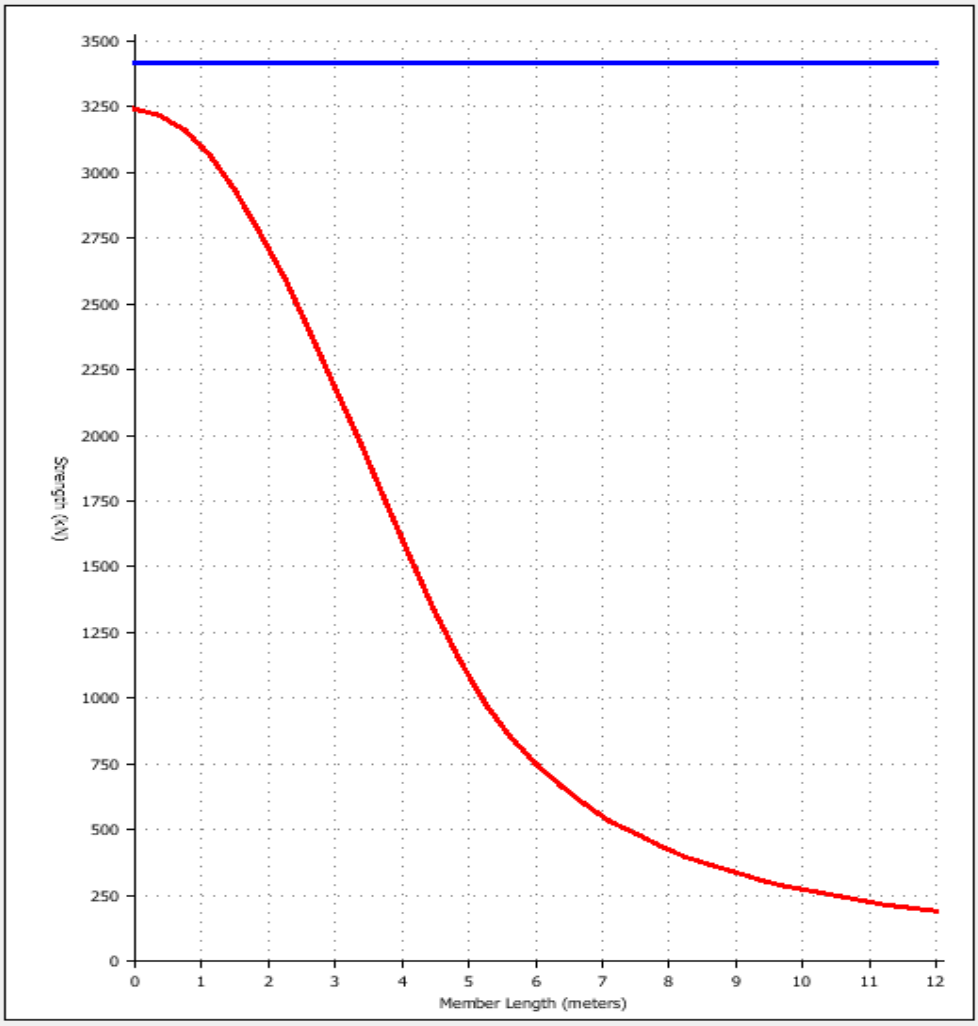


Table 4
Warren Truss Bridge
Cost Calculation Report from Bridge Designer 2016

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Hollow Tube	(12061.5 kg) x ($6.30 per kg) x (2 Trusses) =	$151,974.58
Connection Cost (C)		(21 Joints) x (400.0 per joint) x (2 Trusses) =	$16,800.00
Product Cost (P)	2 - 140x140x7 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 150x150x7 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	6 - 170x170x8 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 180x180x9 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	1 - 190x190x9 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 200x200x10 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	5 - 220x220x11 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 260x260x13 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	2 - 280x280x14 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 300x300x15 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	3 - 320x320x16 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	(19,400 cubic meters) x ($1.00 per cubic meter) =	$19,400.00
	Abutment Cost	(2 standard abutments) x ($5,500.00 per abutment) =	$11,000.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	M + C + P + S	$151,974.58 + $16,800.00 + $11,000.00 + $77,400.00 =	$257,174.58

Table 5
Warren Truss Bridge
Load Test Results Report from Bridge Designer 2016

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Hollow Tube	280x 280x 14	4.00	0.00	3121.25	OK	3481.21	3537.80	OK
2	CS	Hollow Tube	220x 220x 11	4.47	1585.41	1791.30	OK	0.00	2184.05	OK
3	CS	Hollow Tube	220x 220x 11	4.00	1415.13	1843.70	OK	0.00	2184.05	OK
4	CS	Hollow Tube	200x 200x 10	4.47	0.00	1436.26	OK	1578.91	1805.00	OK
5	CS	Hollow Tube	200x 200x 10	4.47	1294.88	1436.26	OK	0.00	1805.00	OK
6	CS	Hollow Tube	180x 180x 9	4.47	0.00	1116.73	OK	1286.19	1462.05	OK
7	CS	Hollow Tube	170x 170x 8	4.47	704.67	917.48	OK	0.00	1231.20	OK
8	CS	Hollow Tube	150x 150x 7	4.47	406.58	662.03	OK	61.82	950.95	OK
9	CS	Hollow Tube	170x 170x 8	4.47	0.00	917.48	OK	693.48	1231.20	OK
10	CS	Hollow Tube	150x 150x 7	4.47	108.36	662.03	OK	360.04	950.95	OK
11	CS	Hollow Tube	150x 150x 7	4.47	72.94	662.03	OK	395.46	950.95	OK
12	CS	Hollow Tube	150x 150x 7	4.47	371.17	662.03	OK	97.23	950.95	OK
13	CS	Hollow Tube	170x 170x 8	4.47	0.00	917.48	OK	658.06	1231.20	OK
14	CS	Hollow Tube	170x 170x 8	4.47	0.00	917.48	OK	955.47	1231.20	OK
15	CS	Hollow Tube	180x 180x	4.47	0.00	1116.73	OK	1250.77	1462.05	OK

			9							
16	CS	Hollow Tube	180x 180x 9	4.47	965.37	1116.73	OK	0.00	1462.05	OK
17	CS	Hollow Tube	200x 200x 10	4.00	1382.57	1487.26	OK	0.00	1805.00	OK
18	CS	Hollow Tube	190x 190x 9	4.47	0.00	1209.64	OK	1542.84	1547.55	OK
19	CS	Hollow Tube	200x 200x 10	4.47	1259.09	1436.26	OK	0.00	1805.00	OK
20	CS	Hollow Tube	220x 220x 11	4.47	1548.69	1791.30	OK	0.00	2184.05	OK
21	CS	Hollow Tube	170x 170x 8	4.47	669.25	917.48	OK	0.00	1231.20	OK
22	CS	Hollow Tube	180x 180x 9	4.47	1000.79	1116.73	OK	0.00	1462.05	OK
23	CS	Hollow Tube	170x 170x 8	4.47	0.00	917.48	OK	990.89	1231.20	OK
24	CS	Hollow Tube	260x 260x 13	4.00	2517.05	2660.84	OK	0.00	3050.45	OK
25	CS	Hollow Tube	300x 300x 15	4.00	3303.01	3616.10	OK	0.00	4061.25	OK
26	CS	Hollow Tube	320x 320x 16	4.00	3771.18	4145.34	OK	0.00	4620.80	OK
27	CS	Hollow Tube	320x 320x 16	4.00	3920.39	4145.34	OK	0.00	4620.80	OK
28	CS	Hollow Tube	320x 320x 16	4.00	3750.49	4145.34	OK	0.00	4620.80	OK
29	CS	Hollow Tube	300x 300x 15	4.00	3261.63	3616.10	OK	0.00	4061.25	OK
30	CS	Hollow Tube	260x 260x 13	4.00	2454.97	2660.84	OK	0.00	3050.45	OK

31	CS	Hollow Tube	140x 140x 7	4.00	0.00	630.23	OK	709.02	884.45	OK
32	CS	Hollow Tube	220x 220x 11	4.00	0.00	1843.70	OK	1941.85	2184.05	OK
33	CS	Hollow Tube	260x 260x 13	4.00	0.00	2660.84	OK	2859.87	3050.45	OK
34	CS	Hollow Tube	280x 280x 14	4.00	0.00	3121.25	OK	3461.04	3537.80	OK
35	CS	Hollow Tube	300x 300x 15	4.00	0.00	3616.10	OK	3768.55	4061.25	OK
36	CS	Hollow Tube	300x 300x 15	4.00	0.00	3616.10	OK	3784.39	4061.25	OK
37	CS	Hollow Tube	260x 260x 13	4.00	0.00	2660.84	OK	2859.35	3050.45	OK
38	CS	Hollow Tube	220x 220x 11	4.00	0.00	1843.70	OK	1920.63	2184.05	OK
39	CS	Hollow Tube	140x 140x 7	4.00	0.00	630.23	OK	692.59	884.45	OK

Table 6
Warren Truss Bridge
Member Details Report from Bridge Designer 2016
Member with the Highest Tension Force/Strength Ratio

Member List | Member Details

Current Material

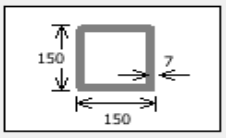
Material Properties:

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	Hollow Tube
Cross-Section Size	150x150x7
Area	0.0040 sq. meters
Moment of Inertia	1.37E-05 meters^4
Member Length	--

Section (mm):



Cost:

Unit Cost	$198.02 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member:

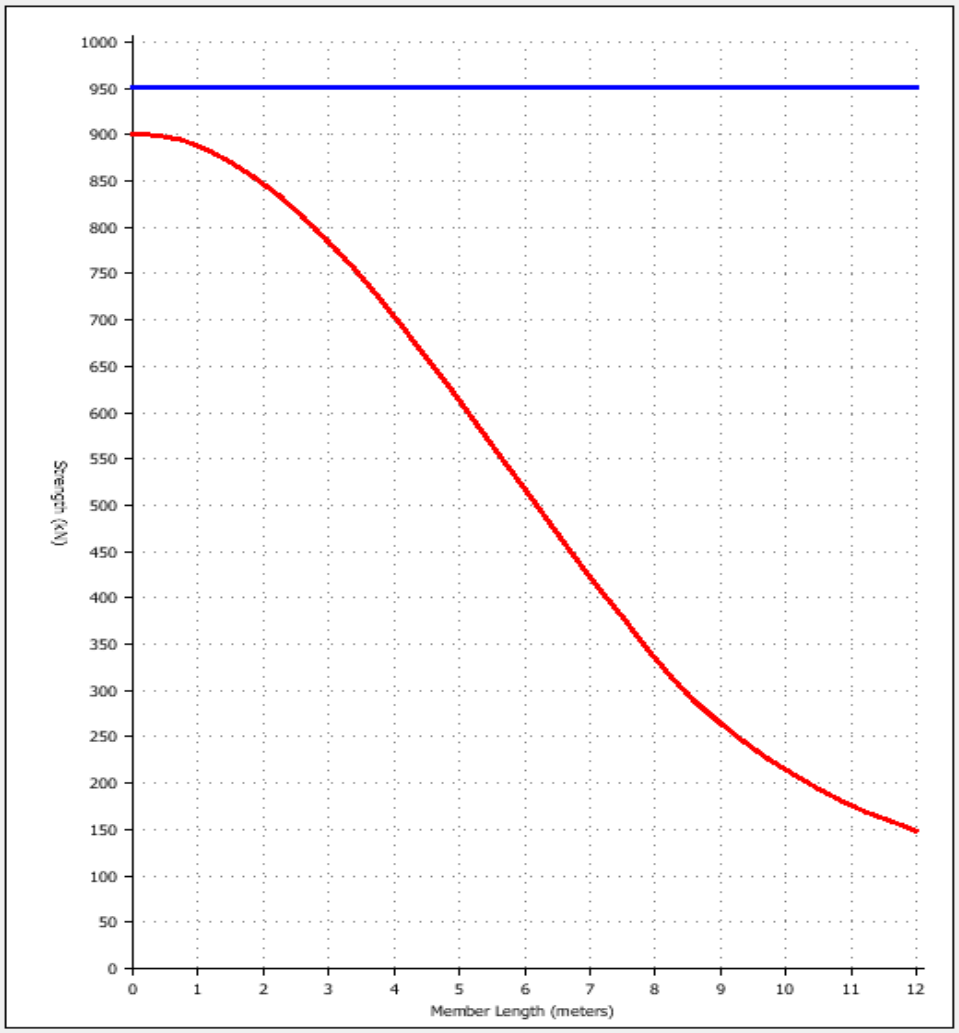


Table 7

HOWE Truss Bridge

Design Team No.	Actual Bridge Weight (grams)	LOAD at Failure (lbs.)	Load at Failure (grams)	Structural Efficiency	Geomean	Design Efficiency
1	78.6	63.5	28803.092	366.4515522	299.2293	1160.5
2	77.9	46.2	20955.9504	269.0109166		
3	73.2	67.6	30662.8192	418.8909727		
4	77.9	108.5	49214.732	631.7680616		
5	73.7	33.9	15376.7688	208.6400109		
6	72.7	32.6	14787.0992	203.3988886		
7	85.1	36.4	16510.7488	194.0158496		
			Average	327.4537503		

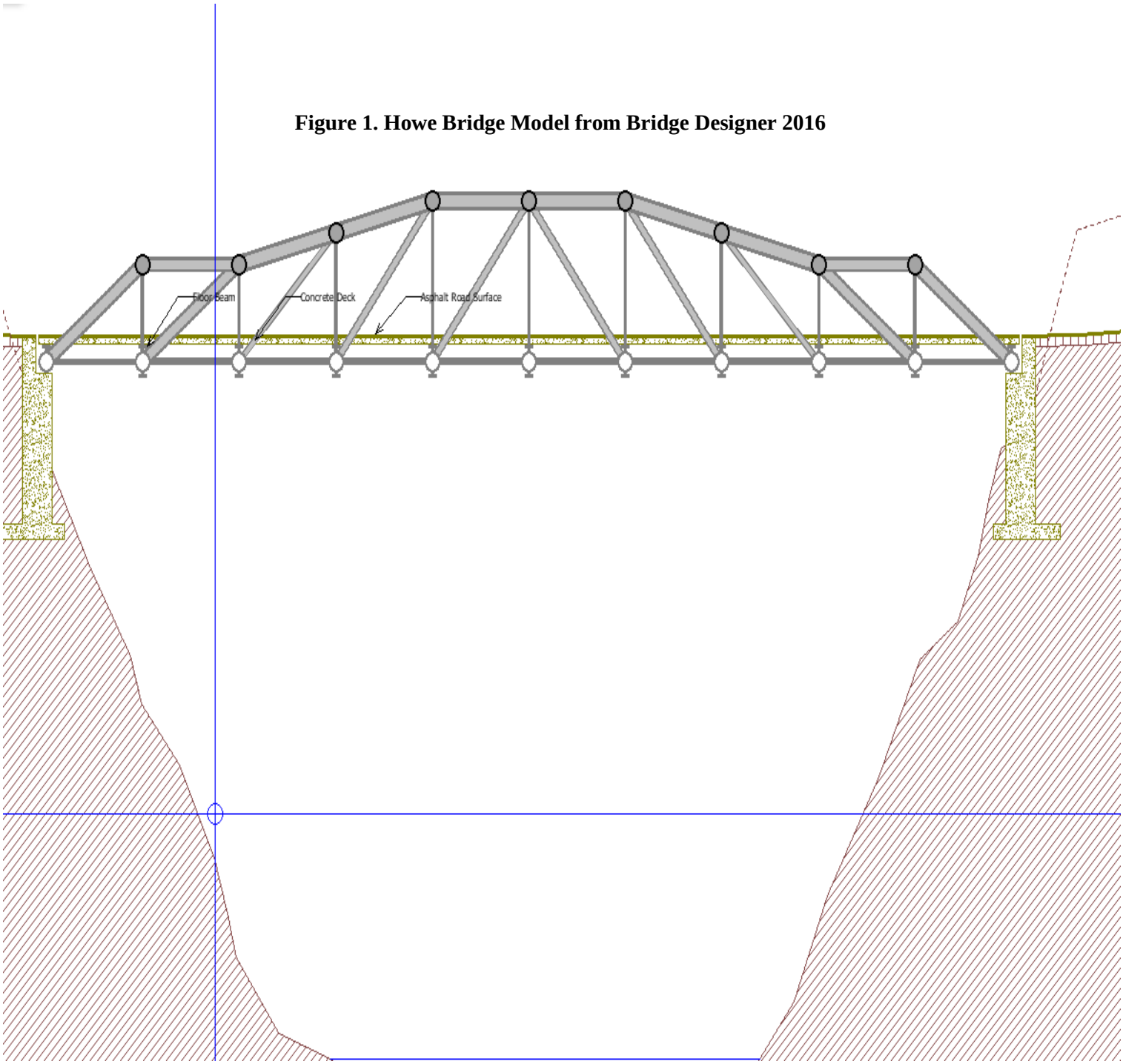
Table 8

WARREN Truss Bridge

Design Team No.	Actual Bridge Weight (grams)	LOAD at Failure (lbs.)	Load at Failure (grams)	Structural Efficiency	Geomean	Design Efficiency
1	71.1	64.3	29166	410.2109705	340.6278	1095.8
2	82.1	78	35380.2	430.9403167		
3	80.2	114.6	51981.7	648.1508728		
4	82.4	56.6	25673.3	311.5691748		
5	80.9	33.6	15240.7	188.3893696		
6	63.2	32.7	14832.3	234.6882911		
7	80.6	59.9	27170.2	337.0992556		
			Average	365.8640359		

FIGURES

Figure 1. Howe Bridge Model from Bridge Designer 2016



Warren Truss Bridge Model from Bridge Designer 2016

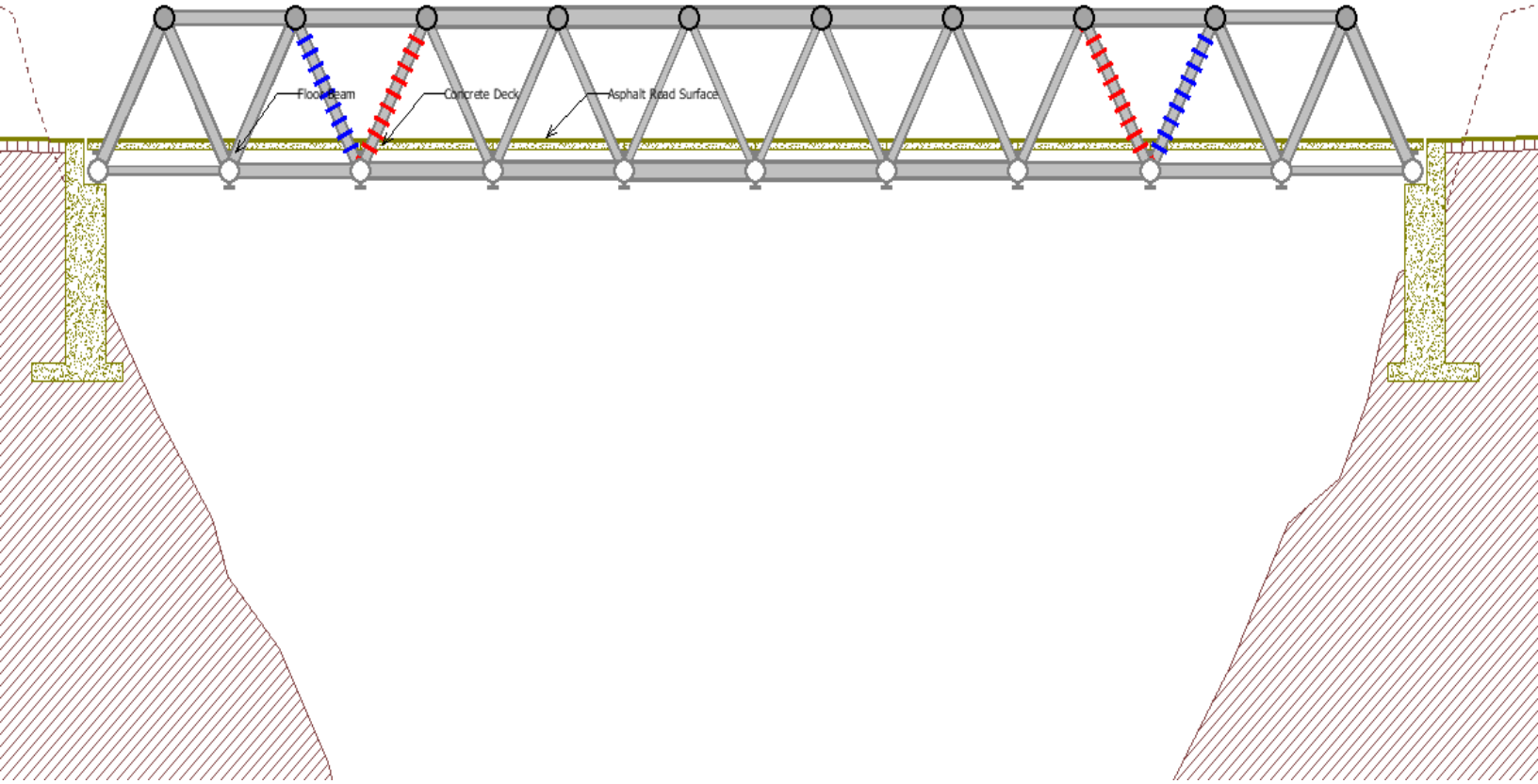


Figure 3

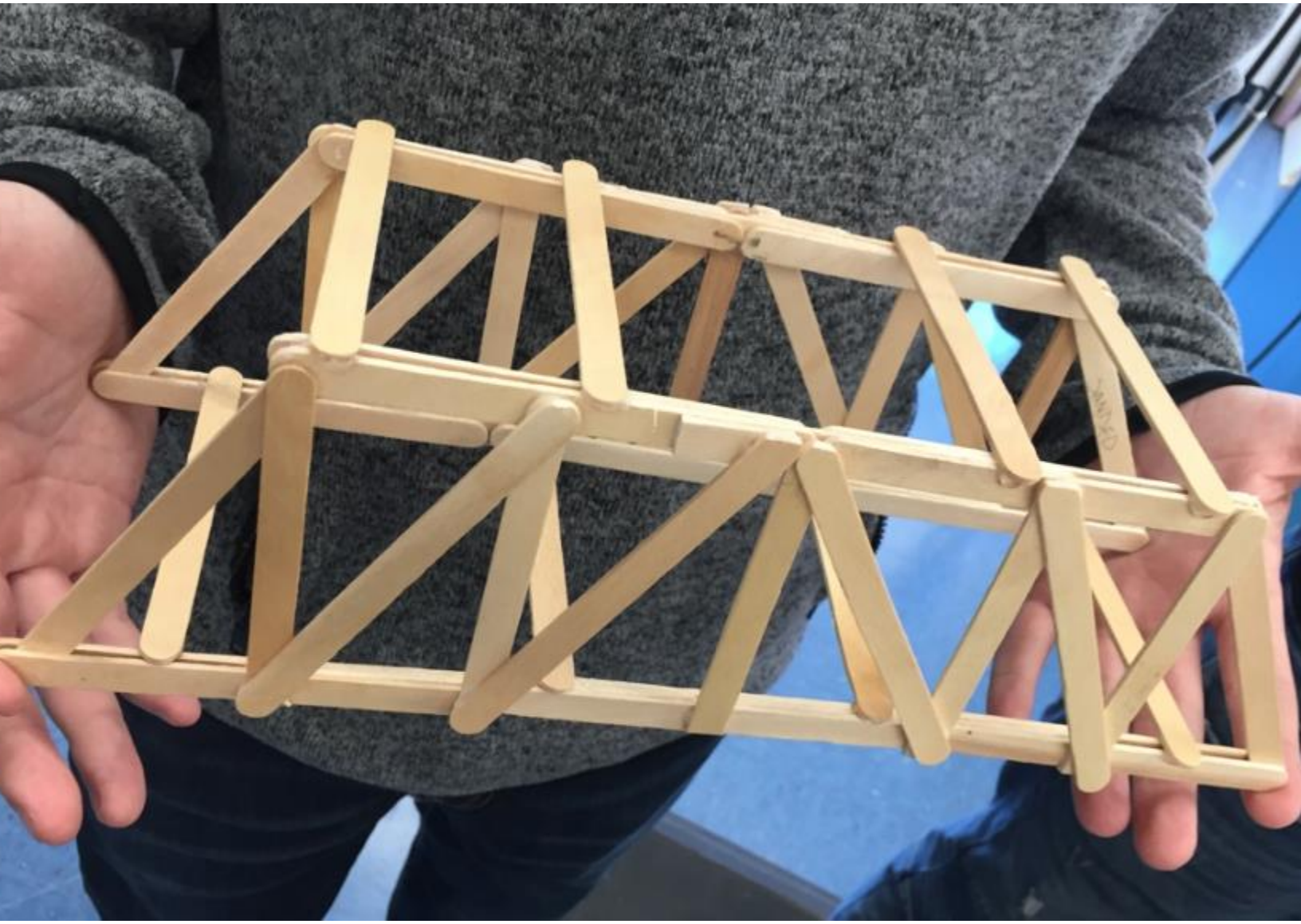


Figure 4

Figure 5

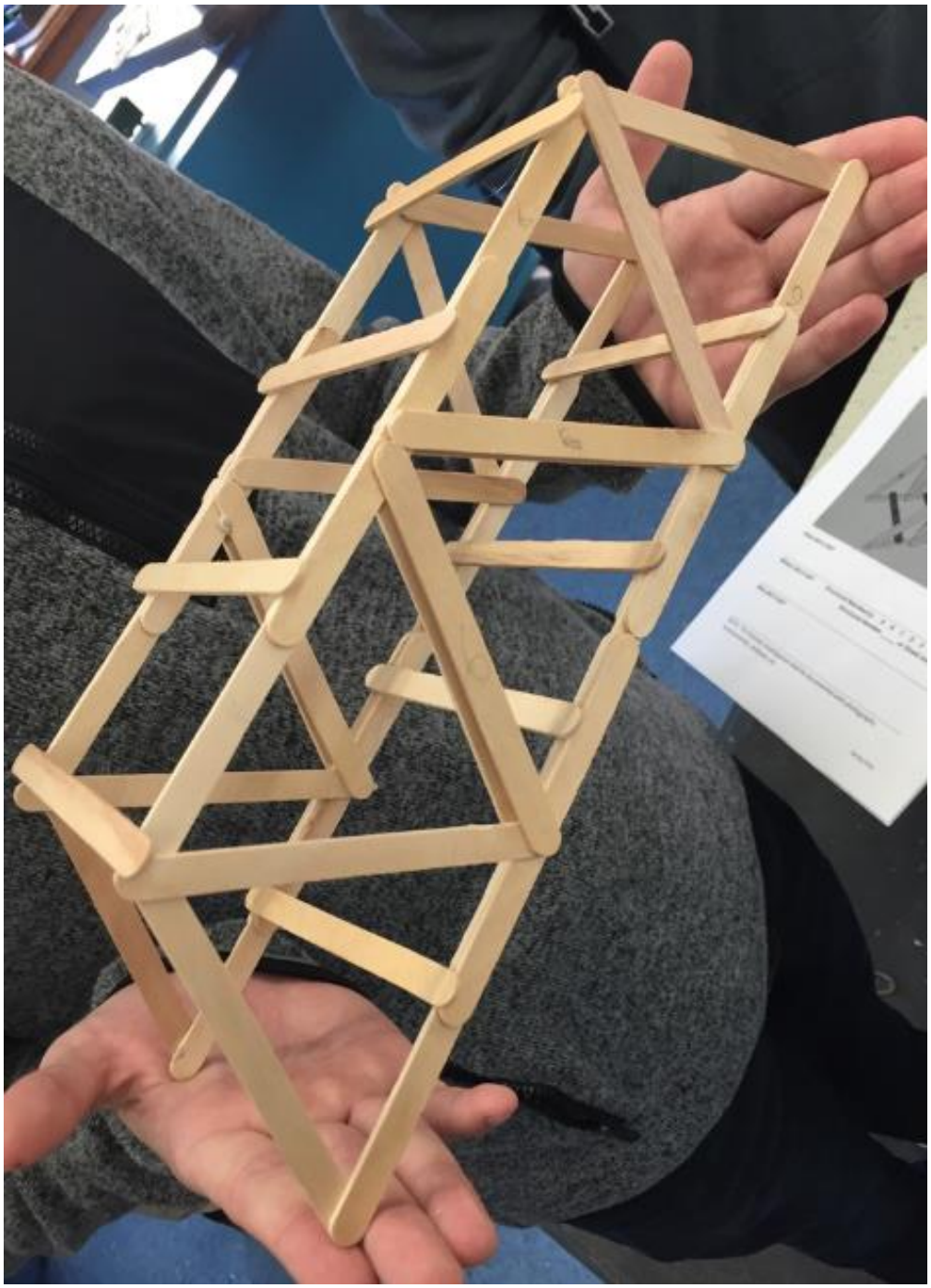


Figure 6

Figure 7

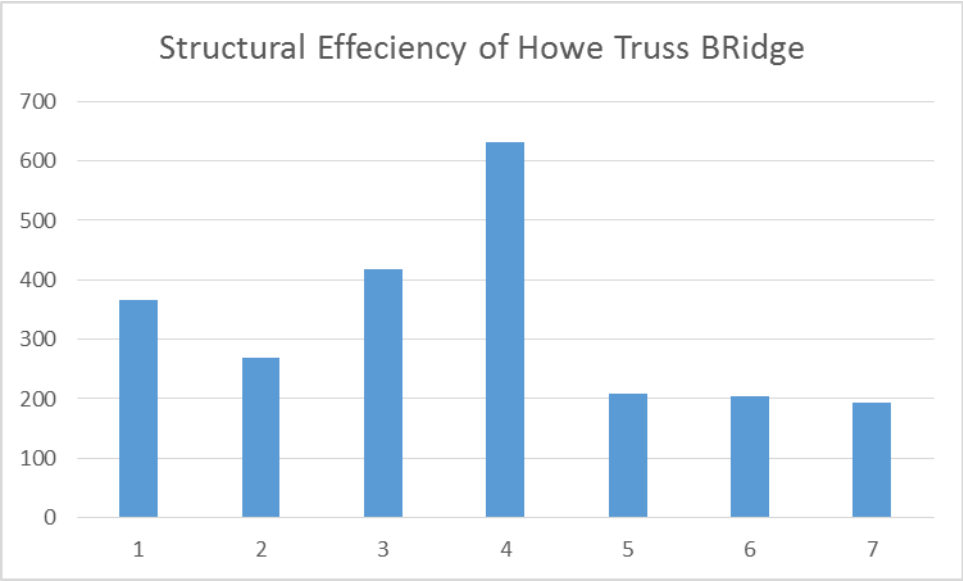
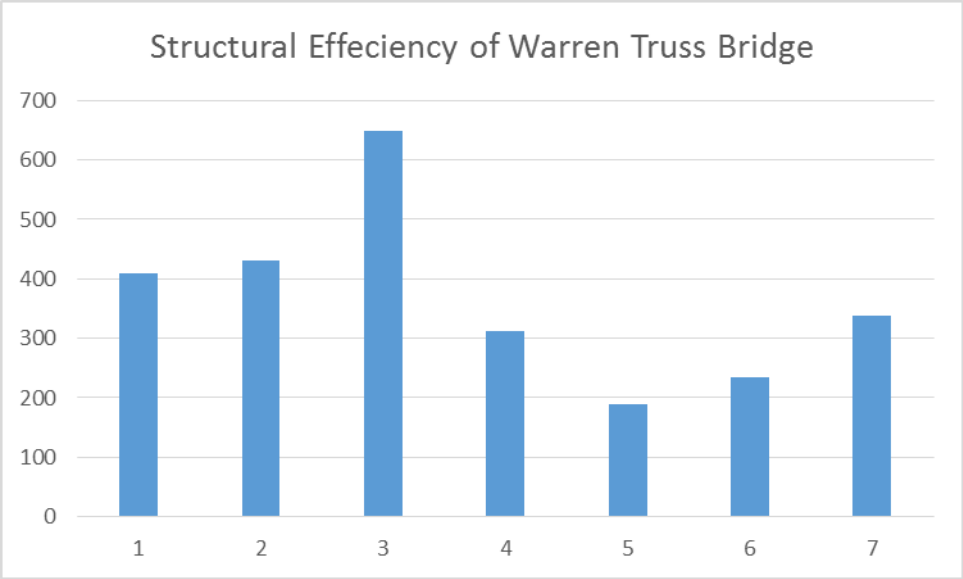

Structural Effeciency of Howe Truss BRidge
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7

Figure 8


Structural Effeciency of Warren Truss Bridge
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7