PENNSTATE

School of Engineering Design, Technology and Professional Programs
213 Hammond Building
University Park, PA 16802-2701

October 19 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. During a 100 year flood, a structurally deficient bridge allowing access to MT. Nittany medical center imploded in Centre County, PA. The task was to design a Warren or Howe truss bridge that is structurally efficient as well as cost efficient to replace the failed bridge and that can withstand the next 100 year flood.

Objective. To build a structurally and cost efficient bridge that will be able to survive 100 year floods.

Design Criteria. A Warren or Howe truss bridge with 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.

Technical Approach.

Phase 1: Economic Efficiency. The bridge was put under intense evaluations in order to achieve the lowest cost possible. The bridges' members were tested with different member thicknesses as well as different materials on a BridgeBuilder2015, a bridge design software. The most cost efficient method was to use members with similar thicknesses and materials. In this way, the bridge was able to dodge the costs of bringing in different sized members because we could mass order the parts. However, for some parts we could get away with much thinner materials because there was less tension and compression forces.

Phase 2: Structural Efficiency. At the locations where the bridge failed, the members that failed were substituted for thicker members. Different types of steel were also tried to achieve the strongest bridge (the compression ratio closest to 1.0). Tubes were stronger for compression and bars were stronger in tension. Achieving a compression ratio of 1.0 is quite difficult, but we found that unifying the materials added some structural efficiency (as well as cost efficiency). The different types of members were used in the correlating force.

Results.

Phase 1: Economic Efficiency. The cost of the Warren bridge was $247,019.84, which is a reasonable cost for the structural efficiency of the bridge. The cost of the Howe bridge was $268,947.72 which is also a reasonable cost, however the structural efficiency was not as good for the price. Limiting our members to have 17 different ones for the Warren bridge and 15 different ones for the Howe bridge, drastically lowered our overall cost compared to a different material and size for each individual member. The use of High-Strength Low-Alloy Steel Hollow Tube in the Howe bridge increased the cost of the bridge in a negative way, but provided the stability that was needed for efficiency. The Warren bridge was the most economically efficient and the supporting data can be found in the attachment 1 section.

Phase 2: Structural Efficiency. The structural efficiency of the Warren bridge was 579.3 which is 200 higher than the average of 380. Compared to the other Warren bridges in our class, our bridge had the highest structural efficiency. The Howe Bridge had a structural efficiency was 388.89, although not as high as the Warren bridge, it is still above the average by a little bit. To obtain maximal structural efficiency, the compression ratio needed to be closest to 1.0 and this was manipulated in the bridge design software. In our actual load test, high structural efficiency was obtained by designing a level bridge that would administer forces evenly across the bride and that had chords exactly connecting the two bridge sides. The Warren bridge was the most structurally efficient based on the ratio and load weight. The structural efficiency compared with those of the other class groups can be found in tables 7 and 8.

Best Solution. The best solution for the project was the Warren bridge because it cost a little over $20,000 less than the Howe Bridge. If you compare the data in tables 1, you can see that the Warren bridge is much more cost efficient and has compression ratios that overall are closer to 1.0. Attachment 2 shows the weight of the bridge and the load of the bridge and contains graphs that compare the weight of the bridge with the weight it supports as a ratio. The structural efficiency of the Warren bridge was top of the class and 200 above the average, while the Howe bridge was in the middle of the class and just slightly above average, but above average none the less.

Our group decided on the Warren bridge because of the structural efficiency as well as the economic efficiency. Because our Warren design had the highest structural efficiency in the class and thus can be labeled as extremely stable. Based on the data in the bridge designer software, the Warren bridge exceled in cost efficiency by totaling $20,00 less than the Howe bridge. In the software, the Warren bridge most successfully maintained its stability with consistent materials, i.e. we were able to standardize our material to almost all carbon steel solid bar. It also most successfully reached a compression ratio of 1.0, which greatly contributed to its structural stability.

In the design of the bridge, our Warren bridge's level top and bottom chords as well as gussets allowed for maximal stability. The level top and bottom chords allowed the force of the load to be evenly distributed and not place too much force on which side which would result in toppling to the side. The gussets, were extra materials that we glued onto the joints of the Warren bride, that provided additional strength and support to the forces. This was a vital component in the success of the load weight.

Conclusions and Recommendations. Our formal recommendation for the trough truss bridge type replacement is the Warren truss bridge. This bridge will be able to withstand the next 100 year flood because our design has a structural efficiency of 579.3. After the bridge design software was used to design a bridge, we load tested a model bridge made of popsicle sticks. The next step in the advancement of the project to the final design of replacement is to simulate the effects of the environment on the bridge. The bridge needs to be tested against wind load, temperature changes, and excess weight due to snow or traffic. This can be calculated mathematically with loads being added and a complex evaluation of the summation of forces and moments of the two force truss members. In addition to this, the model bridge could be tested to failure against these elements in a closed setting. After these, the bridge would be ready for construction.

Warm Regards,

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Howe Truss.

HOWE BRIDGE							
Design Team No.	Height (inches)	Width (inches)	Length (inches)	ESTIMATED Bridge Weight (grams)	ACTUAL Bridge Weight (grams)	ESTIMATED LOAD at Failure (lbs)	LOAD at Failure (lbs.)
1					81.3	74.23	69.7
2					64.3	20	33.8
3					95.8	50	59.6
4					78.5	30	65.4
5					79.4	42	99.7
6					80.4	94	84.2
7					84.7	20	71.0
8					82.6	50	44.3

Howe Truss: Above is the Howe Bridge weght assessment that shows the weight of each team's bridge and the load at which it fails. Note that the weight is measured in grams and must be converted to pounds. Most of the bridge weights were around 80 grams which is very reasonable.

See excel table in Tables section.

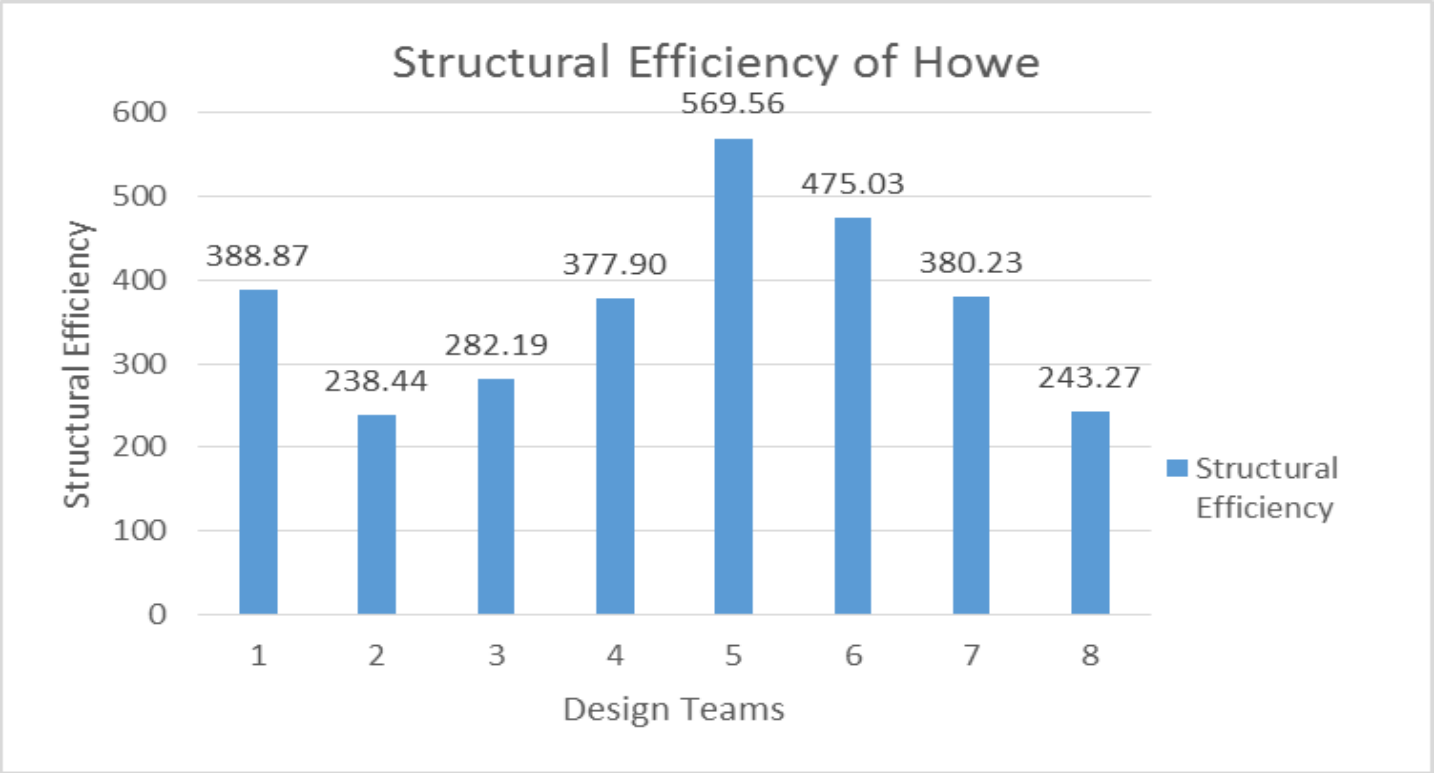


Table 7: Shows the structural efficiency of the all the Howe bridgs in our class. Design team 5 had the highest structural effieciency which was attributed to the symmetry in the alignment of the bridge which allowed for even distribution of force.

Prototype Bridge. The bridge was made from all popsicle sticks that were stable and with minimal amounts of glue. The final product was not completely level , which effected its structural stability. There was a total of 37 members used. It was the size of the picture on the handout that we were given.

Load Testing. The average structural efficiency was 380. The range was 238, with the maximum being 569 and the lowest being 238.

Forensic Analysis. The Howe bridge failed at member 11 and joint 6 which is seen in the attached picture of the bridge after failure. This most likely happened because of the uneven force distribution. It failed by falling off to the side and collapsing from there.

Results. A graph is attached above.

Warren Truss.

EDSGN100_002
Design Project #1
Prof. Berezniak

Prototype Bridge Data

Date: October 23, 2015

WARREN BRIDGE

Design Team No.	Height (inches)	Width (inches)	Length (inches)	ESTIMATED Bridge Weight (grams)	ACTUAL Bridge Weight (grams)	ESTIMATED LOAD at Failure (lbs)	LOAD at Failure (lbs.)
1					81.9	69	104.6
2					77.1	20	33.9
3					74.9	30	50.8
4					75.7	30	38.2
5					80.9	60	55.4
6					90.1	97	75.8
7					87.0	30	70.9
8					83.6	31	90.3

Warren Truss: Above is the Warren Bridge weght assessment that shows the weight of each team's bridge and the load at which it fails. Note that the weight is measured in grams and must be converted to pounds. Most of the bridge weights were around 80 grams which is very reasonable.

See excel table in Tables section.

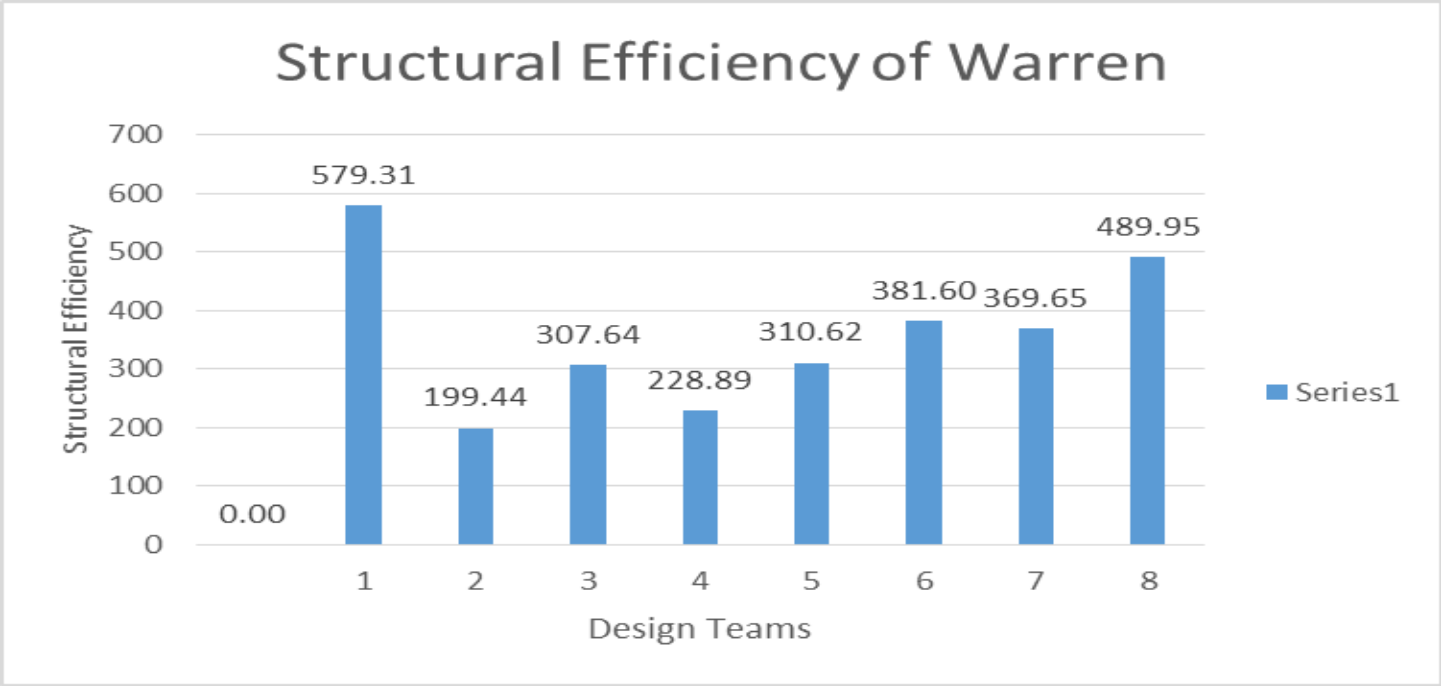
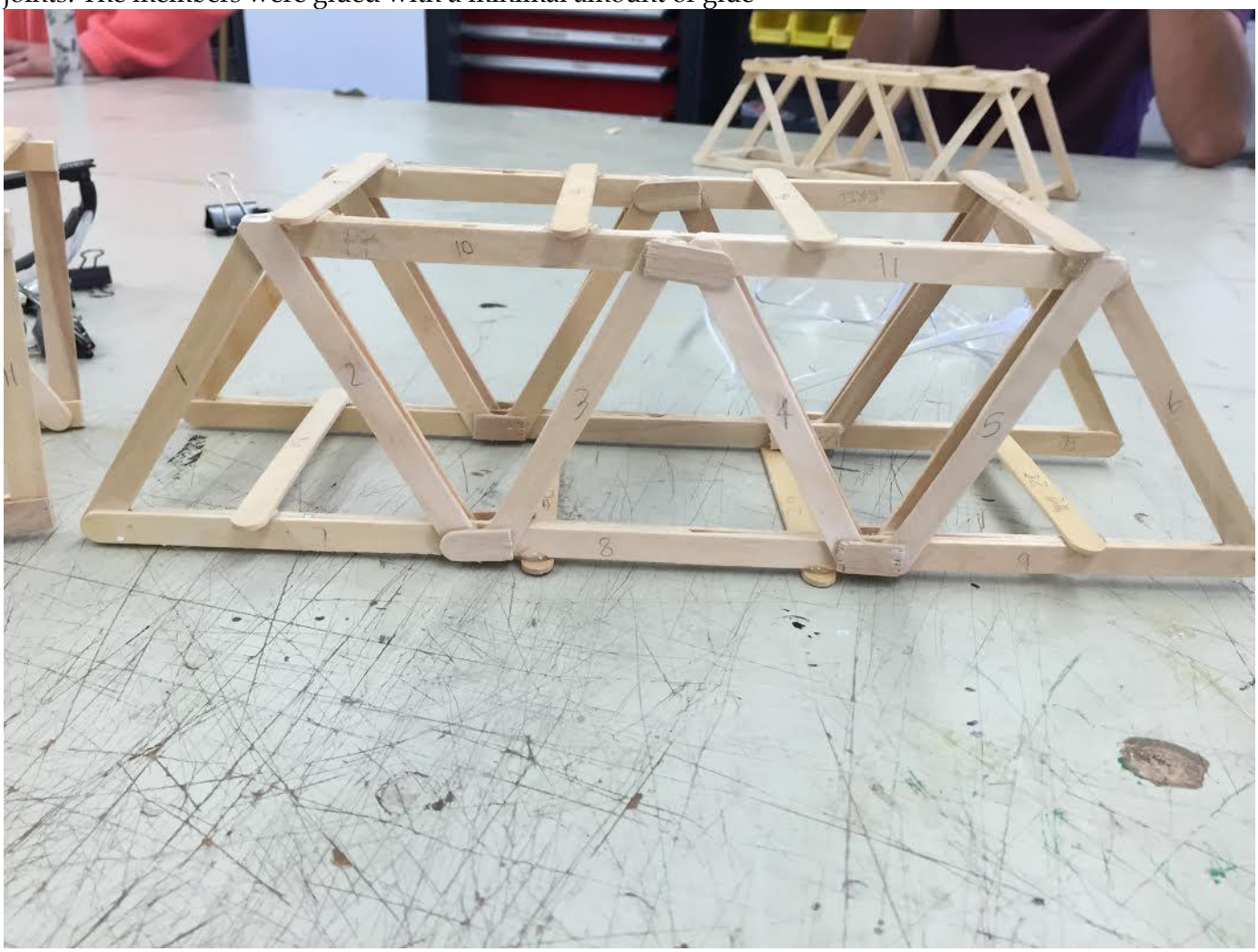


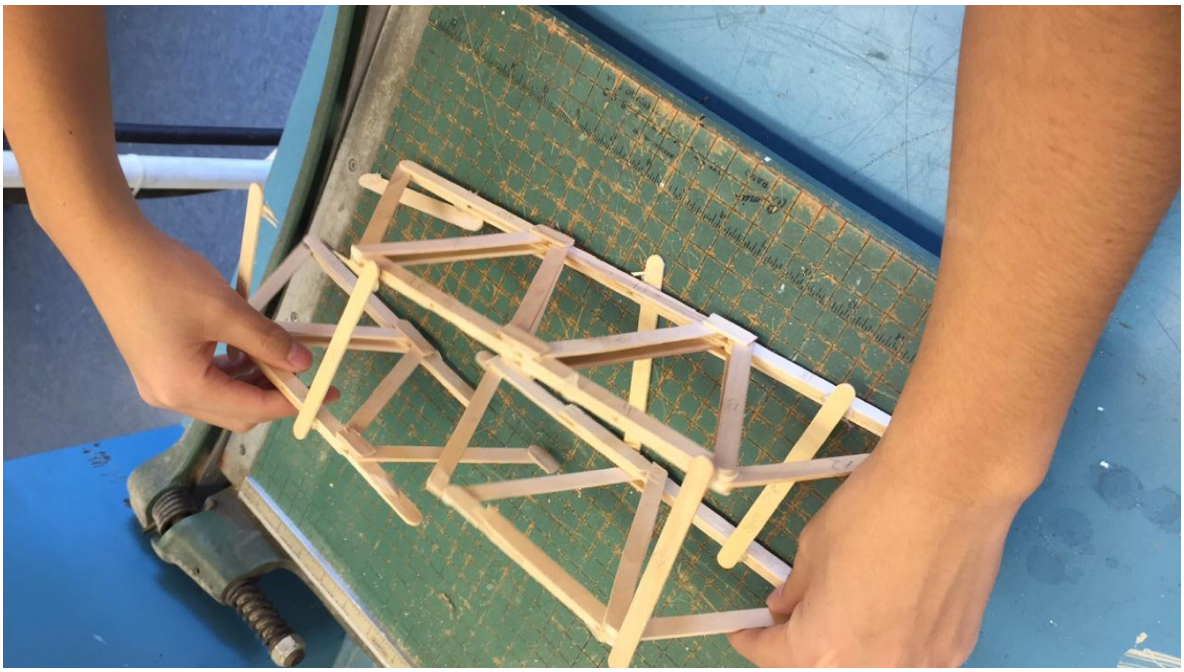
Table 8: Shows the structural efficiency of the all the Warren bridgs in our class. Design team 1(us) had the highest structural effieciency which was attributed to the gussets that were attached at the joints.

Prototype Bridge. This Warren is superior in structural efficiency due to the added gussets on the joints. The members were glued with a minimal amount of glue



Load Testing. The average was 358.2. Our structural efficiency exceeded the average by over 200. The range of the warren bridges was 380. With the maximum being 579 and the minimum being 199.

Forensic Analysis. The Warren bridge failed at member 27 and joint 16 which is seen in the attached picture of the bridge after failure. This most likely happened because of the swaying from the load which made the bridge fall off to the side and collapse from there.



Results. A graph is attached above

TABLES

Type of Cost	*Item*	Cost Calculation	Cost
Material Cost (M)	*Carbon Steel Solid Bar*	(12149.4 kg) x ($4.30 per kg) x (2 Trusses) =	$104,485.00
	Carbon Steel Hollow Tube	(2153.6 kg) x ($6.30 per kg) x (2 Trusses) =	$27,134.84
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	*1 - 55x55 mm Carbon Steel Bar*	(%s per Product) =	$1,000.00
	3 - 60x60 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	3 - 65x65 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 75x75 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	3 - 90x90 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 100x100 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	4 - 120x120 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	1 - 120x120x6 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	3 - 130x130 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	1 - 130x130x6 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	3 - 140x140 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	4 - 160x160 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 160x160x8 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	1 - 170x170 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 180x180x9 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	2 - 200x200x10 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	2 - 220x220x11 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*	$131,619.84 + $21,000.00 + $17,000.00 + $77,400.00 =	$247,019.84

Figure 1: shows the Warren bridge cost data from Bridge Designer 2015, as well as the types and number of each member and material used

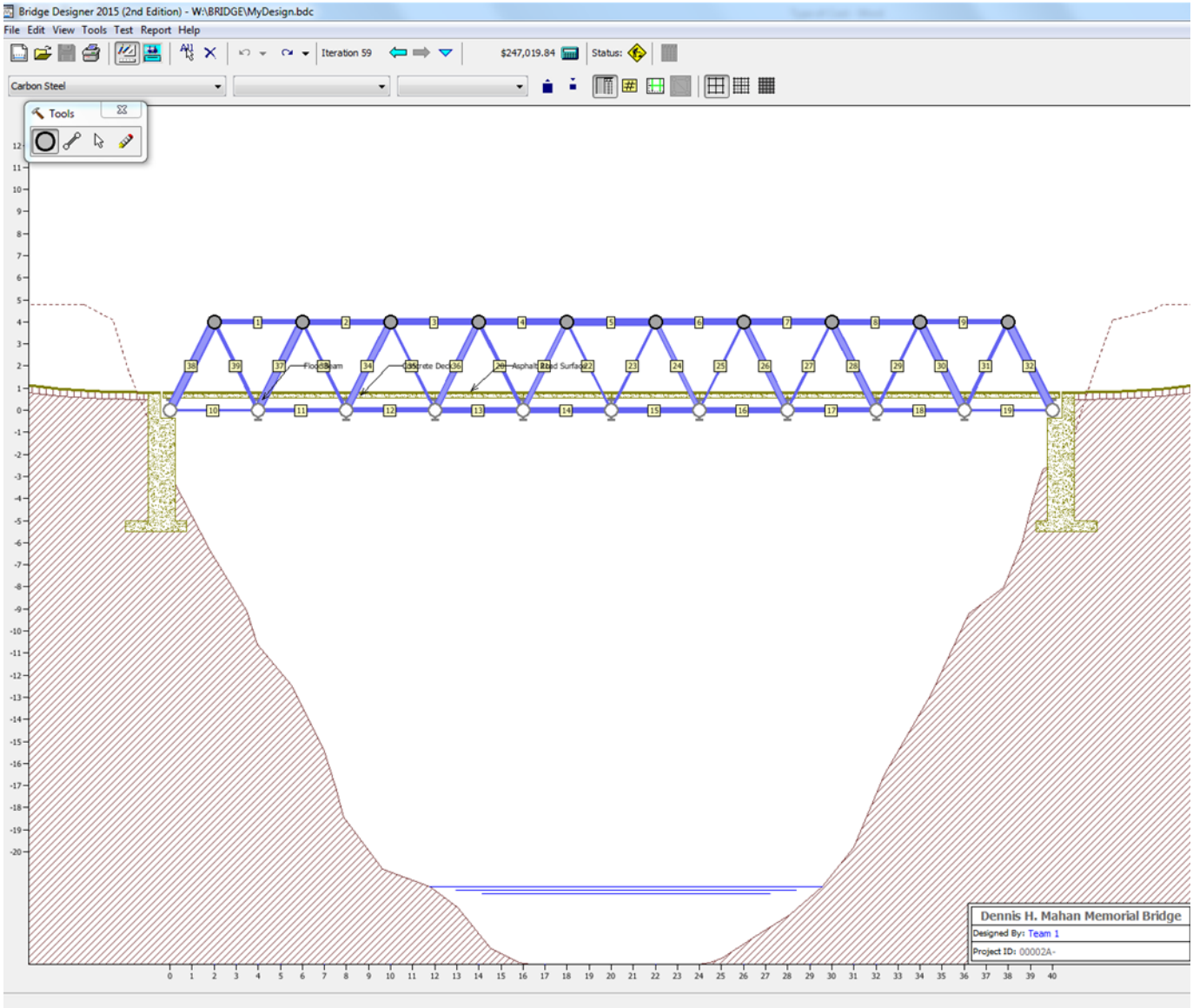


Figure 2: This shows a replica of the Warren truss bridge as designed in the Bridge Designer 2015 program and shows the labeled members

						Load Test Results	
#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Bar	120	4.00	115.47	0.89	0.00
2	CS	Bar	140	4.00	98.97	0.97	0.00
3	CS	Bar	160	4.00	86.60	0.86	0.00
4	CS	Bar	160	4.00	86.60	0.98	0.00
5	CS	Bar	170	4.00	81.51	0.86	0.00
6	CS	Bar	160	4.00	86.60	0.98	0.00
7	CS	Bar	160	4.00	86.60	0.85	0.00
8	CS	Bar	140	4.00	98.97	0.94	0.00
9	CS	Bar	120	4.00	115.47	0.87	0.00
10	CS	Bar	60	4.00	230.94	0.00	0.84
11	CS	Bar	100	4.00	138.56	0.00	0.83
12	CS	Bar	120	4.00	115.47	0.00	0.85
13	CS	Bar	130	4.00	106.59	0.00	0.87
14	CS	Bar	130	4.00	106.59	0.00	0.95
15	CS	Bar	140	4.00	98.97	0.00	0.82
16	CS	Bar	130	4.00	106.59	0.00	0.88
17	CS	Bar	120	4.00	115.47	0.00	0.85
18	CS	Bar	100	4.00	138.56	0.00	0.82
19	CS	Bar	60	4.00	230.94	0.00	0.82
20	CS	Bar	90	4.47	172.13	0.00	0.36
21	CS	Tube	130	4.47	88.24	0.92	0.08
22	CS	Bar	60	4.47	258.20	0.87	0.46
23	CS	Bar	65	4.47	238.34	0.92	0.36
24	CS	Tube	120	4.47	95.96	0.99	0.14
25	CS	Bar	55	4.47	281.67	0.00	0.92
26	CS	Tube	160	4.47	71.97	0.81	0.00
27	CS	Bar	65	4.47	238.34	0.00	0.96
28	CS	Tube	180	4.47	63.97	0.87	0.00
29	CS	Bar	75	4.47	206.56	0.00	0.94
30	CS	Tube	200	4.47	57.58	0.89	0.00
31	CS	Bar	90	4.47	172.13	0.00	0.81
32	CS	Tube	220	4.47	52.34	0.87	0.00
33	CS	Bar	75	4.47	206.56	0.00	0.97
34	CS	Tube	180	4.47	63.97	0.91	0.00
35	CS	Bar	65	4.47	238.34	0.00	1.00
36	CS	Tube	160	4.47	71.97	0.86	0.00
37	CS	Tube	200	4.47	57.58	0.91	0.00
38	CS	Tube	220	4.47	52.34	0.89	0.00
39	CS	Bar	90	4.47	172.13	0.00	0.83

Figure 4: shows the Warren bridge member information

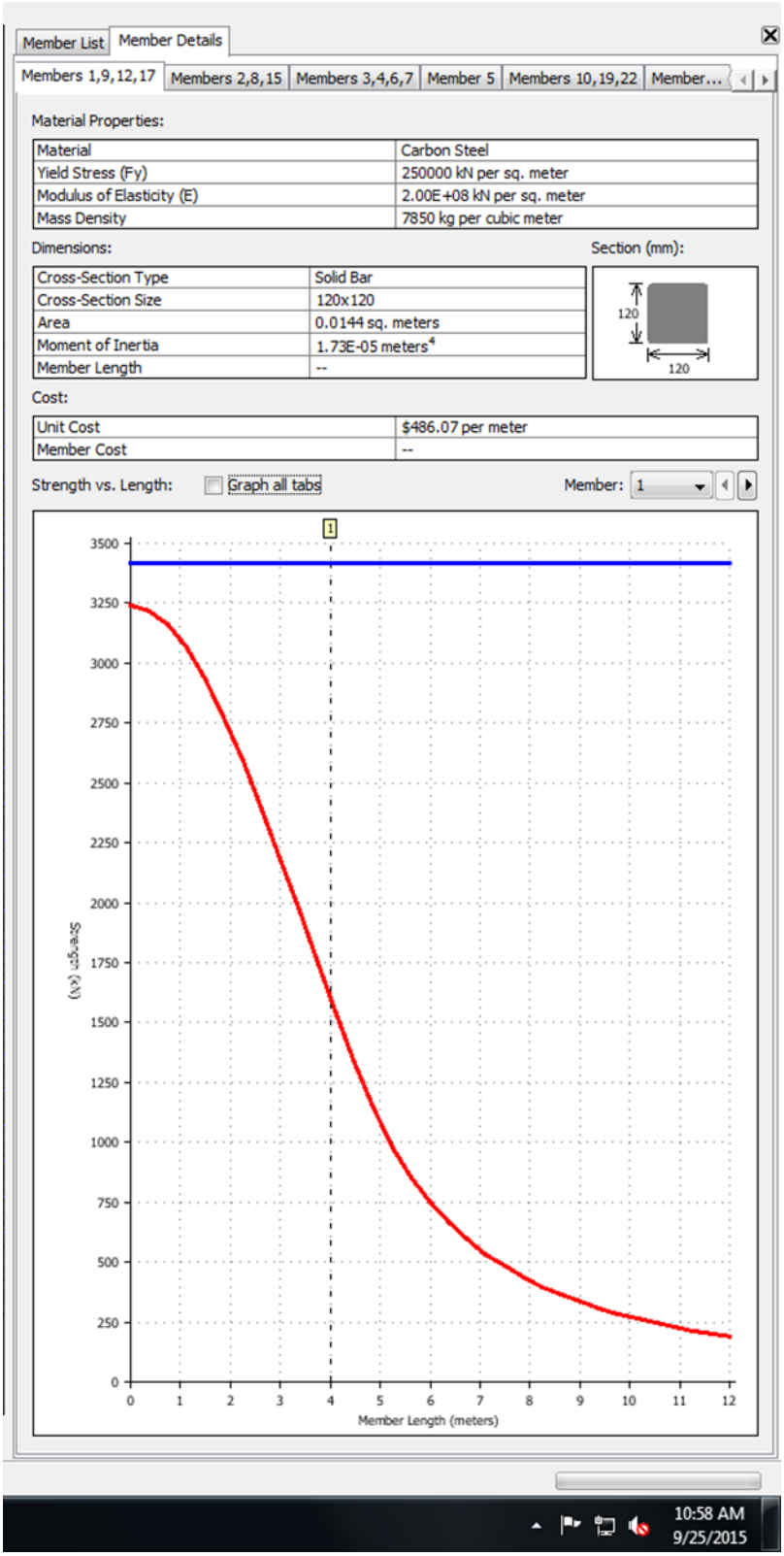


Figure 3: This shows the force ratio of each of the members.

						Load Test Results	
#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Tube	200	4.00	51.50	0.97	0.00
2	HSS	Tube	240	4.00	42.91	0.86	0.00
3	HSS	Tube	260	4.00	39.61	0.94	0.00
4	HSS	Tube	280	4.00	36.78	0.91	0.00
5	HSS	Tube	280	4.00	36.78	0.91	0.00
6	HSS	Tube	260	4.00	39.61	0.93	0.00
7	HSS	Tube	240	4.00	42.91	0.84	0.00
8	CS	Tube	200	4.00	51.50	0.95	0.00
9	CS	Bar	80	4.00	173.21	0.00	0.95
10	CS	Bar	110	4.00	125.97	0.00	0.89
11	CS	Bar	120	4.00	115.47	0.00	0.98
12	CS	Bar	140	4.00	98.97	0.00	0.82
13	CS	Bar	140	4.00	98.97	0.00	0.86
14	CS	Bar	140	4.00	98.97	0.00	0.86
15	CS	Bar	140	4.00	98.97	0.00	0.82
16	CS	Bar	120	4.00	115.47	0.00	0.97
17	CS	Bar	110	4.00	125.97	0.00	0.87
18	CS	Bar	80	4.00	173.21	0.00	0.93
19	CS	Bar	80	4.00	173.21	0.00	0.94
20	CS	Bar	75	4.00	184.75	0.00	0.87
21	CS	Bar	65	4.00	213.18	0.00	0.89
22	CS	Bar	55	4.00	251.93	0.00	0.86
23	CS	Bar	55	4.00	251.93	0.00	0.82
24	CS	Bar	65	4.00	213.18	0.00	0.86
25	CS	Bar	70	4.00	197.95	0.00	0.97
26	CS	Bar	80	4.00	173.21	0.00	0.92
27	CS	Bar	150	5.66	130.64	0.99	0.00
28	CS	Bar	150	5.66	130.64	0.96	0.00
29	CS	Bar	55	4.00	251.93	0.00	0.87
30	CS	Tube	240	5.66	60.69	0.82	0.00
31	CS	Bar	140	5.66	139.97	0.82	0.00
32	CS	Bar	130	5.66	150.74	0.77	0.00
33	CS	Bar	130	5.66	150.74	0.73	0.00
34	CS	Bar	140	5.66	139.97	0.79	0.00
35	CS	Tube	240	5.66	60.69	0.80	0.00
36	CS	Bar	110	5.66	178.14	0.86	0.03
37	CS	Bar	110	5.66	178.14	0.78	0.04

Figure 6: shows the Howe bridge member information.

Type of Cost	Item	Cost Calculation
Material Cost (M)	Carbon Steel Solid Bar	(12125.1 kg) x ($4.30 per kg) x (2 Trusses) =
	Carbon Steel Hollow Tube	(1449.2 kg) x ($6.30 per kg) x (2 Trusses) =
	High-Strength Low-Alloy Steel Hollow Tube	(2429.4 kg) x ($7.00 per kg) x (2 Trusses) =
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses) =
Product Cost (P)	3 - 55x55 mm Carbon Steel Bar	($1,000.00 per Product) =
	2 - 65x65 mm Carbon Steel Bar	($1,000.00 per Product) =
	1 - 70x70 mm Carbon Steel Bar	($1,000.00 per Product) =
	1 - 75x75 mm Carbon Steel Bar	($1,000.00 per Product) =
	4 - 80x80 mm Carbon Steel Bar	($1,000.00 per Product) =
	4 - 110x110 mm Carbon Steel Bar	($1,000.00 per Product) =
	2 - 120x120 mm Carbon Steel Bar	($1,000.00 per Product) =
	2 - 130x130 mm Carbon Steel Bar	($1,000.00 per Product) =
	6 - 140x140 mm Carbon Steel Bar	($1,000.00 per Product) =
	2 - 150x150 mm Carbon Steel Bar	($1,000.00 per Product) =
	2 - 200x200x10 mm Carbon Steel Tube	($1,000.00 per Product) =
	2 - 240x240x12 mm Carbon Steel Tube	($1,000.00 per Product) =
	2 - 240x240x12 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =
	2 - 260x260x13 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =
	2 - 280x280x14 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =
	Excavation Cost	(19,900 cubic meters) x ($1.00 per cubic meter) =
	Abutment Cost	(2 standard abutments) x ($5,250.00 per abutment) =
	Pier Cost	No pier =
	Cable Anchorage Cost	No anchorages =
Total Cost	**M + C + P + S**	**$156,547.72 + $20,000.00 + $15,000.00 + $77,400.00 =**

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Figure 7: shows the Howe bridge cost data from Bridge Designer 2015, as well as the types and number of each member and material used

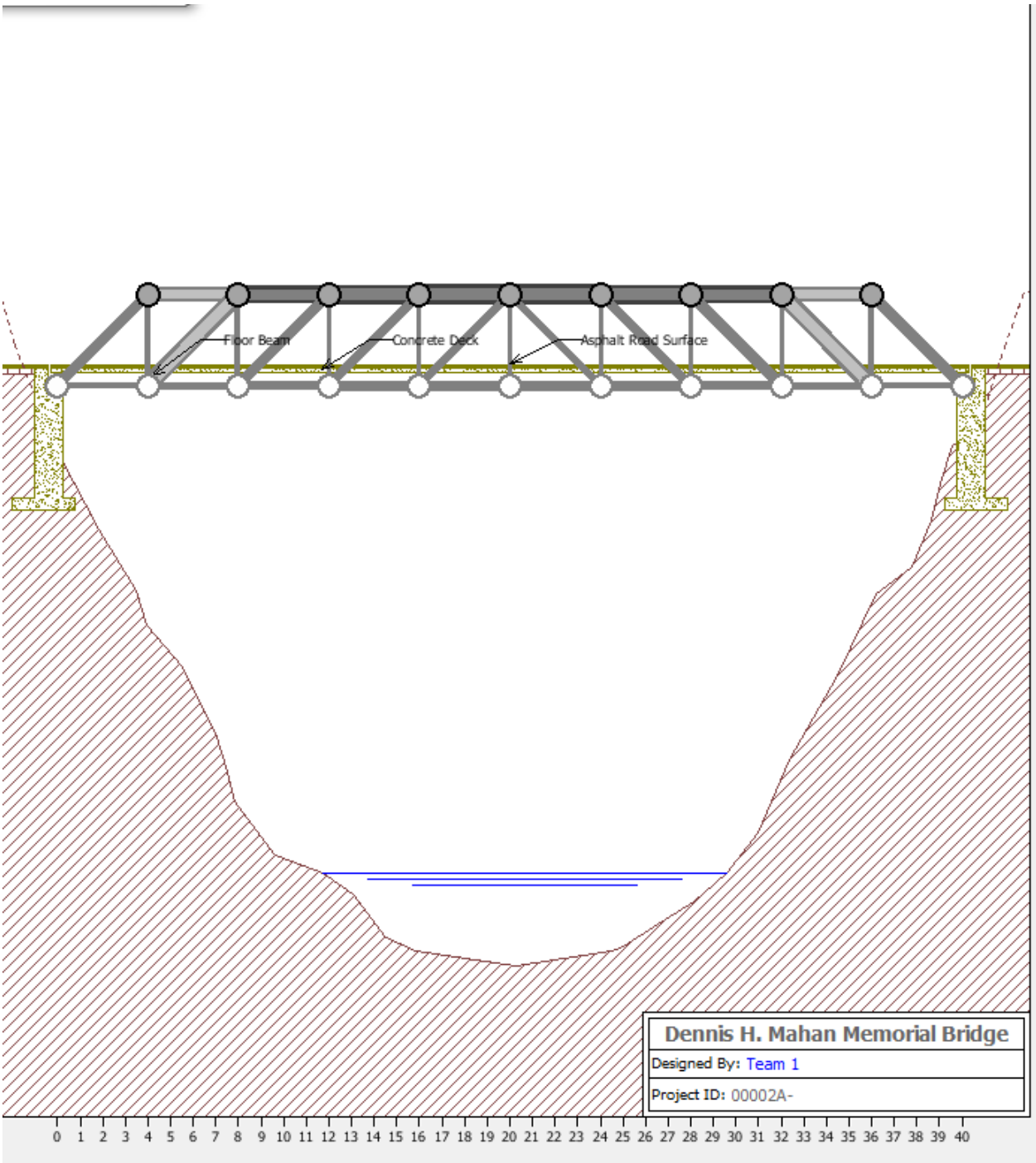


Figure 5: This shows a replica of the Howe truss bridge as designed in the Bridge Designer 2015 program.

Current Material

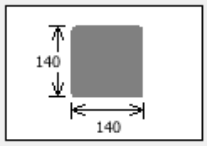
Material Properties:

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	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:

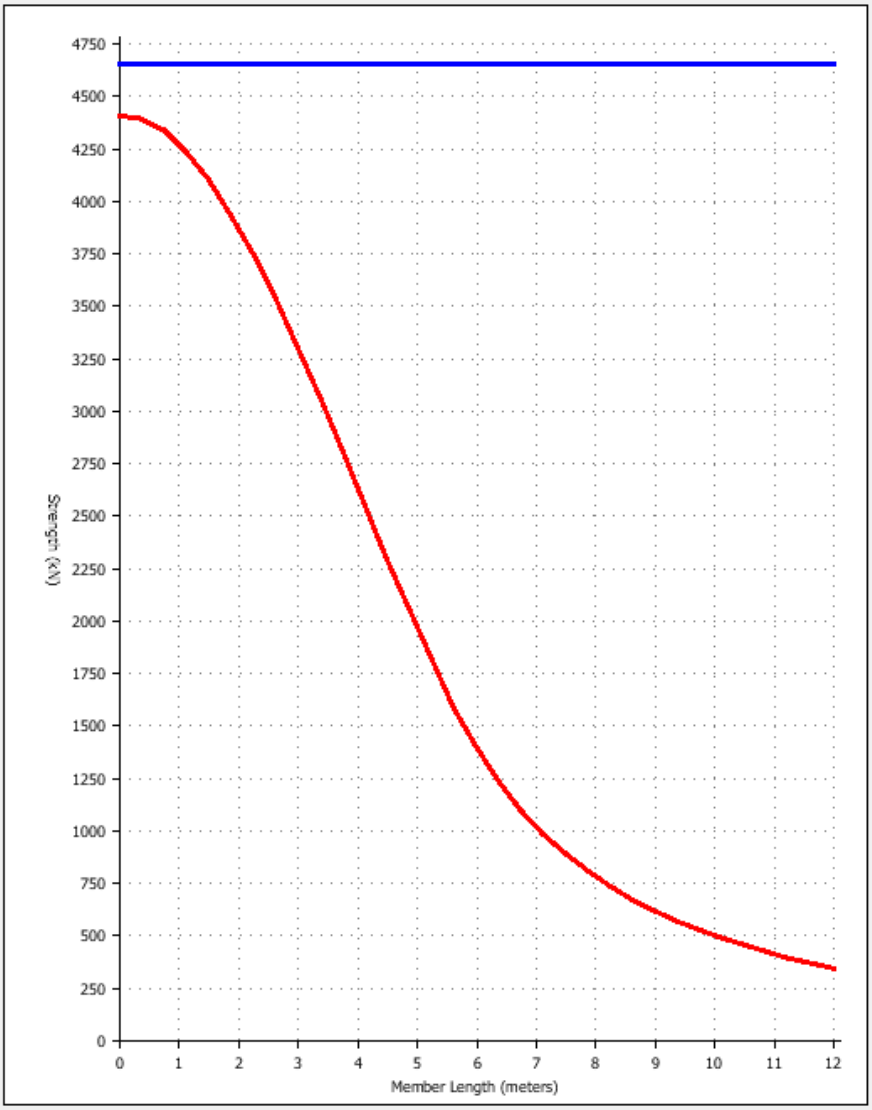


Figure 8: This shows the force ratio of each of the members.

Structural Efficiency Howe Bridge						
Design Team	Load at Failure	Weight(g)	Weight(lb)			Structural Efficiency
1	69.7	81.3	0.179236	0.002205		388.8736
2	33.8	64.3	0.141757			238.4361
3	59.6	95.8	0.211203			282.1935
4	65.4	78.5	0.173063			377.8978
5	99.7	79.4	0.175047			569.5619
6	84.2	80.4	0.177251			475.0314
7	71.0	84.7	0.186731			380.2255
8	44.3	82.6	0.182102			243.2708
Structural Efficiency Warren Bridge						
Design Team	Load at Failure	Weight(g)	Weight(lb)			Structural Efficiency
1	104.6	81.9	0.180558			579.314
2	33.9	77.1	0.169976			199.4397
3	50.8	74.9	0.165126			307.6438
4	38.2	75.7	0.16689			228.8936
5	55.4	80.9	0.178354			310.6186
6	75.8	90.1	0.198636			381.602
7	70.9	87	0.191802			369.6522
8	90.3	83.6	0.184306			489.9455

Tables for structrual efficiency of Warren and Howe Bridges.