PENNSTATE

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

Apr 3, 2015

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

Dear Mr. Kline:

Reference.
PennDOT Engineering District 2-0, Statement of Work, subj: Concept Design for Vehicle Bridge over Spring Creek along Puddintown Road in College Township, Centre County, PA, dated January 30, 2015.

Statement of Problem.
A recent flooding event has completely destroyed a structurally deficient vehicle bridge located over Spring Creek along Puddintown Road in College Township, Centre County, PA. All traffic must now be re-routed around the destroyed bridge, thereby disrupting residential traffic flow, local commerce, and exposing State College residents to considerable risk. The damaged bridge also severely restricts general regional vehicle access to the Mount Nittany Medical Center.

Objective.
As requested by the Pennsylvania Department of Transportation of (PennDOT) Engineering District 2-0, a new vehicle bridge is to be designed and implemented over Spring Creek immediately in order to prevent further disruption in the usual traffic flow.

Design Criteria.
The bridge is to include: standard abutments, no piers (one span), deck material shall be medium strength concrete (0.23meters 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.

Technical Approach.

Phase 1: Economic Efficiency.
Economic efficiency (cost) shall be determined using the Engineering Encounters Bridge Design 2015(EEBD 2015) software. The software will be use 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. Each Warren and Howe truss replacement bridge must be designed to support its own weight (as dead load), plus the weight of two AASHTO H20-44 trucks.

Phase 2: Structural Efficiency.
Two truss bridges (Howe and Warren) shall be created using (60) popsicle sticks, Elmer's white glue, and hot glue. The dimensions of each bridge shall be 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 PennDOT District 2-0. Both bridges will be tested to catastrophic failure. The forensic investigation shall include: why did it fail; where did it fail; and how did it fail. The investigation shall be documented with photographs, sketches, measurements, analyses, etc. 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.

Results.

Phase 1: Economic Efficiency.
After designing a Warren and a Howe Truss bridge on EEBD 2015, optimizing both designs to keep the cost as low as possible, it can be said that, from an economic standpoint the Warren Truss Bridge would be more viable, as it costs $214,832.61 in comparison to the Howe truss bridge cost of $246,137.78. Signifying a saving of $31,305.17 for a bridge that would perform the same function and effectively replace the fallen Puddintown Road Bridge. By same function it is meant that both bridges can support their own weight, plus the weight of two AASHTO H20-44 trucks, providing a safe structure for the crossing of people as well as vehicles.

Phase 2: Structural Efficiency.
After designing and testing prototypes for both A Howe truss bridge and a Warren truss bridge, we were able to calculate the structural efficiency of both designs given the team's results. It can be said that, according to the team's results, from the structural standpoint the Warren truss bridge will be more effective, and this is because it achieved a calculated structural efficiency of 418, while the Howe truss bridge design could only attain a structural efficiency of 218. Also comparing the results to the class, it can also be said that despite a Howe bridge having the maximum structural efficiency of all bridges tested, at 541, the bridge was in fact heavier, and more complexly built than the Warren truss bridge designed by this design team. The Howe Truss Bridge and Warren Truss bridges load tests results for the class provided valuable insight to the structural efficiency of both set of bridges; the Howe truss bridges achieved a maximum of 541 structural efficiency compare to the maximum Warren truss bridge of 443. However, the range in the structural efficiencies for the Howe truss bridge was of 354, as can be seen in table 7, compared to the 268 of the Warren truss bridges, as can be seen in Table 8, meaning that the Warren truss bridges could be asserted to be more evenly structural efficiency, as the results were more evenly match and therefore more precise in providing

an accurate measure of the Warren truss bridge, compared to the Howe truss bridge. This being said, since the Howe truss bridge had a higher maximum structural efficiency in the class, it can be said that it is the most structurally effective solution to the Puddingtown bridge problem.

Best Solution.

Since the Warren truss bridge is more economically efficient, and the Howe truss bridge proved to be more structurally efficient, the choice of a best solution comes down to whether or not both bridges can perform their duty efficiently. As the results achieved on EEBD 2015 prove, both designs are able to withstand large amounts of pressure, and can perform the duties required of them effectively, which is providing a solid replacement for the fallen bridge. As it can be seen in Tables 2 and 5, all members of each design had an acceptable amount forces upon them, and the tension and compression were handled well by all of them, meaning that the designs are safe and can carry required loads.

As mentioned in the results section, and as it can be appreciated in Tables 1 and 4, the Warren truss bridge is the most economically efficient out of the two as it is cheaper and easier to assemble, while still performing the functions required to resolve the problem the town is presented with. The Warren Truss Bridge would be more economically efficient, as it would cost $214,832.61 to construct in comparison to the Howe truss bridge cost of $246,137.78. Despite the Howe bridge being determined to be more structurally efficient given the class results, it is the design team's conclusion that the Warren truss bridge will ultimately prove to be more efficient across the economic and structural fields, proving to be the best solution. As it can be seen in Table's 7 and 8, the Howe truss bridge outperformed the Warren truss bridge in terms of having a higher maximum and minimum load at failure, but did present a higher range than the Warren, which forms part of the rationale for choosing the Warren truss as the best solution. The fact that the Warren bridge's structural efficiency results were more constant, and therefore more precise, means that the results achieved throughout the class can be trusted more, as well as being deemed more accurate at the time of making a decision. The lower range indicates a lower chance of overestimating the true capacity of the bridge, provided that the bridge may not be perfectly built in the future. Further research and designing has to be done prior to moving ahead with the project as the ways in which the bridges failed represents an important point to consider.

Conclusions and Recommendations.

Both bridges are very similar in the way they tested in the EEBD 2015, therefore what makes them stand out in regard to each other is the physical tests carried out in class, and the design team's own judgment and interpretation of the results obtained. As a definitive recommendation, a Warren truss bridge should be built to replace the fallen one. Having been proved to be structurally as well as economically efficient, the bridge will provide a suitable and improved replacement for the fallen Puddintown bridge, and will surely outperform its predecessor if further experimentation and designing takes place. The next step towards finalizing the project before commencing the reconstruction for the bridge should be the creation of a design that includes more cords connecting the Warren trusses, as the true structural efficiency of the bridge could be further explored, and the design could be further refined to increase the capacity that are expected of it. The Warren bridge will prove to be a beneficial investment for the town, as it keeps the amount of money invested at the lowest it can possibly be for a bridge of its kind, and achieves a very high structural efficiency, certainly higher than its predecessor. Additionally, the Warren truss Bridge will outperform its predecessor and prevent any destruction that may be detrimental to the town's economy and dynamics, as was the fall of the original Puddintown bridge. Also, it would reopen speedways to the Mount Nittany Medical Center, which may prove vital in certain emergency situations, as well as diverting traffic that was going through the town. In the end, the environment and movement around town would be safer, bringing back a previous normality to the town and ultimately improving the quality of life.

Respectfully,

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ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss.

The total cost of the Howe truss Bridge is calculated to be $246,137.78, including the base platform cost of $77,400.00 (Table1). The cheapest material of carbon steel is used for all members of the bridge. Hollow tubes are used for members with high compressive force, while solid bars are used for those with high tension force (Table 2). Although the hollow tubes are more expensive, they are lighter and more effective at sustaining compressive forces. The member's thickness is adjusted according to the compressive and tension force it needs to sustain; the thicker it is, the more force it can withstand. For example the central bottom, diagonal and vertical chords are the thickest hollow tubes as they sustain one of the highest compressive forces. Among which, member 37 represents a diagonal member of 5.66m in length (Table 3). In each case the thickness is reduced so that the compressive and tension force/strength ratio is as close to one (Table 2). This helps save material costs, which is a total of $134,737.78. (Table 1).

Warren Truss.

Due to the platform requirements, initial cost before bar and tube components was $77,400 (Table 4). Total cost including members was $214,832.61(Table 4). The Warren bridge was constructed using the cheapest sets of materials possible, while not foregoing strength. Two materials were used, Carbon Steel and Quenched and Tempered Steel. Carbon Steel was used for the solid bars and Quenched and Tempered Steel was used for hollow tubes (Table 5). Tubes, while much lighter, were more expensive and gave up some tensile strength. They were used when tension force was prevalent. Bars were cheaper and were used for compression force. The strongest member length was found to be approximately 4 meters (Table 6), and most members were between 2.5 and 4.5 meters long (Table 5).

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss.

The Howe Truss bridge, weighing about 72.6 grams (160lbs), withheld a load of 34.9 lbs. before its failure. By dividing the load at failure by the bridge's weight, the structural efficiency of the bridge could be determined to be 218. The structural efficiency of this Howe truss bridge was one of the worst in the class, scoring below the average structural efficiency.

Prototype Bridge.

After close examination of previously built Howe truss bridges, the group agreed upon a simple design which aimed to maximize the efficiency, in terms of difficulty to build, adherence to the dimension restrictions of 13.5 inches in length, 4 inches in height and 4.5 inches in width, as well as the structural efficiency. Using only wood and 50 popsicle sticks, the two Howe trusses were built and later connected with 8 extra popsicles using hot glue. To ensure the popsicles stuck well together, various points of connection in the truss were held together by using clips, and were stored like this in order to allow time for the glue to cure.

Load Testing.

This Howe truss bridge was outperformed by almost every bridge built by other design teams. Having a structural efficiency of 218, compared to the class lowest of 187, and far away from the maximum recorded efficiency of 542. The structural efficiency was also well below the overall average structural efficiency of 334. As is was determined by comparing the class results' it turned out that the heaviest bridge had the lowest structural efficiency, but more interestingly, the second heaviest bridge had the highest structural efficiency.

Forensic Analysis.

The Howe truss bridge failed upon hanging 34.9 pounds from the bridge, which was close to the minimum amount that bridges were tested for. A slanted connection between the two truss' caused by the uneven aligned of the 8 interconnecting popsicles, prompted an uneven weight distribution between the two truss, having one of them support the most weight, therefore causing the opposing truss to collapse inwards, which resulted in the total failure of the bridge. The connection between the two trusses was simply not rigid enough to maintain the structure upright which prevented the equal distribution of weight throughout the structure, which would have allowed it to uphold a higher load before failure. The lack of rigidity in the connection, can be described as a design fault, since it was put in place from the beginning through the constraints imposed on the project, in order to prevent the Howe truss bridges from being too structurally efficient, and therefore making them testable in a classroom environment.

Results.

The attached excel bar chart of the Howe truss bridge load tests results can be found below, labeled as Figure 7.

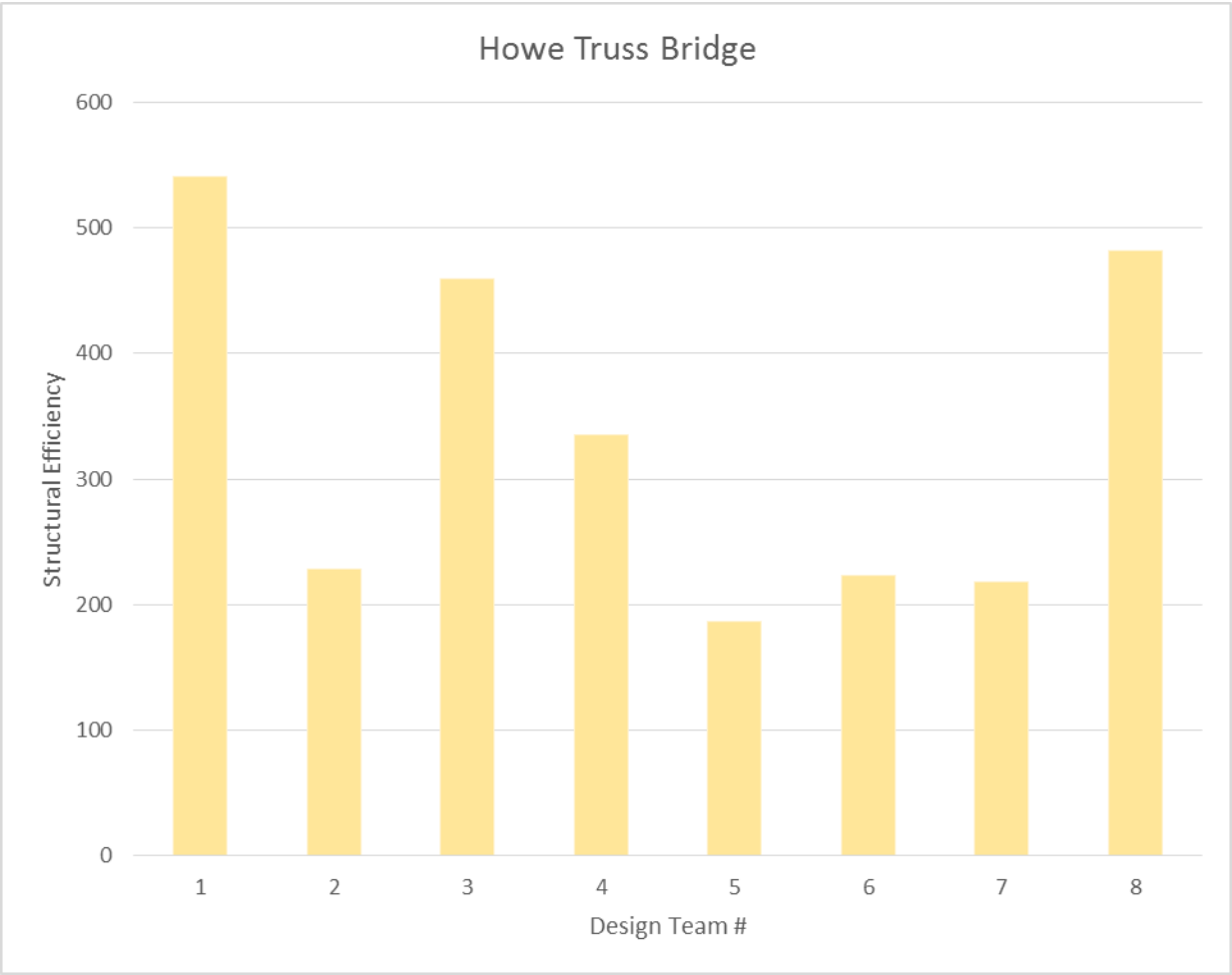


Figure 7. Howe Truss Bridge Structural Efficiencies

Warren Truss.

The Warren Truss bridge, weighing in at 77.6 grams (.171 lbs.), withheld a load of 71.6 lbs. before its failure. The structural efficiency of the bridge, which can be calculated by dividing the load at failure by the bridge's weight, is 418. The structural efficiency of this Warren truss bridge was the second highest in the class, and scored well above the average structural efficiency of 290.

Prototype Bridge.

After analyzing several examples of Warren trusses from the previous year's Engineering Design class, the group decided upon one design which appeared to be the most efficient method of building a Warren truss bridge in order to maximize structural efficiency. Using only wood glue and 50 popsicle sticks, the two trusses were constructed and finally connected with hot glue and 8 popsicle sticks as struts. The trusses were clipped when the glue dried and remained on each truss for one week to allow the glue to cure. The dimensions of the bridge were 13 ¼ inches in length, 4 inches in height, and 4 ½ inches in width.

Load Testing.

This Warren truss bridge outperformed all but one other design team, who's structurally efficiency was 443; however, the bridge that obtained the maximum efficiency weighed about 4 grams heavier. The minimum structurally efficiency was 175, and thus the range was 268. This bridge that was constructed was the second lightest in comparison to the other 7 models, yet still held one of the heaviest loads. Another interesting result is that the heaviest bridge, which was 86.6 grams, had the lowest structural efficiency.

Forensic Analysis.

The Warren truss bridge failed upon hanging 71.5 pounds from the bridge. The uneven weight distribution of sand in the bucket, which was practically inevitable, caused the trusses to tilt and the bridge collapsed. One of the Warren trusses remained intact after the failure, and none of the individual members cracked or split. Therefore, the underlying root of the bridge collapse was a result of the struts failing. The popsicle sticks connected with hot glue to each truss were not strong enough to prevent the trusses from tilting. Additionally, the constraint of using only eight struts for the bridge prevented the Warren truss bridge from being to structurally efficient.

Results.

The attached excel bar chart of the Warren truss bridge load test results can be found below, labeled figure 8.

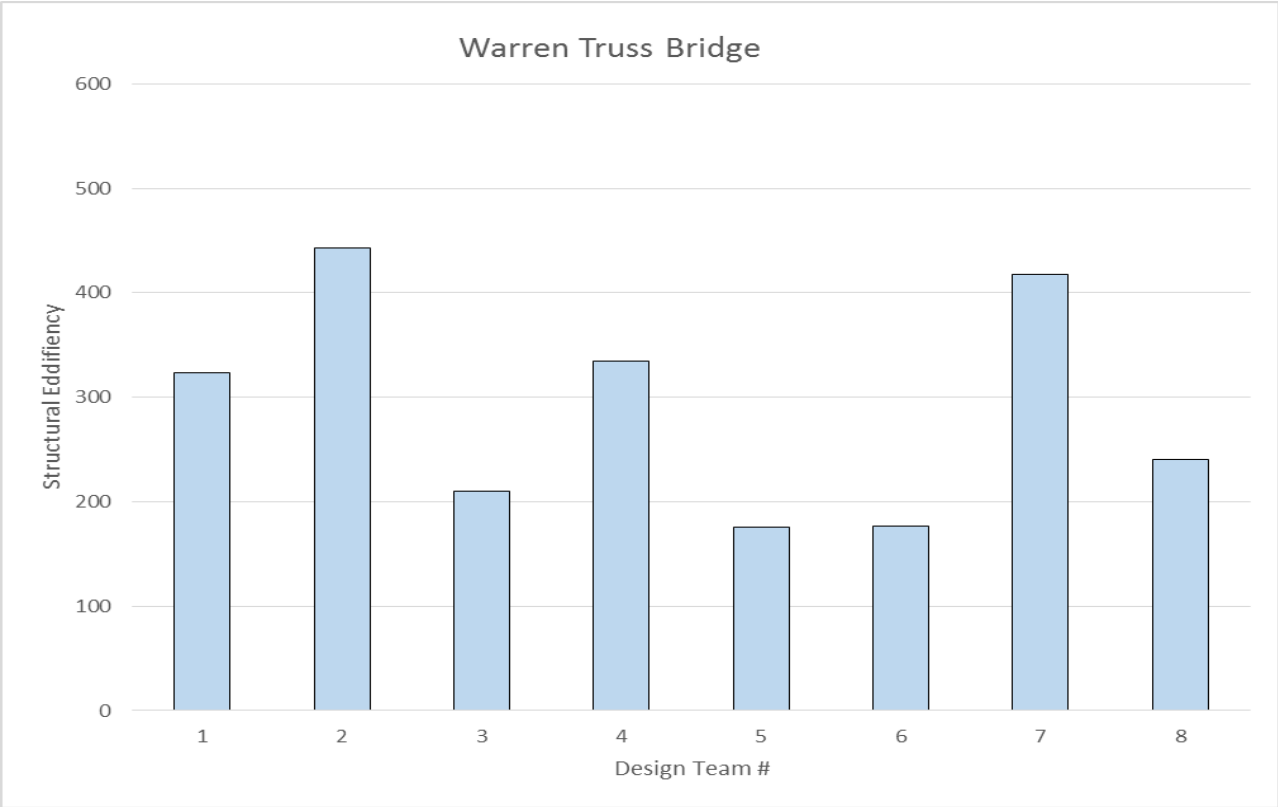


Figure 8. Warren Truss Bridge Structural Efficiencies

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	(5491.1 kg) x ($4.30 per kg) x (2 Trusses) =	$47,223.24
	Carbon Steel Hollow Tube	(6945.6 kg) x ($6.30 per kg) x (2 Trusses) =	$87,514.53
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses) =	$20,000.00
Product Cost (P)	3 - 55x55 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 70x70 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 80x80 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 110x110 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 120x120 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 130x130 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 150x150x7 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 180x180x9 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 200x200x10 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 220x220x11 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 240x240x12 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 260x260x13 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 300x300x15 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 320x320x16 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =	$47,000.00
	Excavation Cost	(19,900 cubic meters) x ($1.00 per cubic meter) =	$19,900.00
	Abutment Cost	(2 standard abutments) x ($5,250.00 per abutment) =	$10,500.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	**M + C + P + S**	**$134,737.78 + $20,000.00 + $14,000.00 + $77,400.00 =**	**$246,137.78**

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	CS	Bar	80	4.00	173.21	0.00	333.51	OK	1412.27	1520.00	OK
2	CS	Bar	70	4.00	197.95	0.00	195.50	OK	1148.60	1163.75	OK
3	CS	Tube	200	5.66	72.83	1261.50	1293.53	OK	0.00	1805.00	OK
4	CS	Bar	70	4.00	197.95	0.00	195.50	OK	882.54	1163.75	OK
5	CS	Tube	180	5.66	80.92	884.43	981.36	OK	0.00	1462.05	OK
6	CS	Tube	200	4.00	51.50	1418.40	1487.26	OK	0.00	1805.00	OK
7	CS	Tube	320	4.00	32.19	3778.16	4145.34	OK	0.00	4620.80	OK
8	CS	Tube	320	4.00	32.19	3757.68	4145.34	OK	0.00	4620.80	OK
9	CS	Tube	300	4.00	34.33	3268.92	3616.10	OK	0.00	4061.25	OK
10	CS	Tube	260	4.00	39.61	2461.16	2660.84	OK	0.00	3050.45	OK
11	CS	Tube	200	4.00	51.50	1386.51	1487.26	OK	0.00	1805.00	OK
12	CS	Tube	240	5.66	60.69	1960.83	2028.51	OK	0.00	2599.20	OK
13	CS	Bar	80	4.00	173.21	0.00	333.51	OK	1386.51	1520.00	OK
14	CS	Bar	110	4.00	125.97	0.00	1181.16	OK	2461.16	2873.75	OK
15	CS	Bar	120	4.00	115.47	0.00	1606.24	OK	3268.92	3420.00	OK
16	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3757.68	4013.75	OK
17	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3927.38	4013.75	OK
18	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3927.38	4013.75	OK
19	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3778.16	4013.75	OK
20	CS	Bar	120	4.00	115.47	0.00	1606.24	OK	3309.88	3420.00	OK
21	CS	Bar	110	4.00	125.97	0.00	1181.16	OK	2522.60	2873.75	OK
22	CS	Bar	80	4.00	173.21	0.00	333.51	OK	1418.40	1520.00	OK
23	CS	Bar	55	4.00	251.93	0.00	74.51	OK	615.35	718.44	OK
24	CS	Tube	150	5.66	96.78	507.27	550.30	OK	85.22	950.95	OK
25	CS	Tube	150	5.66	96.78	462.17	550.30	OK	130.31	950.95	OK
26	CS	Bar	55	4.00	251.93	0.00	74.51	OK	583.46	718.44	OK
27	CS	Tube	180	5.66	80.92	839.33	981.36	OK	0.00	1462.05	OK
28	CS	Bar	70	4.00	197.95	0.00	195.50	OK	850.65	1163.75	OK
29	CS	Tube	200	5.66	72.83	1216.41	1293.53	OK	0.00	1805.00	OK
30	CS	Bar	70	4.00	197.95	0.00	195.50	OK	1116.71	1163.75	OK
31	CS	Tube	220	5.66	66.21	1590.55	1642.86	OK	0.00	2184.05	OK
32	CS	Bar	80	4.00	173.21	0.00	333.51	OK	1380.39	1520.00	OK
33	CS	Bar	55	4.00	251.93	0.00	74.51	OK	624.39	718.44	OK
34	CS	Tube	260	4.00	39.61	2522.60	2660.84	OK	0.00	3050.45	OK
35	CS	Tube	300	4.00	34.33	3309.88	3616.10	OK	0.00	4061.25	OK
36	CS	Tube	240	5.66	60.69	2005.92	2028.51	OK	0.00	2599.20	OK
37	CS	Tube	220	5.66	66.21	1635.64	1642.86	OK	0.00	2184.05	OK

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

Member 37

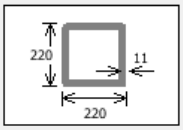
Material Properties:

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	220x220x11
Area	0.0092 sq. meters
Moment of Inertia	6.71E-05 meters^4
Member Length	5.66 meters

Section (mm):



Cost:

Unit Cost	$454.79 per meter
Member Cost	$2572.67

Strength vs. Length: Graph all tabs Member:

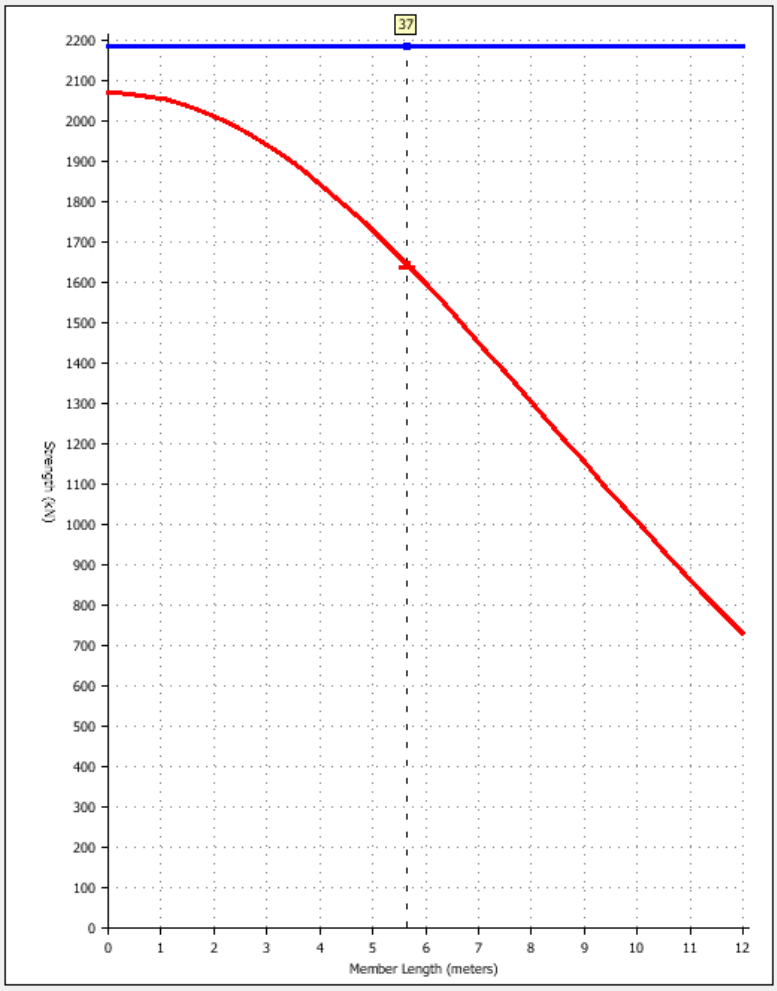


Table 4
Warren Truss Bridge
Cost Calculation Report from Bridge Designer 2015

Cost Calculations Report

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(5353.5 kg) x ($4.30 per kg) x (2 Trusses) =	$46,040.29
	Quenched & Tempered Steel Hollow Tube	(3921.6 kg) x ($7.70 per kg) x (2 Trusses) =	$60,392.32
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	6 - 55x55 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 65x65 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 100x100 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	4 - 110x110 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	6 - 120x120x6 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 130x130 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 140x140x7 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 200x200x10 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	2 - 220x220x11 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	5 - 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**	**$106,432.61 + $21,000.00 + $10,000.00 + $77,400.00 =**	**$214,832.61**

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

Load Test Results

#	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	200	3.16	40.71	2525.78	2800.97	OK	0.00	3501.70	OK
2	QTS	Tube	220	4.12	48.26	2927.94	3164.71	OK	0.00	4237.06	OK
3	QTS	Tube	240	4.00	42.91	3261.65	3958.27	OK	0.00	5042.45	OK
4	QTS	Tube	240	4.00	42.91	3723.78	3958.27	OK	0.00	5042.45	OK
5	QTS	Tube	240	4.00	42.91	3871.21	3958.27	OK	0.00	5042.45	OK
6	QTS	Tube	240	4.00	42.91	3703.30	3958.27	OK	0.00	5042.45	OK
7	QTS	Tube	240	4.00	42.91	3220.68	3958.27	OK	0.00	5042.45	OK
8	QTS	Tube	220	4.12	48.26	2855.56	3164.71	OK	0.00	4237.06	OK
9	QTS	Tube	200	3.16	40.71	2468.16	2800.97	OK	0.00	3501.70	OK
10	QTS	Tube	200	3.61	46.42	2521.21	2662.33	OK	0.00	3501.70	OK
11	CS	Bar	55	2.24	140.84	0.00	238.43	OK	667.21	718.44	OK
12	QTS	Tube	120	3.61	77.36	448.79	648.22	OK	30.55	1260.61	OK
13	CS	Bar	55	3.61	227.09	0.00	91.70	OK	514.13	718.44	OK
14	QTS	Tube	120	4.47	95.96	227.69	464.52	OK	218.22	1260.61	OK
15	CS	Bar	65	4.47	238.34	0.00	116.28	OK	981.63	1003.44	OK
16	QTS	Tube	140	4.47	82.25	695.75	814.77	OK	0.00	1715.83	OK
17	CS	Bar	55	4.47	281.67	0.00	59.61	OK	688.91	718.44	OK
18	QTS	Tube	120	4.47	95.96	402.48	464.52	OK	65.92	1260.61	OK
19	CS	Bar	65	4.47	238.34	72.81	116.28	OK	395.59	1003.44	OK
20	CS	Bar	65	4.47	238.34	108.46	116.28	OK	359.94	1003.44	OK
21	QTS	Tube	120	4.47	95.96	366.83	464.52	OK	101.57	1260.61	OK
22	CS	Bar	55	4.47	281.67	0.00	59.61	OK	653.26	718.44	OK
23	QTS	Tube	140	4.47	82.25	660.10	814.77	OK	0.00	1715.83	OK
24	CS	Bar	65	4.47	238.34	0.00	116.28	OK	945.98	1003.44	OK
25	QTS	Tube	120	4.47	95.96	212.41	464.52	OK	290.19	1260.61	OK
26	CS	Bar	55	3.61	227.09	0.00	91.70	OK	497.71	718.44	OK
27	QTS	Tube	120	3.61	77.36	432.37	648.22	OK	72.75	1260.61	OK
28	CS	Bar	55	2.24	140.84	0.00	238.43	OK	651.93	718.44	OK
29	QTS	Tube	200	3.61	46.42	2463.73	2662.33	OK	0.00	3501.70	OK
30	CS	Bar	100	4.00	138.56	0.00	814.24	OK	2049.95	2375.00	OK
31	CS	Bar	100	4.00	138.56	0.00	814.24	OK	2097.78	2375.00	OK
32	CS	Bar	110	4.00	125.97	0.00	1181.16	OK	2555.33	2873.75	OK
33	CS	Bar	110	4.00	125.97	0.00	1181.16	OK	2822.65	2873.75	OK
34	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3415.69	4013.75	OK
35	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3719.32	4013.75	OK
36	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3735.26	4013.75	OK
37	CS	Bar	130	4.00	106.59	0.00	2091.29	OK	3436.17	4013.75	OK
38	CS	Bar	110	4.00	125.97	0.00	1181.16	OK	2822.65	2873.75	OK
39	CS	Bar	110	4.00	125.97	0.00	1181.16	OK	2528.02	2873.75	OK

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

Member List | Member Details

Member 33

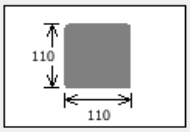
Material Properties:

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	110x110
Area	0.0121 sq. meters
Moment of Inertia	1.22E-05 meters^4
Member Length	4.00 meters

Section (mm):



Cost:

Unit Cost	$408.44 per meter
Member Cost	$1633.74

Strength vs. Length: Graph all tabs Member:

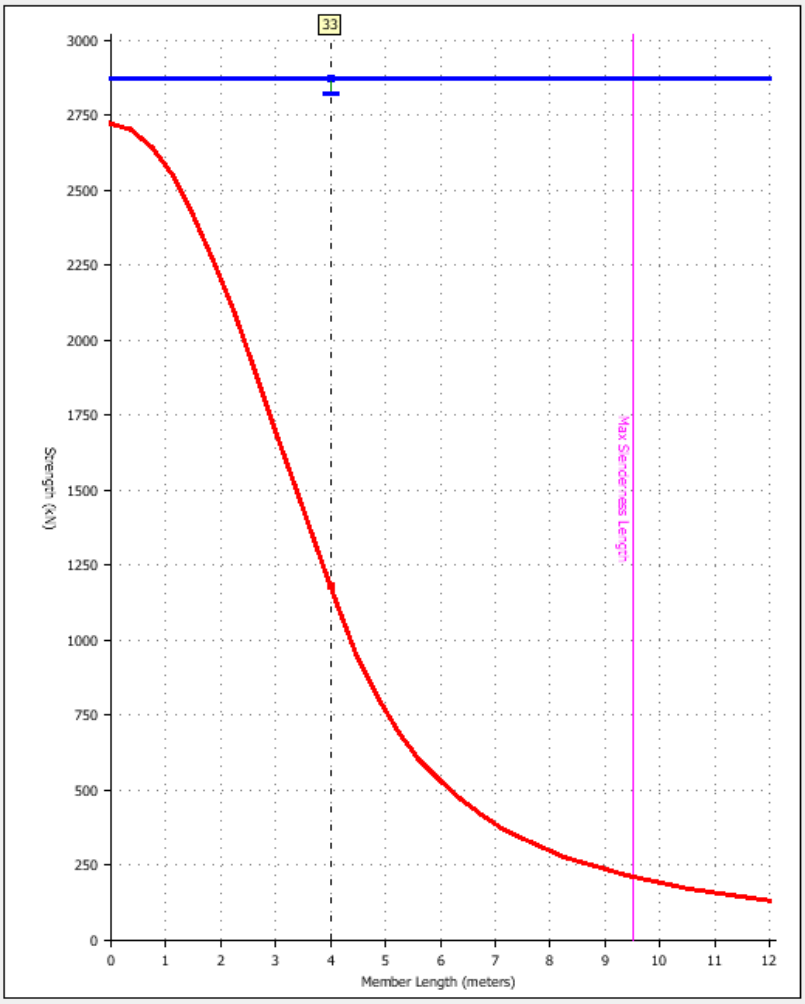


Table 7
Howe Truss Bridge
Load Test Results

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

Table 8
Warren Truss Bridge
Load Test Results

Design Team No.	Actual Bridge Weight (grams)	Actual Bridge Weight (lbs)	LOAD at Failure (lbs)	Structural Efficiency
1	81.1	0.1788	57.8	323
2	82	0.1808	80	443
3	74.8	0.1649	34.7	210
4	78.3	0.1726	57.7	334
5	86.6	0.1909	33.5	175
6	85.4	0.1883	33.3	177
7	77.6	0.1711	71.5	418
8	80.5	0.1775	42.7	241
			minimum	175
			maximum	443
			range	268
			mean	290

FIGURES

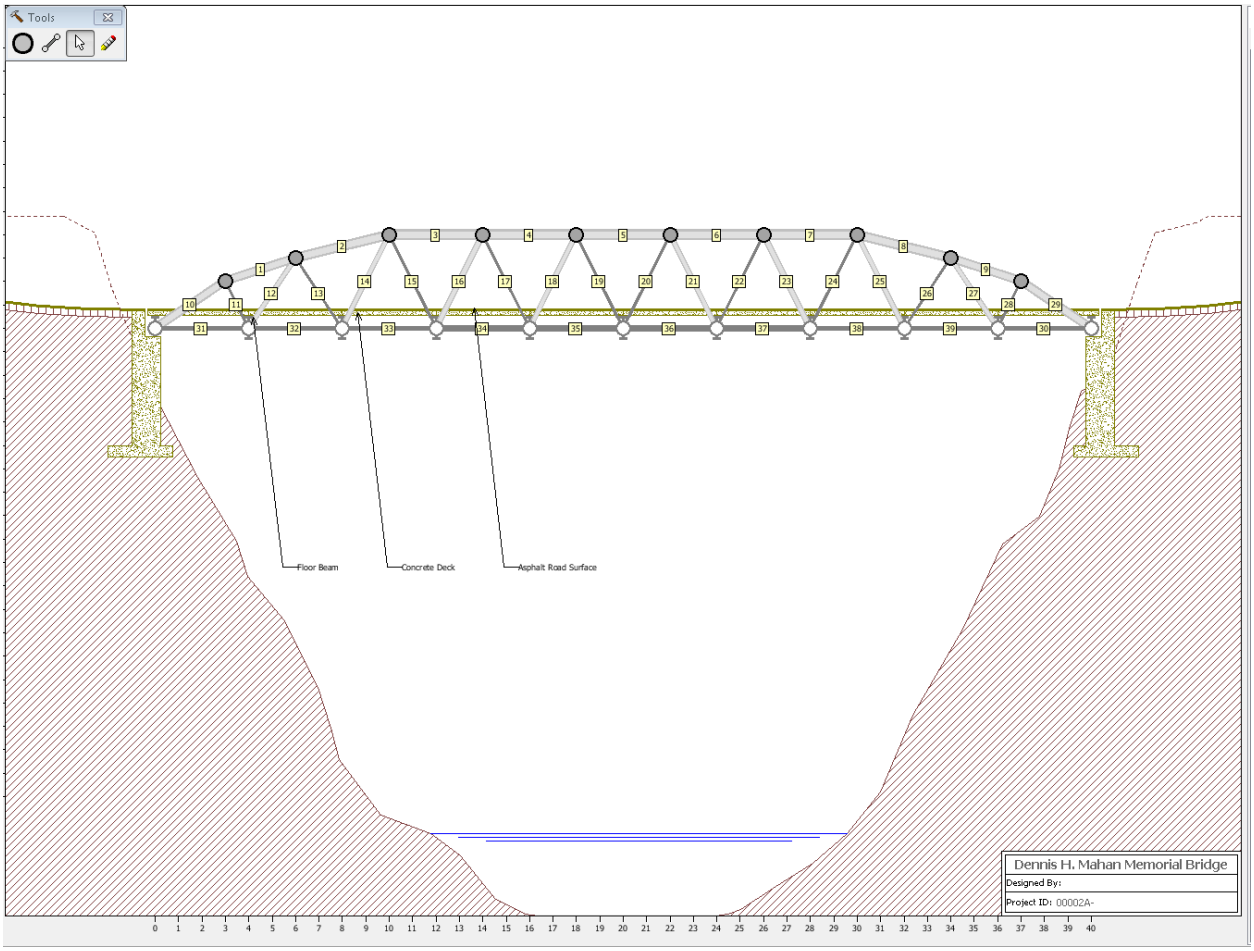


Figure 1. Howe Truss Bridge Model from Bridge Designer 2015

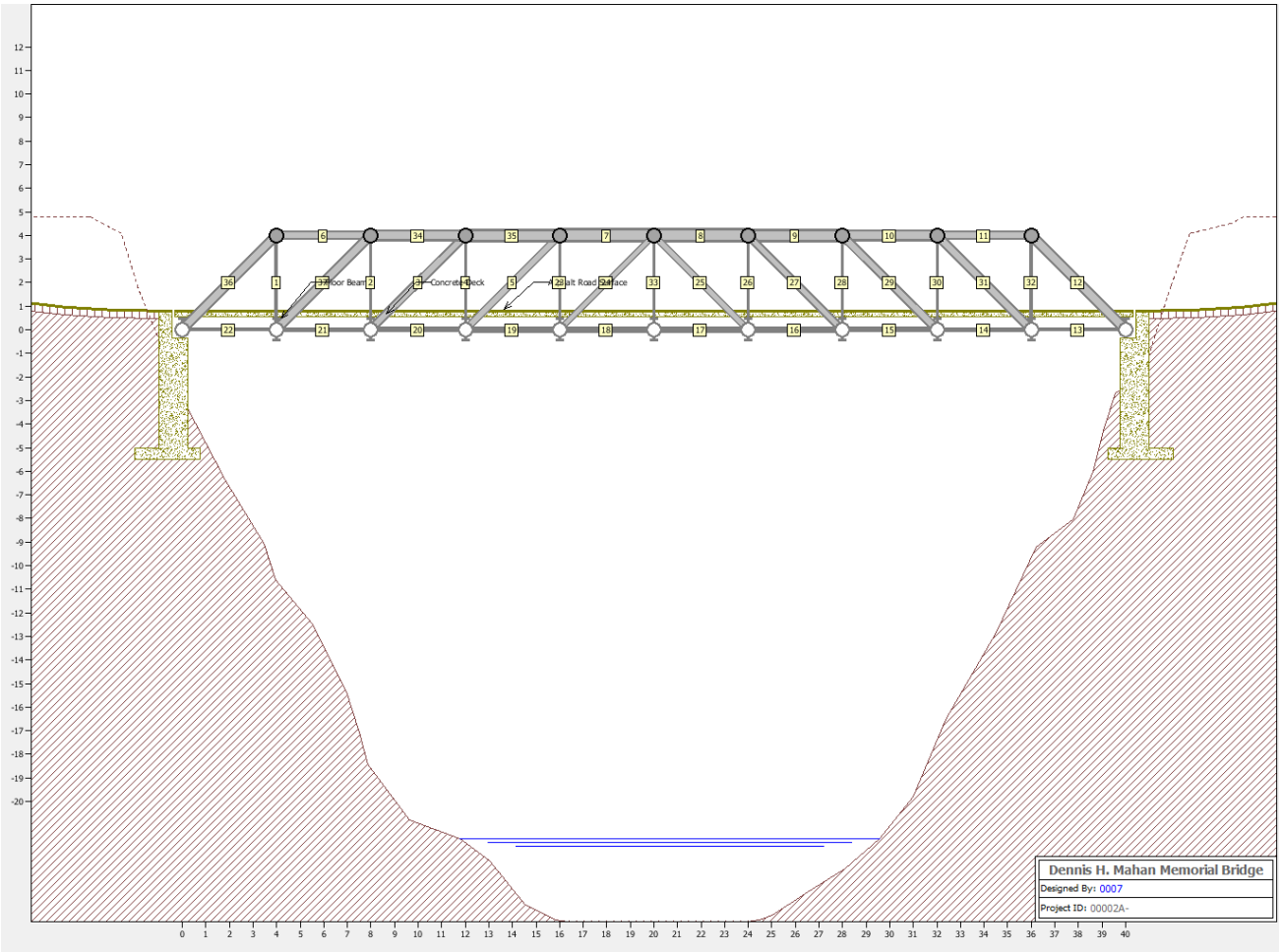


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

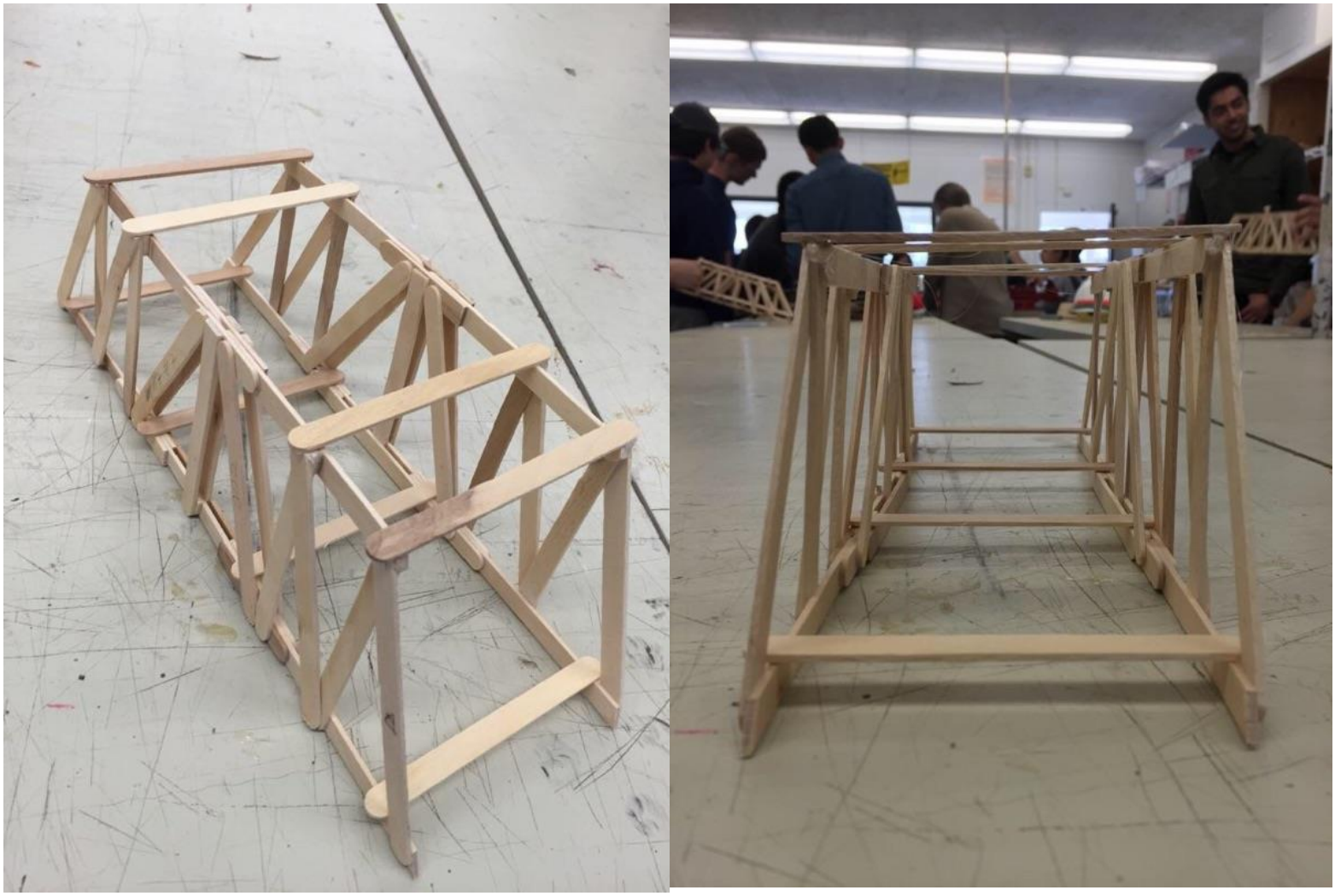


Figure 3. Howe Truss Bridge Prototype before Load Testing

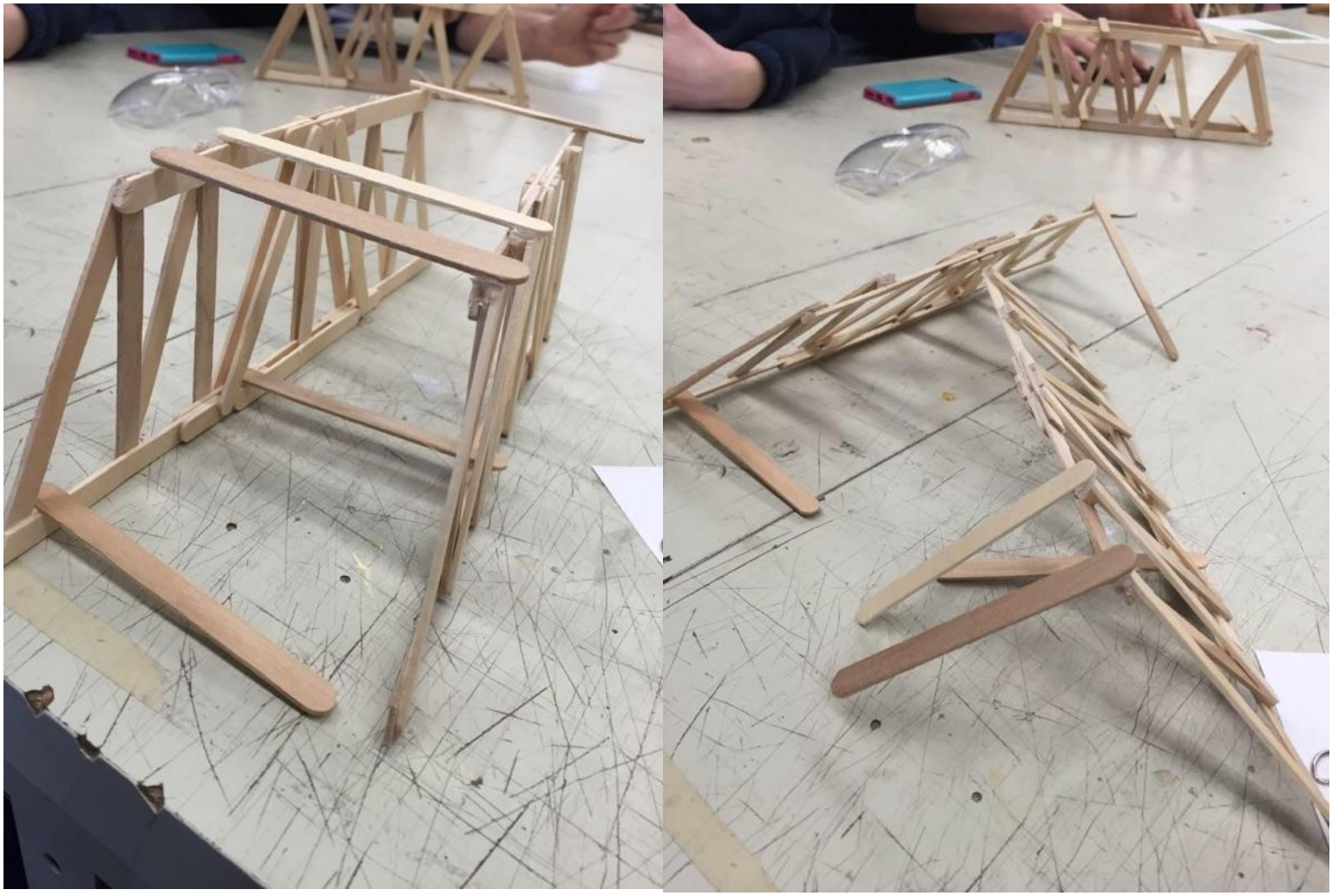


Figure 4. Howe Truss Bridge Prototype Failure after Load Testing

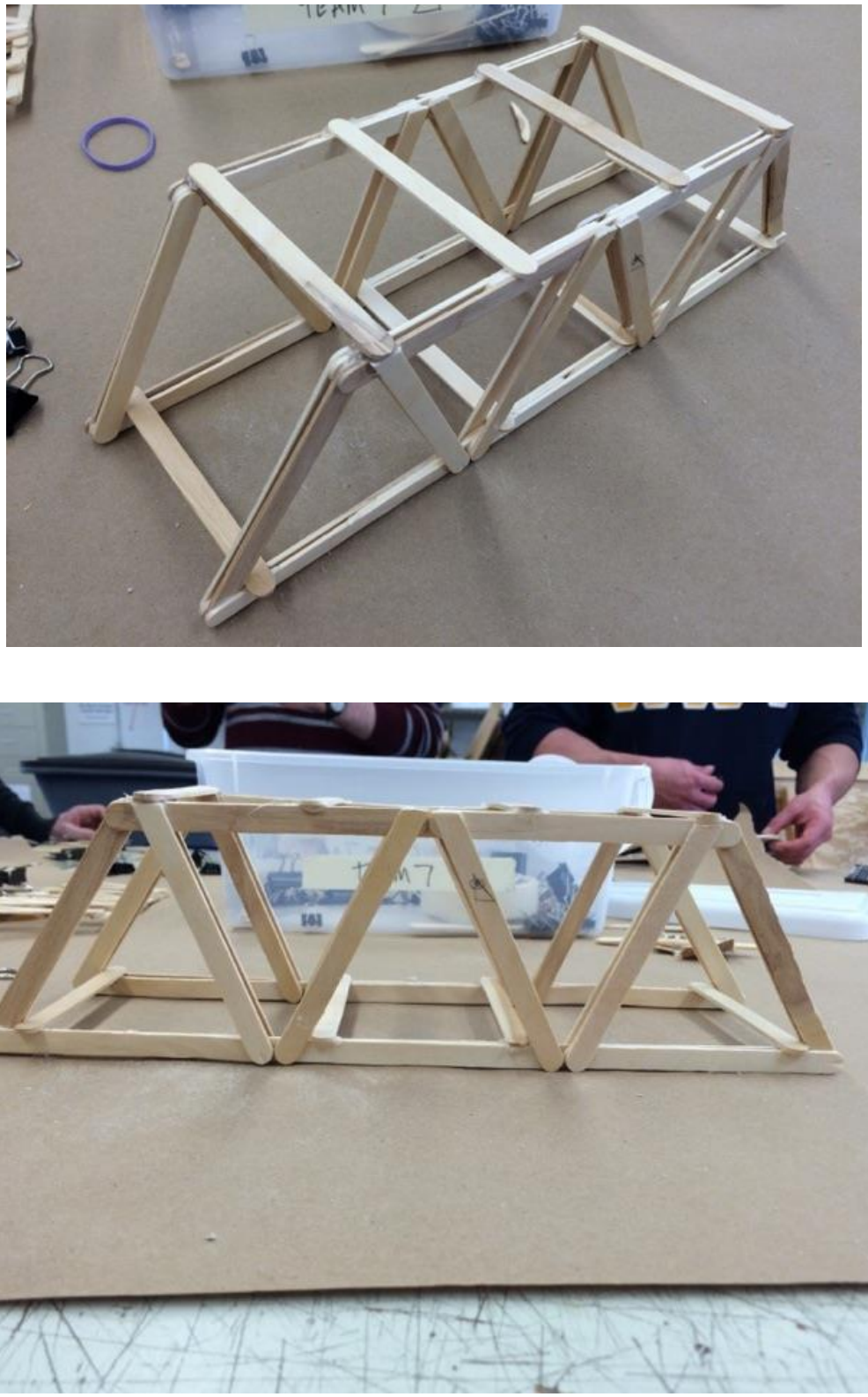


Figure 5. Warren Truss Bridge Prototype before Load Testing

Figure 6. Warren Truss Bridge Prototype Failure after Load Testing