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 structurally deficient vehicle bridge, located along a heavily traveled local road and is designated as a vital lifeline for vehicle access to Mount Nittany Medical Center, is completely destroyed by a recent 1000-year flood event. Now all traffic has to re-route more than 10 miles around the destroyed bridge, thereby disrupting residential traffic flow, local commerce, and exposing State college residents to considerable risk.

## Objective

PennDOT Engineering District 2-0 has initiated an urgent, fast-track project to expedite the design a new vehicle bridge over Spring Creek to replace the structurally deficient vehicle bridge.

## Design Criteria

The bridge must be 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 225kN trucks 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. The bridge shall be analyzed in both Warren through truss bridge and Howe through truss bridge.

## Technical Approach.

### Phase 1: Economic Efficiency.

The economic efficiency of the bridge will be determined using the EEBD 2015 software. The software allows 3 different options for material, bars and tubes, and various sizes of units that can all be manipulated to make the bridge as cheap as possible while still supporting its own weight (dead load) passing the load test (live load) of a single truck driving over.

### Phase 2: Structural Efficiency.

The structural efficiency of the bridge will be determined by creating a prototype bridge of each design with standard (4-1/2 x 3/8 x 1/12 inch) wooden (white birch) Popsicle (craft) sticks and Elmer's white glue. Hot glue may be used only for 8 struts and/or floor beams. Both prototype bridges will have a maximum of sixty (60) Popsicle sticks and approximate final bridge dimensions of 13.5 inches in length, 4 inches in height and 4.5 inches in width. The prototype bridge will be tested to catastrophic failure by hanging a bucket of sand and tools from the bridge, increasing weight until failure. From the tests it will be decided which prototype is more efficient, and this bridge will be used. The failure will also be analyzed to find why, where, and how it the bridge failed.

## Results.

### Phase 1: Economic Efficiency.

According to the data from the bridge design software, both types of bridge can reach the cost around $250,000, which is very economically efficent. The predicted cost of the Howe Truss Bridge is $251347.14, and the predicted cost of the Warren Truss Bridge is $240760.59. In comparison, the result turns out that the Warren Truss is the more economically efficient design. The costs of the bridge was largely reduced by using the different truss and cross-section material.

### Phase 2: Structural Efficiency.

Based on the results data from the load test, the maximum loads of the Howe Truss bridge and the Warren Truss bridge are extremely close. The Howe Truss bridge failed at 71.0 lbs, and the Warren Truss bridge failed at 70.9 lbs. They are both structured by 60 popsicle sticks each. The principle cause of the Howe Truss bridge is the less quality popsicle sticks on the top cord. It broke and caused the weight unevenly loaded on the bridge. However the failure of the Warren Truss bridge is mainly due to the mistake in the construction, instead of material using. The structure of the bridge was slightly crooked when we attached two trusses with hot glue. The uneven stress on the bridge caused the detachment of the top cords, resulting the failure.

### Best Solution.

The Best Solution is the Warren Struss Bridge. Compared to the Howe Truss bridge, it has advantages as follows: i) It is more economically efficient. The total cost of the Warren Truss bridge is less than the cost of Howe Bridge. ii)It has high structural efficiency. Although the Warren Truss bridge costs less, but the result from the load test shows that it takes almost the same loads as the Howe Truss Bridge. The detailed data tables are attached in this report.

**Conclusions and Recommendations.**

The bridge structure recommendation from Design group 7 is the Warren Truss bridge. The next step that should be accomplished is testing the stability of the bridge under real life situation, for instance: weather, location and temperature.

Respectfully,

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# ATTACHMENT 1

## Phase 1: Economic Efficiency

### Howe Truss.

The Howe Truss design was predicted to be slightly less economically efficient than the Warren Truss, according to the WPBD 2013 software. The estimated final cost of the Howe Truss was reduced to $251,347.14 by using carbon steel for all components, the cheapest material available, and then decreasing size of the beams until the load results were as close to 1.00 as possible. By using tubes for units in high tension and bars for units under compression the efficiency of the bridge was improved even further. Table 1 includes the material type, cross section, size, length, slenderness of each member in the Howe Truss. Table 2 includes the load test reports for each member. Table 3 includes a member detail report, the details of the member with the high compression/tension force, and an EEBD 2015 image of the Howe Truss design.

### Warren Truss.

The Warren Truss design was predicted by the WPBD 2013 software to be the most economically efficient and most viable option. The estimated final cost of the Warren Truss bridge was reduced to $240,760.59 by again using carbon steel for all components and then decreasing the size of the beams until load results were as close to 1.00 as possible. Again, tubes were used for units in tension and bars for units under compression. Because the same materials and methods were used for the design of both bridges and the Warren Truss design was less expensive, it is apparent that this design is more efficient. Table 4 includes the material type, cross section, size, length, slenderness of each member in the Howe Truss. Table 5 includes the load test reports for each member. Table 6 includes a member detail report, the details of the member with the high compression/tension force, and an EEBD 2015 image of the Warren Truss design.

# ATTACHMENT 2

## Phase 2: Structural Efficiency

## Howe Truss

**Prototype Bridge**.

The materials used to build the prototype How Truss bridge were popsicle sticks, white glue, and hot glue. 60 popsicle sticks were used, with the main structure held together by white glue. Only the floor beams and struts were held together by hot glue. The approximate final bridge dimensions were 13.5 inches in length, 4 inches in height and 4.5 inches in width.

**Load Testing**

According to the table of the load test results for the Howe Truss bridges, the maximum load was 99.7 lbs. from design team No. 5, and the minimum load was 33.8 lbs. from design team No. 2. The average Load at failure for all design teams was 66.0 lbs. The range of the results was 65.9. Design team 7 managed to build a Howe Truss bridge with a load at failure of 71.0, 5 lbs above the average. Design team 7 achieved such success due to using better quality popsicles for the Howe Truss bridge construction. Only 4 teams out of 8 obtained a load at failure result greater than the average result.

**Forensic Analysis**.

Design team No.7's Howe Truss bridge had a load failure of 71.0 lbs. Failure was due to the top cord breaking as a result of the of the pull from the bottom cord breaking from the load. From analyzing the broken bridge, the cords that failed were a result of using popsicle sticks of less quality, which were unable to hold the load.

**Results**.

See Table 7.

## Warren Truss.

### Prototype Bridge.

The materials used to build the prototype Warren Truss bridge were popsicle sticks, white glue, and hot glue. 60 popsicle sticks were used, with the main structure held together by white glue. Only the floor beams and struts were held together by hot glue. The approximate final bridge dimensions were 13.5 inches in length, 4 inches in height and 4.5 inches in width.

### Load Testing

According to the table of the load test results for the Warren Truss bridges, the maximum load was 104.6 lbs. from design team No. 1, and the minimum load was 33.9 lbs. from design team No. 2. The average Load at failure for all design teams was 65.0 lbs. The range of the results was 70.7. Design team 7 managed to build a Howe Truss bridge with a load at failure of 70.9, 5.9 lbs above the average. Design team 7 achieved such success due to using better quality popsicles for the Warren Truss bridge construction. Only 4 teams out of 8 obtained a load at failure result greater than the average result.

### Forensic Analysis.

Design team No.7's Warren Truss bridge had a load failure of 70.9 lbs. Failure was due the bridge being slightly crooked resulting in the failure of the end post and top cords detaching from the bridge struture. From analysis of the Warren Truss bridge, failure only occure in areas where hot glue was used as a binding agent, the main structure of the bridge maintained its construction otherwise.

### Results.

See Table 8.

**TABLE**

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 | (5412.6kg) x ($4.30 per kg) x (2 Trusses) = | $46,548.14 |
| | Carbon Steel Hollow Tube | (7095.2kg) x ($6.30 per kg) x ( 2 Trusses) = | $89,399.00 |
| Connection Cost (C) | | (20 joints) x (500.0 per joint) x (2 Trusses ) = | $20,000.00 |
| Product Cost (P) | 1 – 50x50 mm Carbon Steel Bar | ($1,000.00 per Product) = | $1,000.00 |
| | 2 – 55x55 mm Carbon Steel Bar | ($1,000.00 per Product) = | $1,000.00 |
| | 1 – 60x60 mm Carbon Steel Bar | ($1,000.00 per Product) = | $1,000.00 |
| | 1 – 65x65 mm Carbon Steel Bar | ($1,000.00 per Product) = | $1,000.00 |
| | 2 – 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 |
| | 1 – 140x140x7 mm Carbon Steel Tube | ($1,000.00 per Product) = | $1,000.00 |
| | 1 – 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 |
| | 1 – 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 |
| | 3 – 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 Anchorage = | $0.00 |
| Total Cost | M+C+P+S | $135,974.14+ $20,200.00 +$18,000.00+77,400.00 | $251,347.14 |

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

| # | Material Type | Cross Section | Size (mm) | Length (m) | Compression Force | Compression Strength | Compress-ion Status | Tension Force | Tension Strength | Tension Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CS | Hollow Tube | 260x260x13 | 5.66 | 2007.13 | 2449.94 | OK | 0.00 | 3050.45 | OK |
| 2 | CS | Hollow Tube | 200x200x10 | 4.00 | 1419.26 | 1487.26 | OK | 0.00 | 1805.00 | OK |
| 3 | CS | Hollow Tube | 260x260x13 | 4.00 | 2523.24 | 2660.84 | OK | 0.00 | 3050.45 | OK |
| 4 | CS | Hollow Tube | 300x300x15 | 4.00 | 3309.79 | 3616.10 | OK | 0.00 | 4061.25 | OK |
| 5 | CS | Hollow Tube | 320x320x16 | 4.00 | 3777.62 | 4145.34 | OK | 0.00 | 4620.80 | OK |
| 6 | CS | Hollow Tube | 320x320x16 | 4.00 | 3756.32 | 4145.34 | OK | 0.00 | 4620.80 | OK |
| 7 | CS | Hollow Tube | 300x300x15 | 4.00 | 3267.50 | 3616.10 | OK | 0.00 | 4061.25 | OK |
| 8 | CS | Hollow Tube | 260x260x13 | 4.00 | 2460.21 | 2660.84 | OK | 0.00 | 3050.45 | OK |
| 9 | CS | Hollow Tube | 200x200x10 | 4.00 | 1386.04 | 1487.26 | OK | 0.00 | 1805.00 | OK |
| 10 | CS | Solid Bar | 110x110 | 4.00 | 0.00 | 1181.16 | OK | 2523.24 | 2873.75 | OK |
| 11 | CS | Solid Bar | 120x120 | 4.00 | 0.00 | 1606.24 | OK | 3309.79 | 3420.00 | OK |
| 12 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3777.62 | 4013.75 | OK |
| 13 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3926.39 | 4013.75 | OK |
| 14 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3926.39 | 4013.75 | OK |
| 15 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3756.32 | 4013.75 | OK |
| 16 | CS | Solid Bar | 120x120 | 4.00 | 0.00 | 1606.24 | OK | 3267.50 | 3420.00 | OK |
| 17 | CS | Solid Bar | 110x110 | 4.00 | 0.00 | 1181.16 | OK | 2460.21 | 2873.75 | OK |
| 18 | CS | Solid Bar | 55x55 | 4.00 | 0.00 | 74.51 | OK | 624.39 | 718.44 | OK |
| 19 | CS | Solid Bar | 50x50 | 4.00 | 0.00 | 50.89 | OK | 583.64 | 593.75 | OK |
| 20 | CS | Solid Bar | 60x60 | 4.00 | 0.00 | 105.53 | OK | 850.45 | 855.00 | OK |
| 21 | CS | Solid Bar | 70x70 | 4.00 | 0.00 | 195.50 | OK | 1116.24 | 1163.75 | OK |
| 22 | CS | Solid Bar | 80x80 | 4.00 | 0.00 | 333.51 | OK | 1379.91 | 1520.00 | OK |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 23 | CS | Hollow Tube | 220x220x11 | 5.66 | 1589.87 | 1642.86 | OK | 0.00 | 2184.05 | OK |
| 24 | CS | Hollow Tube | 200x200x10 | 5.66 | 1215.74 | 1293.53 | OK | 0.00 | 1805.00 | OK |
| 25 | CS | Hollow Tube | 180x180x9 | 5.66 | 839.43 | 981.36 | OK | 0.00 | 1462.05 | OK |
| 26 | CS | Hollow Tube | 140x140x7 | 5.66 | 462.69 | 474.03 | OK | 129.79 | 884.45 | OK |
| 27 | CS | Hollow Tube | 150x150x7 | 5.66 | 506.63 | 550.30 | OK | 85.85 | 950.95 | OK |
| 28 | CS | Solid Bar | 55x55 | 4.00 | 0.00 | 74.51 | OK | 614.90 | 718.44 | OK |
| 29 | CS | Hollow Tube | 180x180x9 | 5.66 | 883.79 | 981.36 | OK | 0.00 | 1462.05 | OK |
| 30 | CS | Solid Bar | 65x65 | 4.00 | 0.00 | 145.35 | OK | 881.95 | 1003.44 | OK |
| 31 | CS | Hollow Tube | 200x200x10 | 5.66 | 1260.47 | 1293.53 | OK | 0.00 | 1805.00 | OK |
| 32 | CS | Solid Bar | 70x70 | 4.00 | 0.00 | 195.50 | OK | 1147.87 | 1163.75 | OK |
| 33 | CS | Hollow Tube | 240x240x12 | 5.66 | 1635.33 | 2028.51 | OK | 0.00 | 2599.20 | OK |
| 34 | CS | Solid Bar | 80x80 | 4.00 | 0.00 | 333.51 | OK | 1412.57 | 1520.00 | OK |
| 35 | CS | Solid Bar | 80x80 | 4.00 | 0.00 | 333.51 | OK | 1386.04 | 1520.00 | OK |
| 36 | CS | Hollow Tube | 240x240x12 | 5.66 | 1960.16 | 2028.51 | OK | 0.00 | 2599.20 | OK |
| 37 | CS | Solid Bar | 80x80 | 4.00 | 0.00 | 333.51 | OK | 1419.26 | 1520.00 | OK |

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

Member List | Member Details

Member 26

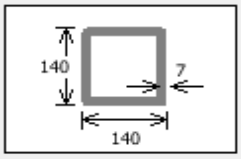
Material Properties:

| | |
|---|---|
| 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 | 140x140x7 |
| Area | 0.0037 sq. meters |
| Moment of Inertia | 1.10E-05 meters$^4$ |
| Member Length | 5.66 meters |

Section (mm):




Cost:

| | |
|---|---|
| Unit Cost | $184.17 per meter |
| Member Cost | $1041.83 |

Strength vs. Length: Graph all tabs Member:

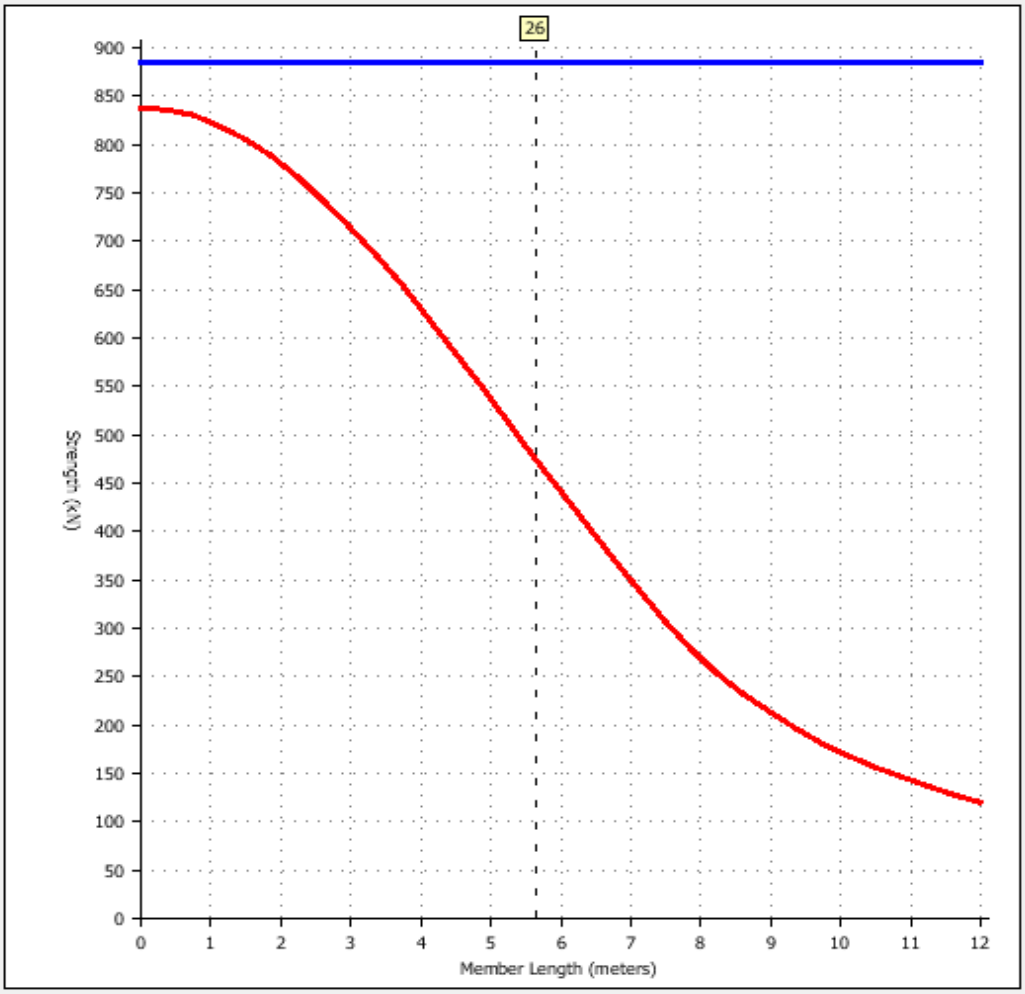


**Table 4**
**Warren Truss Bridge**
**Cost Calculation Report from Bridge Designer 2015**

| Type of Cost | Item | Cost | Calculation Cost |
|---|---|---|---|
| Material Cost (M) | Carbon Steel Solid Bar | (5113.5 kg) x ($4.30 per kg) x (2 Trusses) = | $43,976.43 |
| | Carbon Steel Hollow Tube | (6538.4 kg) x ($6.30 per kg) x (2 Trusses) = | $82,384.16 |
| Connection Cost (C) | | (21 Joints) x (500.0 per joint) x (2 Trusses) = | $21,000.00 |
| Product Cost (P) | 4 - 55x55 mm Carbon Steel Bar | (%s per Product) = | $1,000.00 |
| | 2 - 65x65 mm Carbon Steel Bar (%s per Product) = | (%s per Product) = | $1,000.00 |
| | 2 - 75x75 mm Carbon Steel Bar (%s per Product) = | (%s per Product) = | $1,000.00 |
| | 3 - 90x90 mm Carbon Steel Bar | (%s per Product) = | $1,000.00 |
| | 1 - 100x100 mm Carbon Steel Bar | (%s per Product) = | $1,000.00 |
| | 2 - 100x100x5 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 2 - 110x110 mm Carbon Steel Bar | (%s per Product) = | $1,000.00 |
| | 4 - 130x130 mm Carbon Steel Bar | (%s per Product) = | $1,000.00 |
| | 2 - 140x140x7 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 2 - 160x160x8 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 2 - 180x180x9 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 4 - 200x200x10 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 2 - 220x220x11 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 2 - 260x260x13 mm Carbon Steel Tube | (%s per Product) = | $1,000.00 |
| | 2 - 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 | (19,900 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 | $126,360.59 + $21,000.00 + $16,000.00 + $77,400.00 = | $240,760.59 |

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

| # | Material Type | Cross Section | Size (mm) | Length (m) | Compression Force | Compression Strength | Compressi-on Status | Tension Force | Tension Strength | Tension Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CS | Hollow Tube | 220x220x11 | 4.47 | 1582.31 | 1791.30 | OK | 0.00 | 2184.05 | OK |
| 2 | CS | Solid Bar | 90x90 | 4.47 | 0.00 | 427.38 | OK | 1576.05 | 1923.75 | OK |
| 3 | CS | Hollow Tube | 200x200x10 | 4.00 | 1412.46 | 1487.26 | OK | 0.00 | 1805.00 | OK |
| 4 | CS | Hollow Tube | 260x260x13 | 4.00 | 2511.92 | 2660.84 | OK | 0.00 | 3050.45 | OK |
| 5 | CS | Hollow Tube | 300x300x15 | 4.00 | 3295.87 | 3616.10 | OK | 0.00 | 4061.25 | OK |
| 6 | CS | Hollow Tube | 320x320x16 | 4.00 | 3762.46 | 4145.34 | OK | 0.00 | 4620.80 | OK |
| 7 | CS | Hollow Tube | 320x320x16 | 4.00 | 3910.85 | 4145.34 | OK | 0.00 | 4620.80 | OK |
| 8 | CS | Hollow Tube | 320x320x16 | 4.00 | 3741.74 | 4145.34 | OK | 0.00 | 4620.80 | OK |
| 9 | CS | Hollow Tube | 300x300x15 | 4.00 | 3254.44 | 3616.10 | OK | 0.00 | 4061.25 | OK |
| 10 | CS | Hollow Tube | 260x260x13 | 4.00 | 2449.76 | 2660.84 | OK | 0.00 | 3050.45 | OK |
| 11 | CS | Hollow Tube | 200x200x10 | 4.00 | 1380.03 | 1487.26 | OK | 0.00 | 1805.00 | OK |
| 12 | CS | Hollow Tube | 220x220x11 | 4.47 | 1546.05 | 1791.30 | OK | 0.00 | 2184.05 | OK |
| 13 | CS | Solid Bar | 55x55 | 4.00 | 0.00 | 74.51 | OK | 691.41 | 718.44 | OK |
| 14 | CS | Solid Bar | 90x90 | 4.00 | 0.00 | 534.22 | OK | 1916.73 | 1923.75 | OK |
| 15 | CS | Solid Bar | 110x110 | 4.00 | 0.00 | 1181.16 | OK | 2853.10 | 2873.75 | OK |
| 16 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3473.10 | 4013.75 | OK |
| 17 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3775.11 | 4013.75 | OK |
| 18 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3759.29 | 4013.75 | OK |
| 19 | CS | Solid Bar | 130x130 | 4.00 | 0.00 | 2091.29 | OK | 3452.97 | 4013.75 | OK |
| 20 | CS | Solid Bar | 110x110 | 4.00 | 0.00 | 1181.16 | OK | 2853.69 | 2873.75 | OK |
| 21 | CS | Solid Bar | 100x100 | 4.00 | 0.00 | 814.24 | OK | 1937.84 | 2375.00 | OK |
| 22 | CS | Solid | 55x55 | 4.00 | 0.00 | 74.51 | OK | 707.63 | 718.44 | OK |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Bar | | | | | | | | |
| 23 | CS | Hollow Tube | 200x200x10 | 4.47 | 1291.87 | 1436.26 | OK | 0.00 | 1805.00 | OK |
| 24 | CS | Solid Bar | 75x75 | 4.47 | 0.00 | 206.11 | OK | 1283.69 | 1335.94 | OK |
| 25 | CS | Hollow Tube | 180x180x9 | 4.47 | 998.41 | 1116.73 | OK | 0.00 | 1462.05 | OK |
| 26 | CS | Solid Bar | 65x65 | 4.47 | 0.00 | 116.28 | OK | 988.76 | 1003.44 | OK |
| 27 | CS | Hollow Tube | 160x160x8 | 4.47 | 702.58 | 833.29 | OK | 0.00 | 1155.20 | OK |
| 28 | CS | Solid Bar | 55x55 | 4.47 | 0.00 | 59.61 | OK | 692.04 | 718.44 | OK |
| 29 | CS | Hollow Tube | 140x140x7 | 4.47 | 405.36 | 586.91 | OK | 63.05 | 884.45 | OK |
| 30 | CS | Hollow Tube | 140x140x7 | 4.47 | 369.97 | 586.91 | OK | 98.43 | 884.45 | OK |
| 31 | CS | Solid Bar | 55x55 | 4.47 | 0.00 | 59.61 | OK | 656.65 | 718.44 | OK |
| 32 | CS | Hollow Tube | 160x160x8 | 4.47 | 667.20 | 833.29 | OK | 0.00 | 1155.20 | OK |
| 33 | CS | Solid Bar | 65x65 | 4.47 | 0.00 | 116.28 | OK | 953.37 | 1003.44 | OK |
| 34 | CS | Hollow Tube | 180x180x9 | 4.47 | 963.03 | 1116.73 | OK | 0.00 | 1462.05 | OK |
| 35 | CS | Solid Bar | 75x75 | 4.47 | 0.00 | 206.11 | OK | 1247.86 | 1335.94 | OK |
| 36 | CS | Hollow Tube | 200x200x10 | 4.47 | 1256.05 | 1436.26 | OK | 0.00 | 1805.00 | OK |
| 37 | CS | Solid Bar | 90x90 | 4.47 | 0.00 | 427.38 | OK | 1539.79 | 1923.75 | OK |
| 38 | CS | Hollow Tube | 100x100x5 | 4.47 | 73.55 | 212.76 | OK | 394.85 | 451.25 | OK |
| 39 | CS | Hollow Tube | 100x100x5 | 4.47 | 108.93 | 212.76 | OK | 359.47 | 451.25 | OK |

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

Member List | Member Details

Member 3

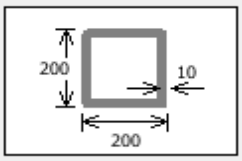
Material Properties:

| | |
|---|---|
| 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 | 200x200x10 |
| Area | 0.0076 sq. meters |
| Moment of Inertia | 4.59E-05 meters$^4$ |
| Member Length | 4.00 meters |

Section (mm):




Cost:

| | |
|---|---|
| Unit Cost | $375.86 per meter |
| Member Cost | $1503.43 |

Strength vs. Length: Graph all tabs Member:

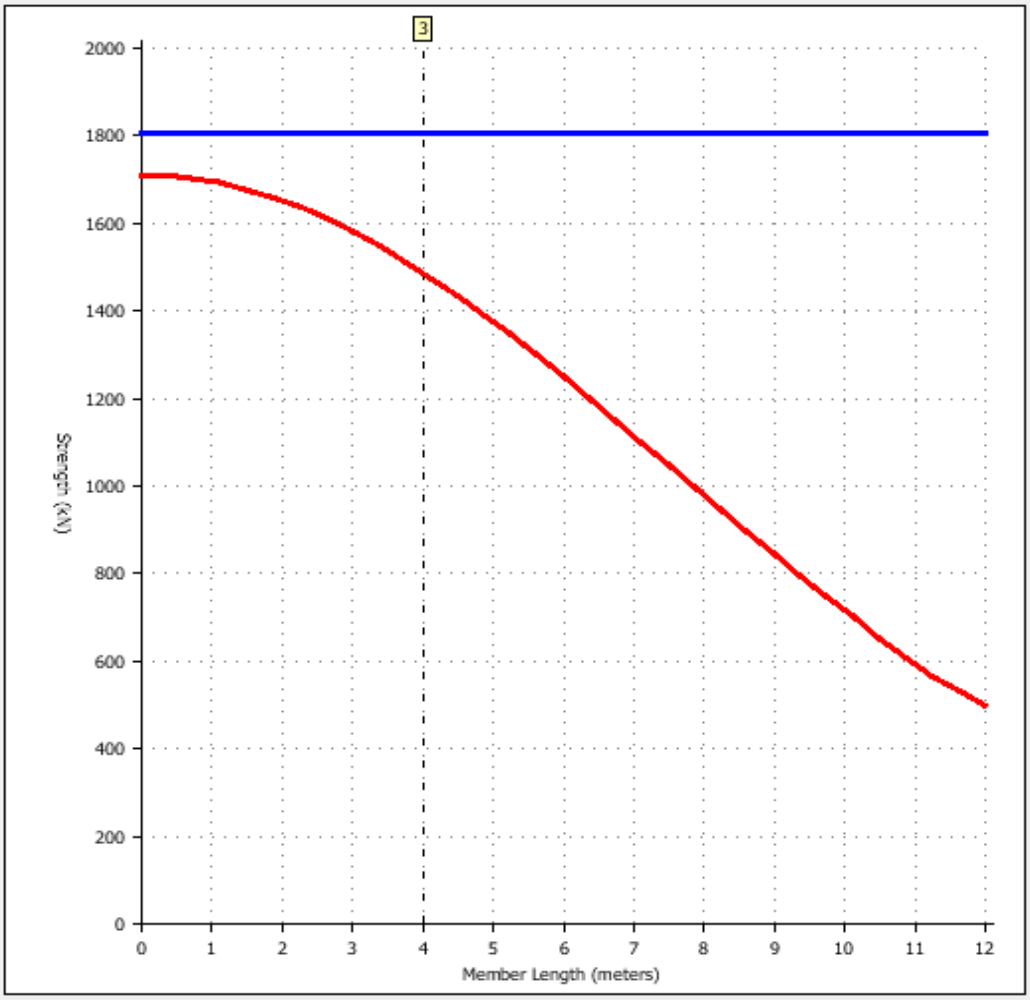


**Table 7**
**Howe Truss Bridge**
**Load Testing Results**

| Design Team No. | Actual 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 | 0.186 | 71.0 | 381.7 |
| 8 | 82.6 | 0.182 | 44.3 | 243.4 |
| | | | **Minimum** | **238.0** |
| | | | **Maximum** | **567.7** |
| | | | **Range** | **329.7** |
| | | | **Mean** | **369.8** |

**Table 8**
**Warren Truss Bridge**
**Load Testing Results**

| Design Team No. | Actual Bridge Weight (grams) | Bridge Weight (lbs) | LOAD at Failure (lbs) | Structural Efficiency |
|---|---|---|---|---|
| 1 | 81.9 | 0.181 | 104.6 | 578.0 |
| 2 | 77.1 | 0.170 | 33.9 | 199.4 |
| 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 | 692.1 |
| 7 | 87.0 | 0.192 | 70.9 | 369.3 |
| 8 | 83.6 | 0.184 | 90.3 | 490.8 |
| | | | **Minimum** | **199.4** |
| | | | **Maximum** | **692.1** |
| | | | **Range** | **492.7** |
| | | | **Mean** | **397.2** |

# FIGURES

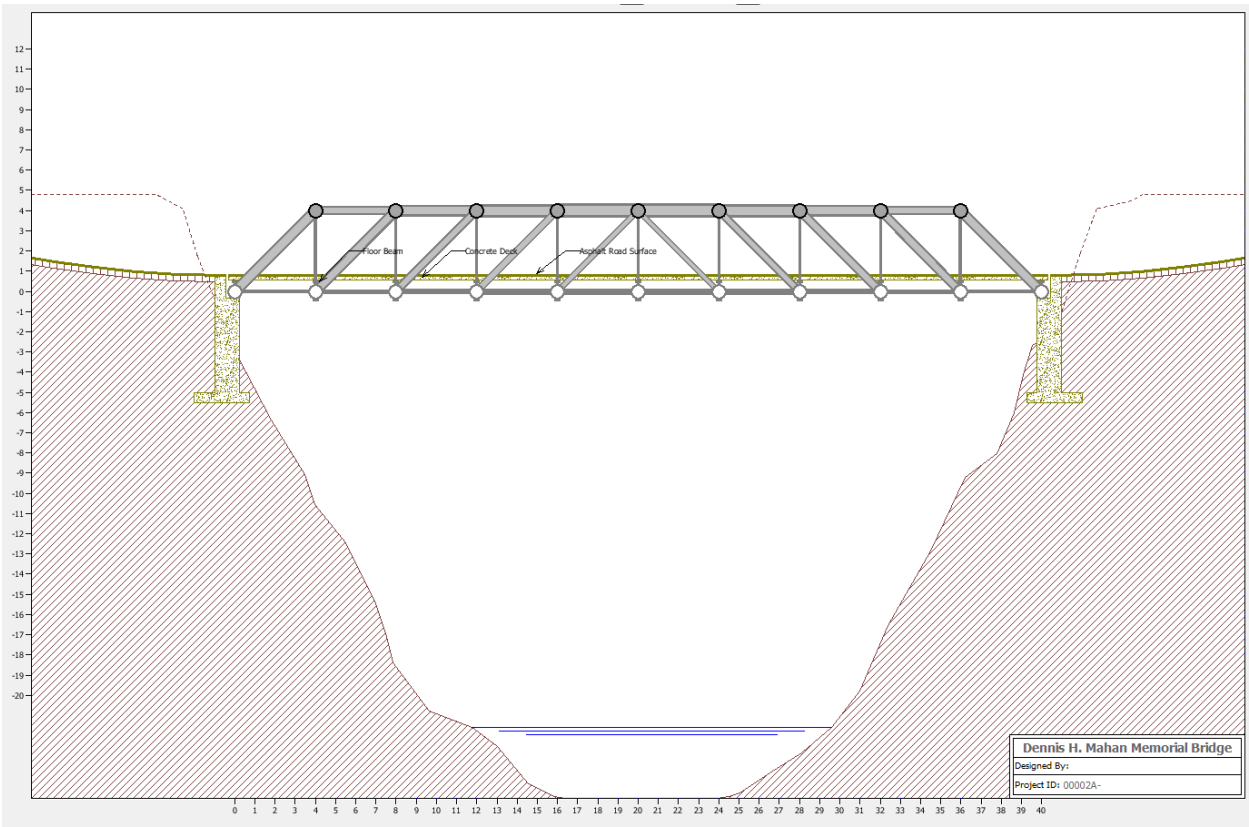



**Figure 1. Howe Truss Bridge Model from Bridge Designer 2015**

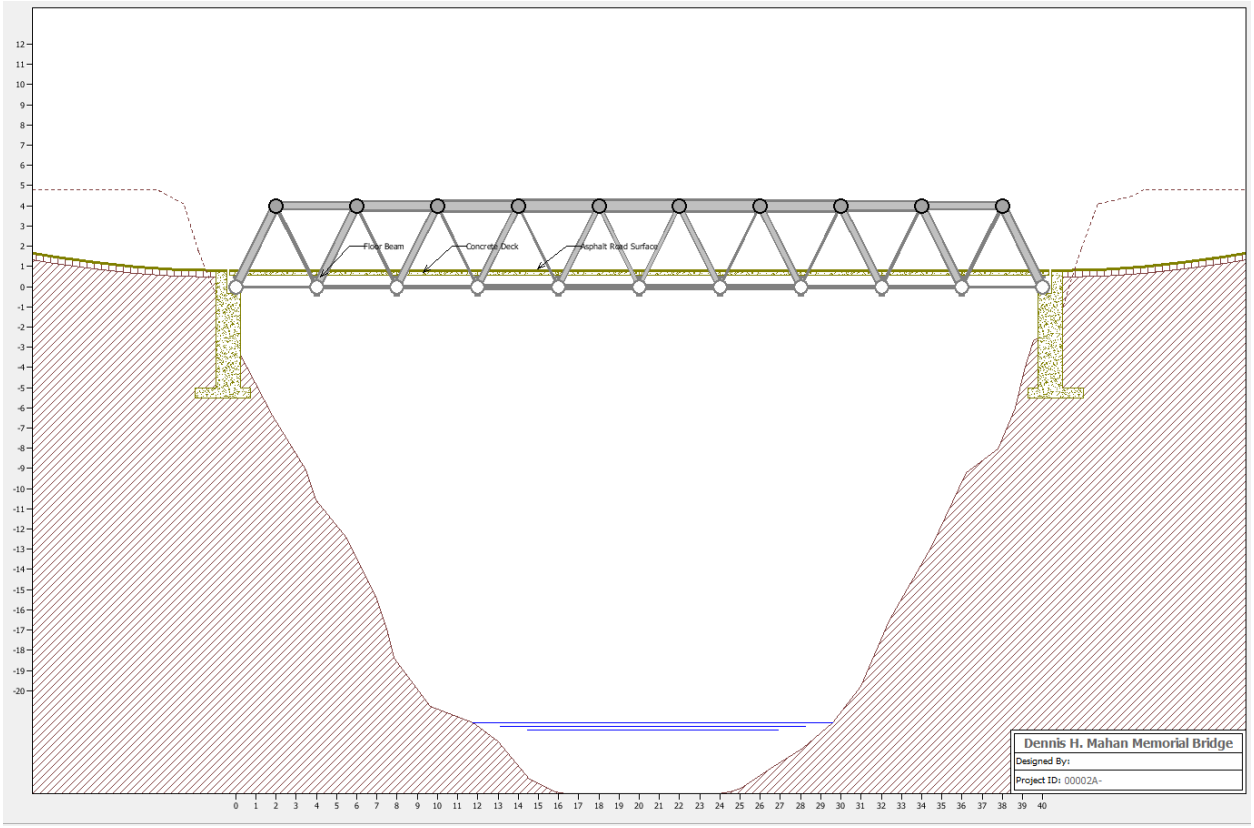



**Figure 2. Warren Truss Bridge Model from Bridge Designer 2015**

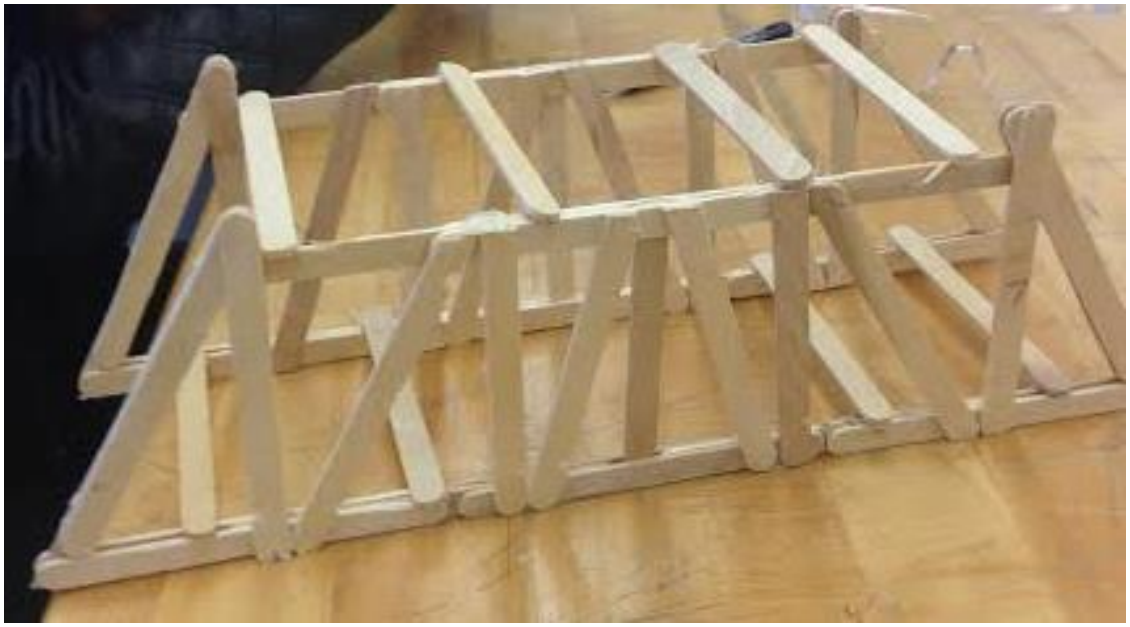


**Figure 3. Howe Truss Bridge Prototype before Load Testing**

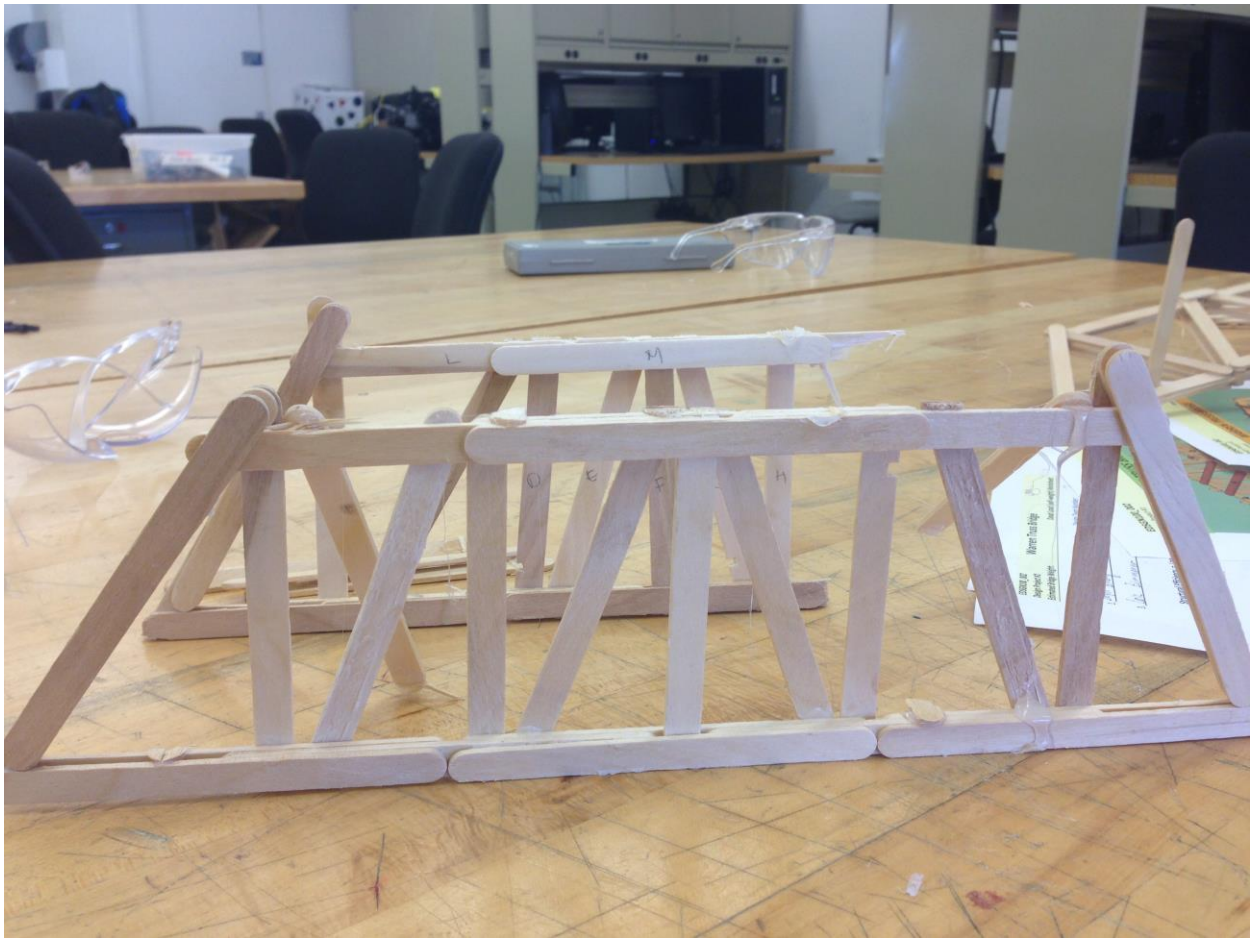


**Figure 4. Howe Truss Bridge Prototype Failure after Load Testing**

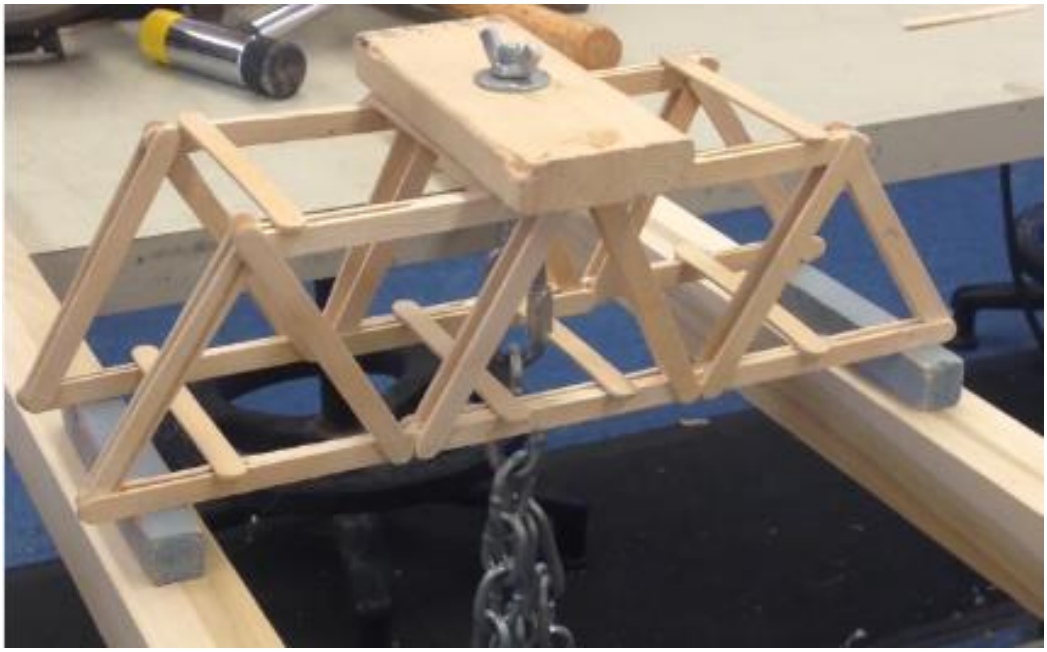


**Figure 5. Warren Truss Bridge Prototype before Load Testing**

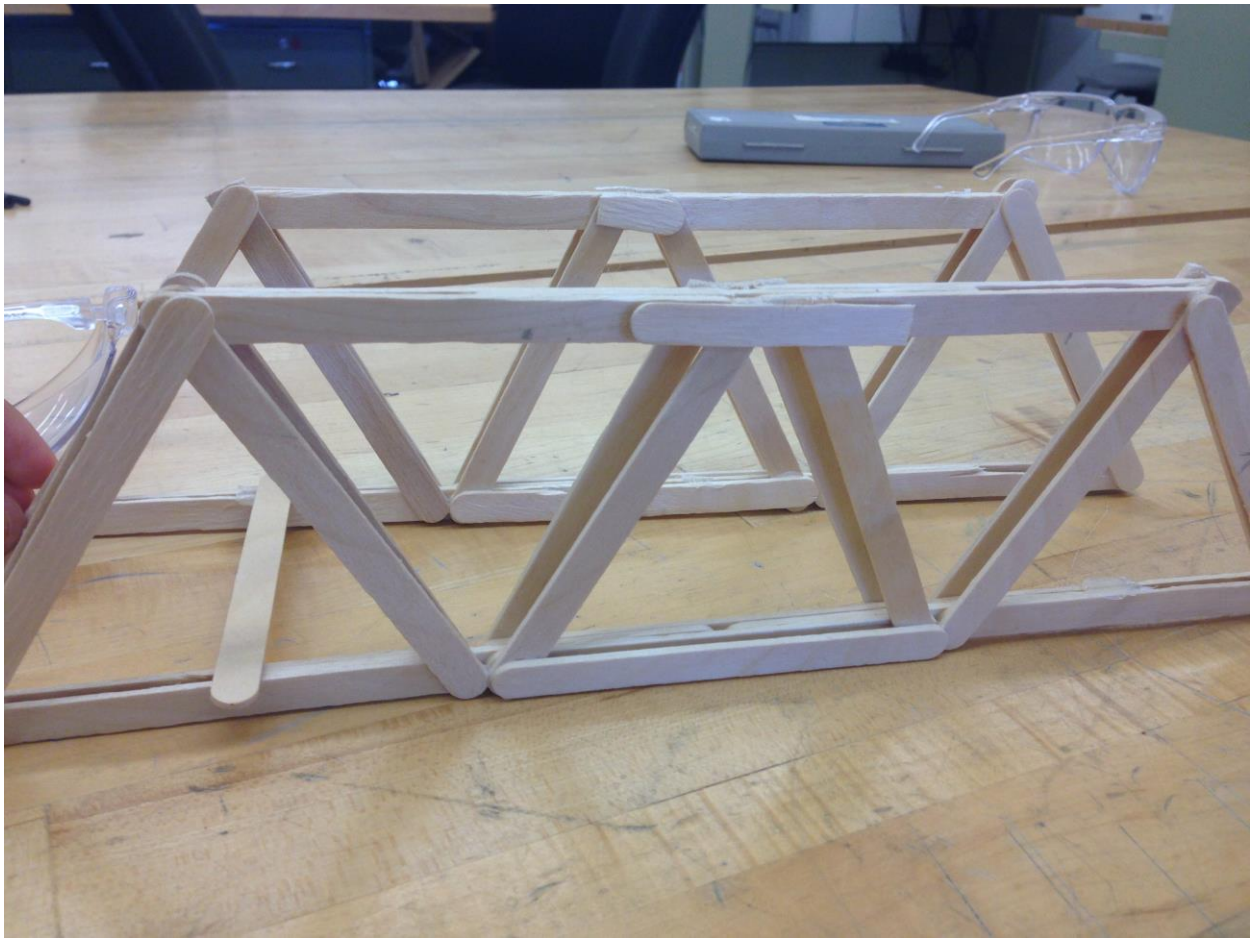


**Figure 6. Warren Truss Bridge Prototype Failure after Load Testing**

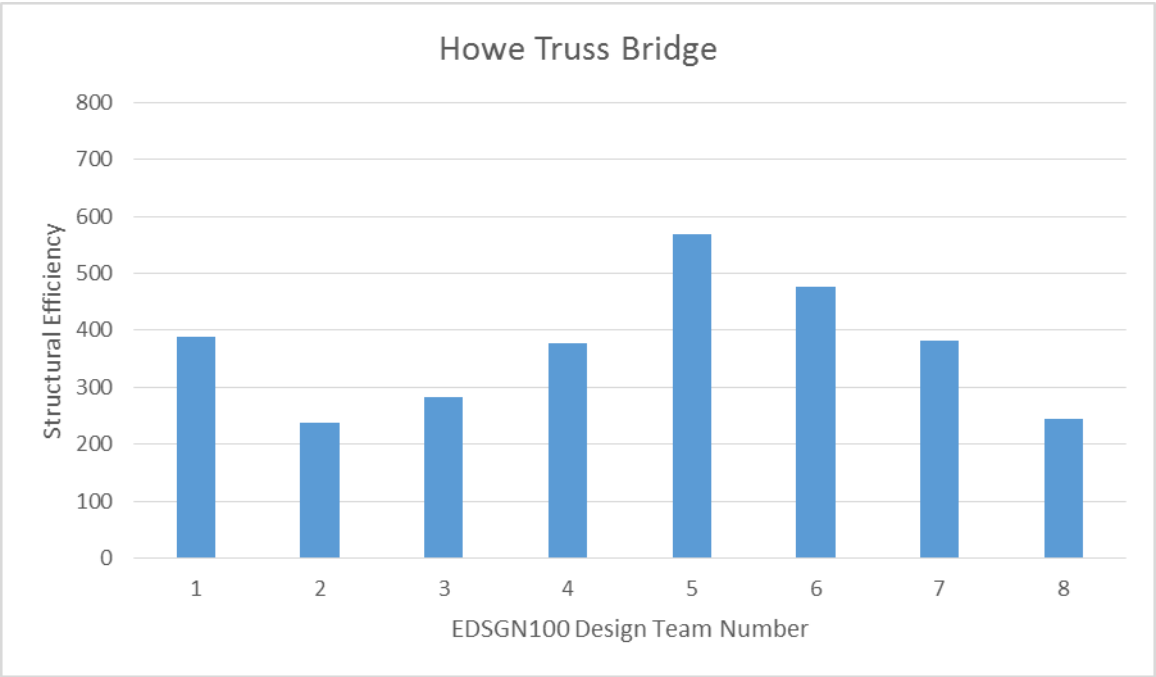



Figure 7. Howe Truss Bridge Structural Efficiencies

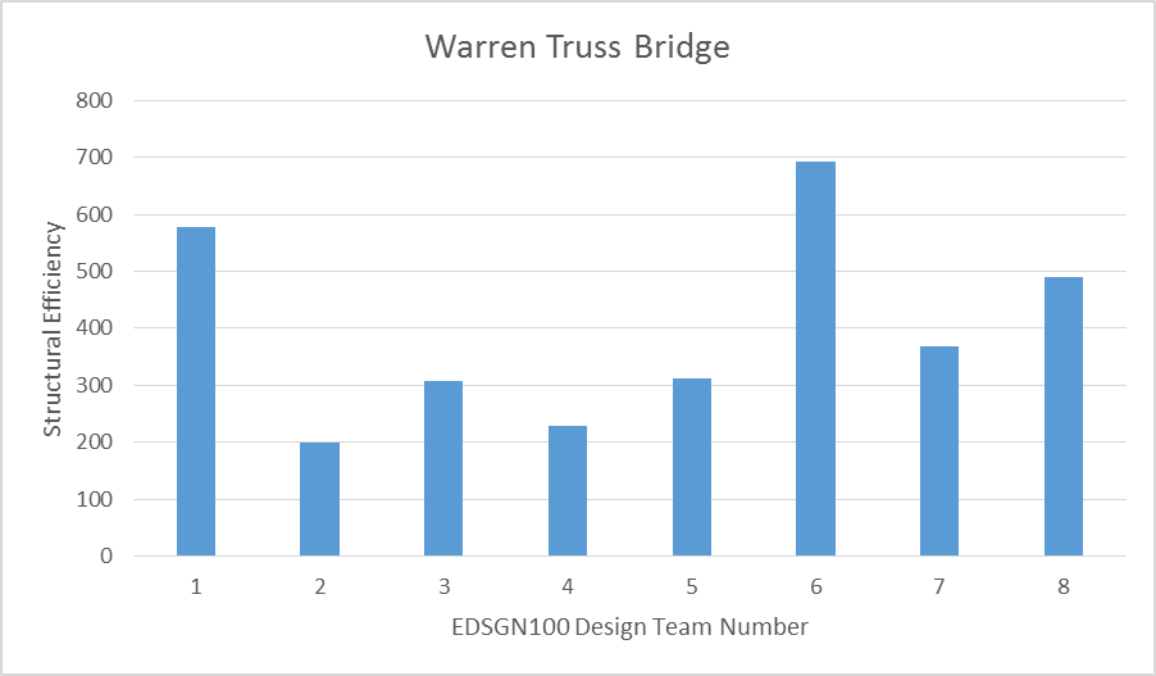



Figure 8. Warren Truss Bridge Structural Efficiencies