Team R

Project 2.3.2: West Point Bridge Design

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Ms. Chou Period 7

Principles of Engineering 2017-2018

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Design Brief

Client: American Bridge Company

Target Consumer: people who want to cross the Trinity River

Designers: Team R (Ranju Krishna, Roshni Vakil)

Problem Statement: People who want to cross a certain segment of the Trinity River are currently unable. There needs to be some pathway for automobiles to be able to cross.

Design Statement: We will design a stable, cost effective, bridge to connect both sides of the river to get people across. It will also be simplistic and aesthetic.

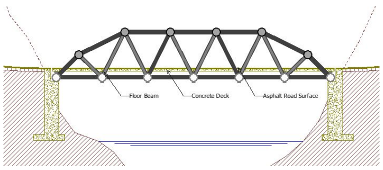
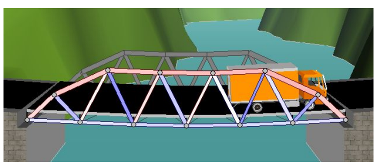
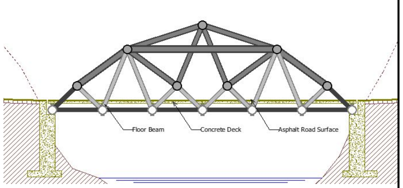
Constraints:
- Must be designed utilizing the West Point Bridge Design Software
- Must span the length of the river bed
- Must carry a two-lane highway
- Must safely carry the truck to the other side
- Must have a low cost (preferably under $300,000)
- Must be a realistic and viable solution
- Movement of the bridge during truck crossing must be limited

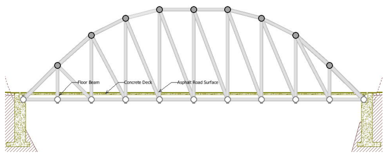
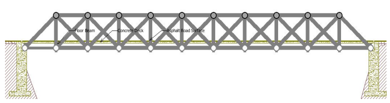
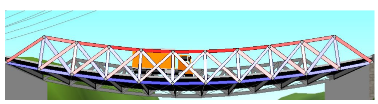
Deliverables:
- An electronic document containing the following-
    - Design Brief - containing all items neatly organized on one page
    - Research Summary - data collected based on truss design and materials used
    - Brainstorm Diagrams in Design Matrix numerically and verbally assessing each design
    - Modifications - Sketches illustrating major changes made to selected bridge
    - Final Bridge Design - final design with load tests, cost calculations, and member property reports
    - Final Design Justification - written explanation of materials used and design chosen
    - References - all sources cited APA
- A notebook section containing the following-
    - Design Brief notes
    - Project Logs detailing daily contributions
    - Investigation Tables

Research Summary

In order to effectively design a low cost and stable bridge, majority of the research was put into deciding the material and the design of the member. From our findings, we found that quenched and tempered steel is “less brittle and more ductile without sacrificing hardness” (Shape Cut Steel, 2015). However, the expense for this material increases the overall cost of the bridge marginally. On the other hand, Carbon steel has a high “strength and hardness” but has a lower “ductility and malleability of the steel” (University of Mauritius, n.d). With this information in mind, we decided to use only carbon steel for our bridges. For its low cost, the material was incredibly durable. The design of the members, with the options being hollow tube or solid bar, was found to have its own pros and cons. A solid bar is more sturdy, but is also more heavy and expensive. A hollow tube is much more inexpensive and can stand more tension, but the durability of the member is lacking. Due to this, we combined the two types together when designing the bridge, using hollow tubes when there is “a number in the compression column” and “a zero in the tension column” and a bar when there is “a number in tension and zero in compression” or when “if there is a number in both” (Loudoun County Public Schools [LCPS], n.d). When researching the various types of designs for the bridge, we concluded that the speciality of each bridge varied from design to design. For example, according to SkyCiv, the Pratt truss is a more “efficient design” and is best suited for “horizontal spans” (Carigliano, 2015). The Warren truss is able to “ to spread the load evenly across a number of different members” but not with “concentrated loads”, while also maintaining a “fairly simple design” (Carigliano, 2015). Finally, the Howe truss is the complete “reverse” of a Pratt, with “diagonal members in compression” and “vertical members in tension”, meaning the “constructability” is worsened (Carigliano, 2015). The design that seemed best suited was the Warren truss, as the distribution of weight was the key selling point when researching improvements for the truss design. The investigation tables were also a main source of information to strengthen the bridge, particularly in meeting the cost constraint. After conducting the tests required for the table, we saw that although excavating increased the price initially, by reducing the number of members required it significantly reduced the cost of our bridges overall. The length of the arch abutments and piers also played a role in the cost, where the shorter the length, the cheaper. We found that central piers were quite cheap and greatly helped in reducing overall tension and compression in our designs. The material of the members were also found in the tables, as previously stated above.

Decision Matrix - Assignment of Values

	Simplicity (1: worst - 10: best)	Aesthetic 1: worst - 10: best)	Stability 1: worst - 10: best)	Cost 1: worst - 10: best)	Total Score
Design #1 -Roshni, Curved triangle design  	9 This score is decided due to the design consisting of only a few triangles. 1 in this case is if the bridge uses many members, while 10 is if the bridge consists of less than 10 members in the middle.	3 This design was given a three because the overall style of the bridge was quite lacking, and the bridge would not be very noticable. A 1 would have been awarded if the look of the bridge was just too bare.	8 The first design was the most stable out of all the bridges, so it was given the highest score. Although a few blue and red lines were present, so the score had to be reduced by 2.	10 If the bridge stayed within the $300,000 price range, the bridge was instantly awarded a 10 which is why this score is a perfect 10.	30
Design #2 -Roshni, Curved Star design in middle  	5 The amount of members in the middle of the bridge is about 15, which is what we decided would be a five. The pattern of the truss was also quite intricate, with a star design in the middle.	6 The look of this bridge is very pleasing to the eye, however it also appears a little busy overall. Our mid value was awarded when the bridge was creative only, thus giving this a 6.	6 The bridge was scored a 6 due to a significan t amount of red and blue lines, but all of them being in a lighter shade.	10 Similar to the bridge above, the bridge was below the decided price range, thus being a 10.	27
Design #3 -Ranju, Curved triangle design	4 The member	7 This bridge is	5 This	10 This	24

 	count for this truss is 17, which is close to the decided number to get a 5, but two members more. For this reason we reduced the score by one. The design is also somewhat simple relying on triangles, but too many.	designed very elegantly yet also simple, but a bit too simple. A 10 is given if the bridge is simple yet also creative, which is why we reduced the score by 3.	design had only a few red and blue lines, however they were extremely red and blue, resulting in a score of 5.	bridge also follows suit, being awarded a 10 due to the price staying below $300,000	
Design #4 -Ranju  	3 The amount of members used was the most out of all four designs, which instantly reduced the score to a 3. The design was also too intricate, having too many boxes and triangles.	4 This bridge was too cluttered, while also following too closely to Howe’s truss. However, the design showed an attempt of creativity, which lead to the final score being 4.	4 The truss has many red and blue lines, however a smaller amount being a deeper shade of the two colors. This is why the score was a 4 instead of a 5.	2 This bridge was the only bridge that was above the price range ($694,610), but the decided value for 1 was if the cost was above $700,000, giving this bridge a 2.	13

Decision Matrix - Explanations

<u>Design 1:</u>

This bridge's design was based on the Warren Truss model for the sake of simplicity and effectivity. We reasoned that the simpler the bridge, the fewer members would need to be utilized. The fewer members that were utilized, the lower the cost of the bridge would be. To further reduce number of members required, we excavated to four feet. In addition, Warren Trusses are known for their ability to spread "load fairly evenly between members" (Carigliano, 2015). This would ensure that no single beam was under a significant amount of either tension or compression. A majority of this bridge's central beams were thicker and hollow because they were better able to withstand tension than thinner, solid beams. Conversely, the external framing was comprised of solid beams because we found them to be better at handling the compression that they were under. For strength and durability, we used only quenched and tempered steel in this design. Since this bridge cost less than $300,000, moved the least, and had an overall less amount of either tension of compression on is beams, we decided to work off of this design to create our final bridge.

<u>Design 2:</u>

This bridge was designed primarily for aesthetics, although feasibility and price were also taken into consideration. Its structural outline was heavily influenced by the design of the Fink Truss because we read that it "can be very efficient at transmitting loads to the support" (Carigliano, 2015). As with everything in engineering, an efficient model is always prefered. In an effort to remain within the budget, however, almost all of the members were hollow, thinner beams. This included the beams under compression, although we read up that solid beams are more resistant to being squeezed and deformed that way. Only the base beams were solid because a completely sturdy and reliable base is essential. We could not afford to solidify anything else. To keep within the $300,000 price range, we also made the internal beams of the design, the ones under the least tension, out of carbon steel. It was cheaper that way. Everything else was constructed out of the more sturdy quenched and tempered steel.

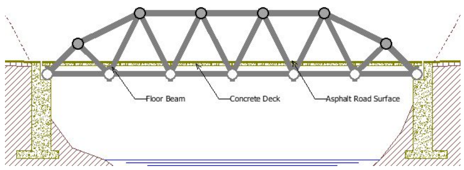
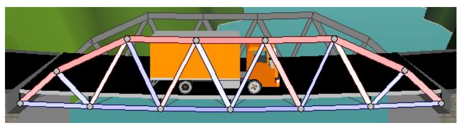
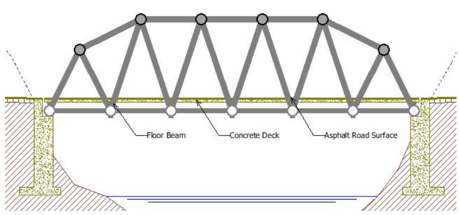
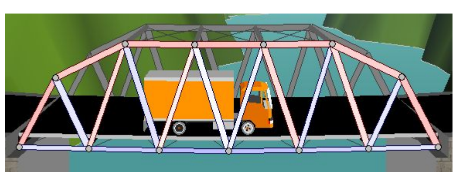
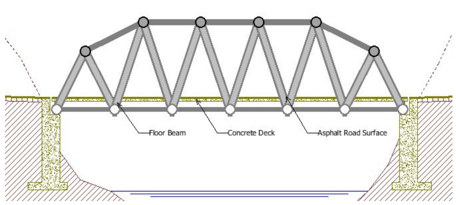
<u>Design 3:</u>

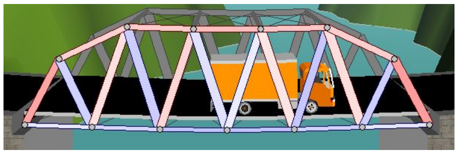
For this design the main category that was being focused on was aesthetics. Due to this, other qualities of the bridge such as stability and cost were not taken too seriously into consideration when brainstorming. The basis of the truss was very roughly based on the Pratt truss, as the structure appears to be quite creative and has an interesting pattern. However the design in this truss is marginally different to the Pratt truss. This bridge includes the side to side triangle schematic, but is more elongated and is not facing each other, unlike the back to back design of Pratt's. The materials of design three consist of quench tempered steel as a hollow tube. This decision was made in order to reduce the cost, as the bridge was originally over budget. The hollow tube made the bridge immensely unstable, however we were able to stay within the price range, hitting a final cost of $297, 001.95. The final score for design three was a twenty-eight out of forty, putting it in second place. The loss of points was due to the sheer instability of the bridge, while its most prominent category was aesthetics.

Design 4:

The goal for the fourth bridge was to focus more on simplicity rather than cost, durability, and other aspects the decision matrix graded on. This bridge uses the design of Howe's truss as a template, since the overall structure of the truss is quite simple, but also sturdy. The materials used for the truss were carbon steel bars. The usage of these materials dramatically increased the price of the bridge, due to the amount of members used and the overall length. The environment in which the bridge is constructed also plays a major factor in the cost. Design four was excavated at a height of twenty-four meters, which increases the length from end to end, thus increasing the price. The final cost of this design was $694,610.14, immensely above our price range. the fourth bridge is very unstable due to the height and material, resulting in the lowest score of the four bridges.

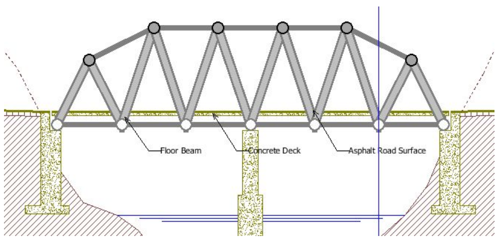
Modifications

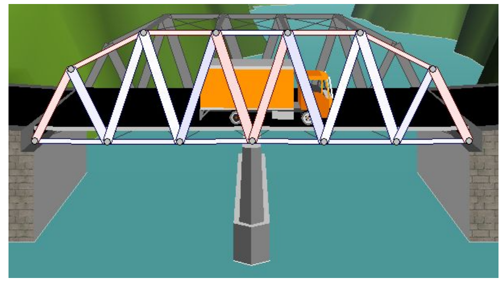
Modification Number	Image	Description
1	 	Our original design cost $294,298.83, leaving only $5,701.17 for modifications. We felt like that was not enough money, so we looked up ways to reduce the price. From our research, we discerned that for its extremely low cost, carbon steel is significantly more effective than quenched and tempered steel. So we changed our entire bridge to carbon steel and the price dropped to $260,531.17. However, the bridge was then significantly more unstable. To compensate for that, we made all of the previously hollow internal beams solid. The cost rose to $296,015.10, leaving us $3,984.90 to renovate with.
2	 	After messing around with our bridge for a bit, we realized that increasing the overall height significantly reduced both the tension and compression on all beams across our design. The only problem is that our total cost was over $300,000. Our design required $344,936.67 to construct.
3		To reduce the cost, we then made the internal members thicker and hollow. The price fell to $299,323.12 and somewhat alleviated the tension on the beams that were turning blue and being pulled apart. It did however, significantly increase the compression on the internal beams being squeezed. You can see to the left how the edge most bars turned significantly more red in comparison

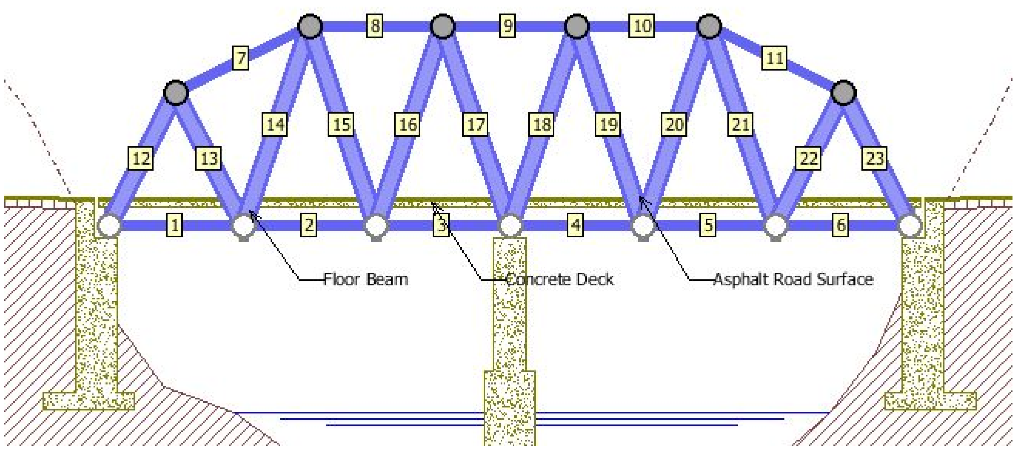
		to the previous iteration of our design.

Final Bridge Design

Final Design







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Member List/ Load Test Results

Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slenderness	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	272.52	4655.00	OK
2	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	327.33	4655.00	OK
3	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	164.17	4655.00	OK
4	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	176.11	4655.00	OK
5	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	324.08	4655.00	OK
6	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	255.81	4655.00	OK
7	CS	Bar	140	4.47	110.66	482.80	2315.16	OK	0.00	4655.00	OK
8	CS	Bar	140	4.00	98.97	332.45	2633.62	OK	0.00	4655.00	OK
9	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	9.64	4655.00	OK
10	CS	Bar	140	4.00	98.97	355.65	2633.62	OK	0.00	4655.00	OK
11	CS	Bar	140	4.47	110.66	452.90	2315.16	OK	0.00	4655.00	OK
12	CS	Tube	260	4.47	44.29	609.38	2606.47	OK	0.00	3050.45	OK
13	CS	Tube	260	4.47	44.29	0.00	2606.47	OK	356.21	3050.45	OK
14	CS	Tube	260	6.32	62.63	0.96	2350.84	OK	330.43	3050.45	OK
15	CS	Tube	260	6.32	62.63	120.84	2350.84	OK	135.45	3050.45	OK
16	CS	Tube	260	6.32	62.63	0.00	2350.84	OK	532.13	3050.45	OK
17	CS	Tube	260	6.32	62.63	549.62	2350.84	OK	0.00	3050.45	OK
18	CS	Tube	260	6.32	62.63	585.25	2350.84	OK	0.00	3050.45	OK
19	CS	Tube	260	6.32	62.63	0.00	2350.84	OK	567.76	3050.45	OK
20	CS	Tube	260	6.32	62.63	156.07	2350.84	OK	99.82	3050.45	OK
21	CS	Tube	260	6.32	62.63	0.00	2350.84	OK	351.58	3050.45	OK
22	CS	Tube	260	4.47	44.29	0.00	2606.47	OK	333.79	3050.45	OK
23	CS	Tube	260	4.47	44.29	572.01	2606.47	OK	0.00	3050.45	OK

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Member Details

Member List | Member Details

Current Material

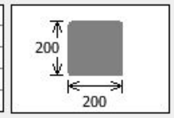
Material Properties:

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	200x200
Area	0.0400 sq. meters
Moment of Inertia	1.33E-04 meters^4
Member Length	--

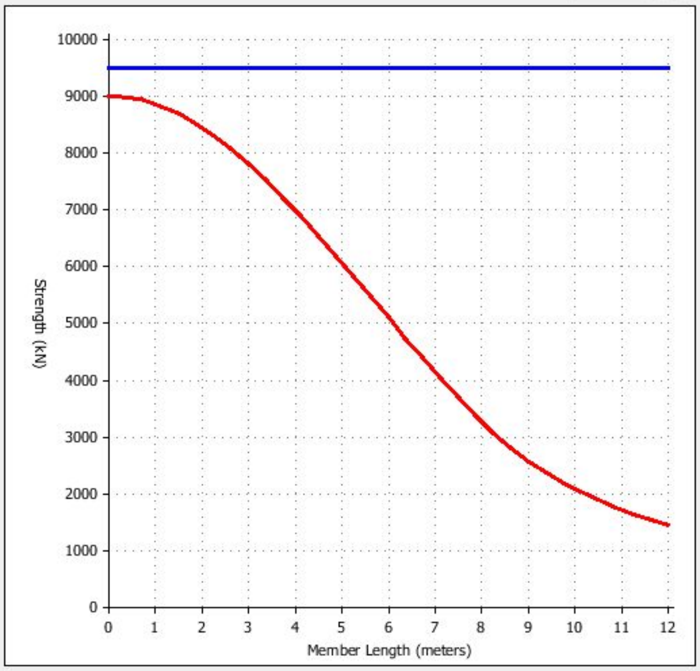
Section (mm):



Cost:

Unit Cost	$1350.20 per meter
Member Cost	--

Strength vs. Length: Graph all tabs Member:



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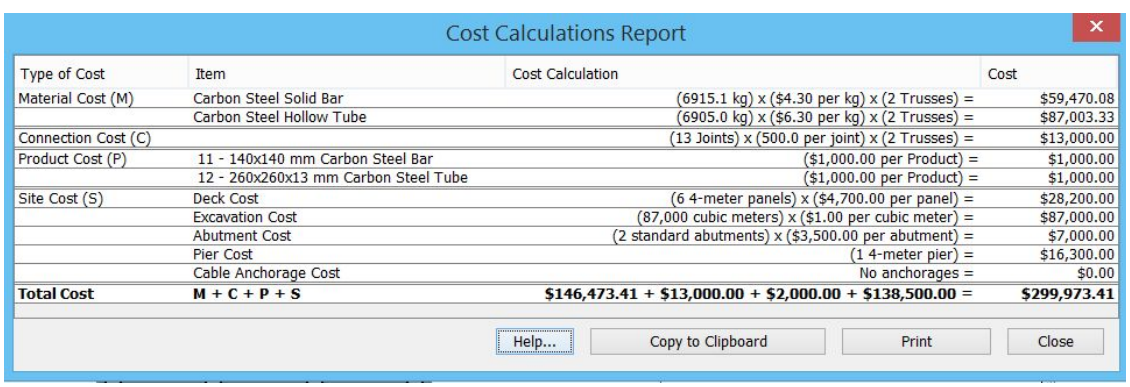
Cost Calculations



Cost Calculations Report

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(6915.1 kg) x ($4.30 per kg) x (2 Trusses) =	$59,470.08
	Carbon Steel Hollow Tube	(6905.0 kg) x ($6.30 per kg) x (2 Trusses) =	$87,003.33
Connection Cost (C)		(13 Joints) x (500.0 per joint) x (2 Trusses) =	$13,000.00
Product Cost (P)	11 - 140x140 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	12 - 260x260x13 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(6 4-meter panels) x ($4,700.00 per panel) =	$28,200.00
	Excavation Cost	(87,000 cubic meters) x ($1.00 per cubic meter) =	$87,000.00
	Abutment Cost	(2 standard abutments) x ($3,500.00 per abutment) =	$7,000.00
	Pier Cost	(1 4-meter pier) =	$16,300.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	**M + C + P + S**	**$146,473.41 + $13,000.00 + $2,000.00 + $138,500.00 =**	**$299,973.41**

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Final Design Justification

For our final design we modified our original Warren Truss until the amount of tension and pressure on each beam was as minimal as possible. To reiterate, we chose a Warren truss to be our basis because it is one of the most structurally simple designs. It requires very few beams, which is beneficial in situations like this where there is a price constraint. In addition, although Warren trusses are not the most ideal for concentrated loads, their ability to spread the weight evenly among members compensates for that fact. So no single beam should ever be under extensive tension or compression as long as the load is within a reasonable range and is applied vertically. From trial and error as well as prior research, we found that thicker, hollow beams are more effective under high tension and that solid beams deform less under compression. We used these findings in our truss to minimize the movement in high tension or high compression sections. In addition, to reduce the number of beams needed, we excavated down to four feet. We also added 1 pier as a central support. The pier did a great deal to stabilize our bridge. Adding it significantly reduced the amount of visible blue and red in our simulation (indicative of tension and compression respectively) and limited swaying. Our entire bridge was made out of carbon steel because we realized through experimentation that quenched and tempered steel is not significantly stronger. Its price, however, is significantly greater. For that extra money spent, one could add a couple more beams using carbon steel in order to solidify the strength of the bridge as a whole.

Works Cited

University of Mauritius (n.d.). Discuss the Properties of Plain Carbon Steel. Retrieved from http://www.uom.ac.mu/faculties/foe/mped/Students_Corner/notes/EnggMaterials/Steelbklet.pdf

Shape Cut (2015, June 05). What is quenched and tempered steel? Retrieved March 21, 2018, from https://www.shapecut.com.au/blog/what-is-quenched-and-tempered-steel/

Carigliano, S. (2015, March 30). Types of Truss Structures. Retrieved March 21, 2018, from https://skyciv.com/education/types-of-trusses/

Loudoun County Public Schools (n.d.). When to Use a Hollow Tube or Bar. Retrieved March 21, 2018, from https://www.lcps.org/cms/lib/VA01000195/Centricity/Domain/3310/When to use a HOLLOW TUBE or BAR.pdf