P233: Bridge Design Project

Bridge to Success

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Date: 03/19/21 - 04/14/21

Period: 3

Table of Contents

Design Brief

Client:	American Bridge Company
Designer:	Kiki Feng, Sruti Mani, Anish Patil, and Gracy Sutaria
Problem Statement:	Our client has given us the task of constructing a cost efficient bridge that crosses Trinity River.
Design Statement:	Our group has designed a bridge that can support a truck for the cheapest price possible. With the use of different metal parts, in addition to hollow and solid members, our bridge is safe, sturdy, and cost efficient.
Constraints:	- Must be 12-24 meters above the water, meeting all WPB Designer Constraints - 4 in-class work days minus 1 period for 2.3 Quiz - Use a decision matrix to prove the validity of your design selection - Documentation deliverables will be due on April 2 at 11:59 pm. - The design will be pitched to the class starting on April 13.
Individual Deliverables:	- Brainstormed ideas - Investigation table
Team Deliverables:	- Documentation - Final Design - Gantt Chart - Slide Deck - Presentation

Research Summary

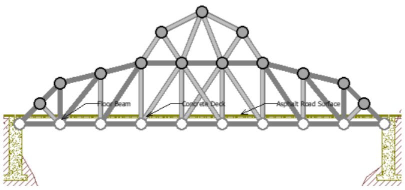
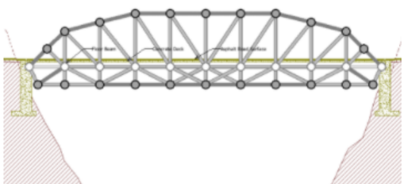
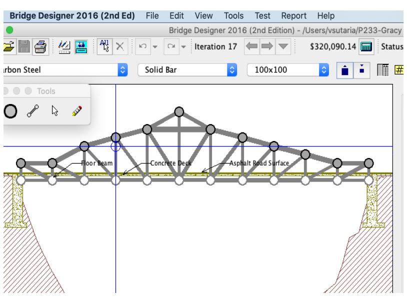
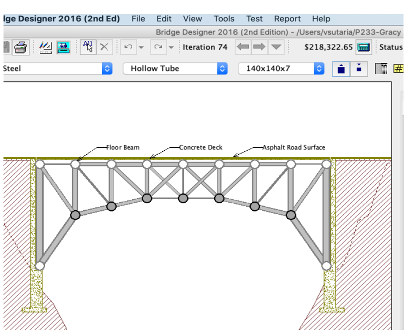
After several tests in the bridge design software, our team was able to conclude that lowering the deck elevation and having fewer members cost less than having a higher elevation with more supports. The hollow tubes were able to compress much easier than the solid member. With this information, using the hollow tubes around the outer layers of the bridge along with central supports made the bridge more cost effective. The bottom parts of the bridge, in addition to the parts that could have snapped during the test, would be more efficient as solid members. Solid members are more beneficial when used in parts that break or cave in. While building the bridge, replacing broken hollow pieces with solid members increased the price, but allowed the bridge to stand without adding additional supports.

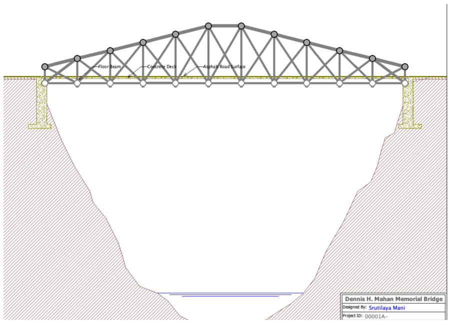
Adding more members allowed the bridge to become more sturdy, but added weight and cost. The weight, specifically, could end up affecting if the bridge works or not. The solution to this, once again, could be to replace hollow tubes, increase joints, or replace thin hollow members with thicker ones.

With additional cross sections embedded into the truss, the bridge is able to become more durable. The additional members add to the total cost and weight, while also helping spread the impact of the added forces.

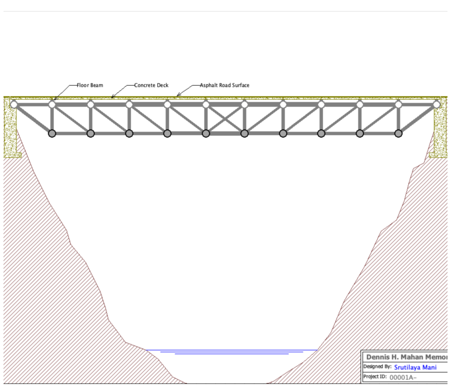
There are six main types of bridges that are used. The first kind, also the most common, are beam bridges. These are cost effective and use bending to carry vertical loads. When bent, the bridge undergoes horizontal compression, however, this is then balanced out by the bridge’s horizontal tensions. The next kind are trusses. Truss bridges compress on the upper members while undergoing tensions throughout the bottom. There are also arch bridges where members are on the bottom of the bridge rather than the top. This type of bridge is able to prevent horizontal and vertical movement, keeping the bridge in static equilibrium. Next are suspension bridges. The loads are able to be transferred between the towers, then, compressing vertically to the ground. Furthermore, there are the cantilevers. They are made of three spans where two are anchored down while the middle one rests between the two. The central part has opposite forces being acted on it, upper being compression and bottom being tension. This inner part is able to carry the forces of compression and tension to the outer parts, balancing the forces. The final type is the cable-stray. Similar to the suspension bridges, they feature two large towers with cables running down. The difference here is that the towers transfer forces to the cables that input horizontal compression onto the bridge (Shirley-Smith, 2020, par. 5-11).

<u>Brainstormed Ideas</u>

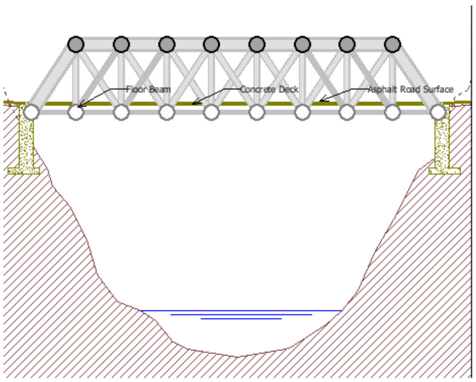
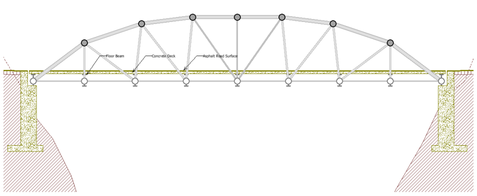
Bridge Images	Bridge Description
	Name: Anish Patil Date: 3/30/21 Design: #1 Description: 16m deck, no abutments, no cable anchorages, medium strength, standard loading, carbon steel, cost: $296,026.31.
	Name: Anish Patil Date: 3/30/21 Design: #2 Description: 20m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, quenched and tempered steel, cost: $290,630.80.
	Name: Gracy Sutaria Date: 3/29/21 Design: #1 Description: 24m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, 46 members, $320,090.14.
	Name: Gracy Sutaria Date: 3/29/21 Design: #1 Description: 24m deck, 12m arch abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, 35 members, $218,322.65.



Name: Sruti Mani
Date: 3/30/21
Design: #1
Description: 24m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, cost: $342,323.92. My first design is a bridge that has a 24 meter elevation deck and made of carbon steel. Certain members are thicker than others to support the weight of a truck. All of the members on top are also thicker than the ones on the bottom to better support and prevent the bridge from breaking. The trusses are supported as there is a cross in between each of the four joints. This bridge passed the truss and load test as it successfully carried the truck across the bridge without breaking. The cost of the bridge is $342,323.92.



Name: Sruti Mani
Date: 4/05/21
Design: #2
Description: 24m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, cost: $359,350.52. My second bridge design also has a 24 meter elevation and is also made of carbon steel as that is the strongest material available for a bridge. I ensured that the bridge would be supportive throughout as I increased the member size as it neared the center of the bridge as I found that this provided optimal support. The middle of the bridge has two supporting middle members to provide balance to the bridge and carry the load. This bridge passed the truss and load test as it successfully carried the truck across the bridge without breaking. The cost of the bridge is $359,350.52.

	Name: Kiki Feng Date: 3/30/21 Design: #1 Description: 16m deck, no abuntments, no piers, no cable anchorages, medium strength, standard loading, quenched and tempered steel, Cost:$334,966.68. This is my first bridge that I designed. Here, I focused on the stability and safety of the bridge. I lowered the deck a little since I was able to find out that the overall bridge is a lot cheaper and used a mix of solid and hollow quenched tubes. The bottom and a few of the supports in between are solid while the border is hollow. The cross sections allow extra support, allowing the truck to cross multiple times. In total, the bridge costs $334,966.68.
	Name: Kiki Feng Date: 4/11/21 Design: #2 Description: 12m deck, no abuntments, no piers, no cable anchorages, medium strength, standard loading, quenched and tempered steel, cost: $189,351.86. This is my second, more affordable bridge design. It is made full of quenched and tempered steel, both solid and hollow. The bottom supports along with the middle ones are made of solid members while the outer and rest of the center supports are made of hollow tubes. I lowered the deck to the lowest height allowed in the constraints, decreasing the price. Similarly to the first design, there are cross sections connecting the joints together with members allowing more support. In total the bridge cost $189,351.86.

Decision Matrix

	Design	Design Features
Kiki Feng	A	16m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, quenched and tempered steel, cost: $334,966.68
Kiki Feng	B	12m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, quenched and tempered steel, cost: $189,351.86
Sruti Mani	C	24m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, cost: $342,323.92
Sruti Mani	D	24m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, cost: $359,350.52
Anish Patil	E	16m deck, no abutments, no cable anchorages, medium strength, standard loading, carbon steel, cost: $296,026.31
Anish Patil	F	20m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, quenched and tempered steel, cost: $290,630.80
Gracy Sutaria	G	24m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, $320,090.14
Gracy Sutaria	H	24m deck, 12m arch abutments, no piers, no cable anchorages, medium strength, standard loading, carbon steel, $218,322.65

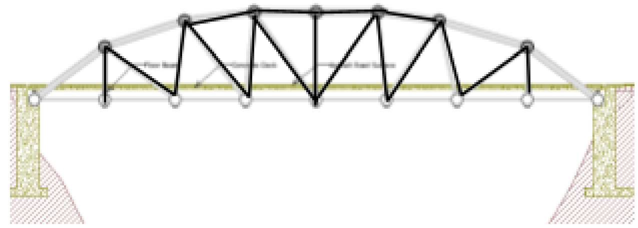
	Cost	Static Equilibrium	Safety	Sturdy	Aesthetic	Total
A	1	3	4	3	3	14
B	5	4	4	5	4	22
C	1	5	4	3	5	18
D	1	5	3	3	3	15
E	2	3	4	3	3	15
F	2	3	4	4	5	18
G	2	5	4	2	2	15

H	3	5	3	2	4	17

Each of the designs were rated from 1 to 5 in the categories of the cost, static equilibrium, safety, sturdiness, and aesthetic. If the design was the cheapest of all the designs then it would be rated a 5, while the most expensive would be rated as 1 in the category of cost. The category of static equilibrium sees if the design has either tension, compression, or is completely in static equilibrium. If it is in static equilibrium then the designs would be rated as a 5, while lots of tension or compression, would be rated as 1. The next category was safety, looking to see if the bridge isn't wobbly or moving around much. The category of sturdiness looks to see if the bridge is even functional, that a truck can go on without breaking. So the design is rated 1 if it isn't functional at all, or 5 if it is functional but also extremely sturdy. The last category that the bridges were rated on was their aesthetic, or how good they look. The bridge is a 1 if the members and joints aren't symmetrical and clean, or 5 if the bridge is symmetrical and additionally looks pleasing to the eyes. The evaluation of the bridge designs revealed that Kiki's second design, B is the best design because it received the most points. In the category of cost, design B received a 5 out of 5 because it was the cheapest bridge compared to the other bridges. For static equilibrium, design B received a 4 out of 5 because it wasn't entirely in static equilibrium as it still had tension and compression forces. Design B also received a 4 out of 5 because when the truck went on the bridge, the bridge did dip down a bit. However, the bridge scored 5 out of 5 in sturdiness because the bridge was fully functional since it didn't break from the weight of the truck. Lastly, it scored 4 out of 5 on aesthetics because everything was symmetrical, but the members weren't exactly 90 degrees. This gives design B a score of 22 points and therefore it is the best design proposed to our client, the American Bridge Company. Especially because the main thing the American Bridge Company is looking for is a cheap bridge that is functional.

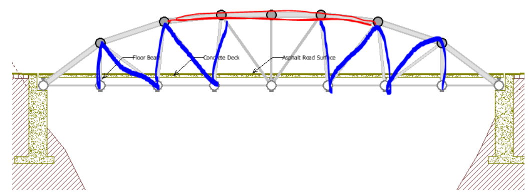
Design Modification Log

Gracy - 4/11/21:



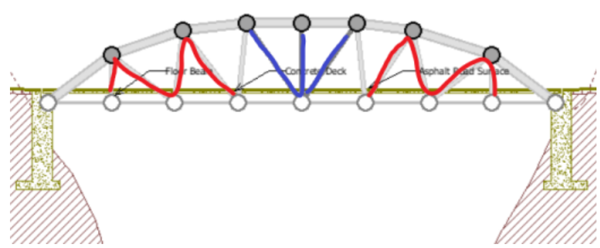
The first modification I made to Kiki's second design was decreasing the size of members 19 and 21 from 90mm to 75mm and the second modification I made was that I decreased the size of member 20 from 90mm to 70mm. These members are shown in the picture to the right. By decreasing the size of these members, the cost decreased from $189,351.86 to $184,998.76. I additionally decreased the size of members 9-18 from 110mm to 100mm and this decreased the cost even more to $183,879.40. Then I decreased members 3-6 from 200mm to 190mm. The final cost was $182,970.52. I continued to try other things but that just made the bridge more expensive and less sturdy, the opposite of the only two requirements.

Kiki - 4/11/21



I was able to modify the inner supports, decreasing the cost by a bit while still keeping the bridge stable enough for the truck to pass. Members 9-18 changed from being 110mm in size to 100mm. In addition to this, the price went down about $1,000. I was also able to change most of the middle members on the top of the truss (members 22-25) to 190*190*10 rather than 200. Once again this was able to decrease the cost by $1,000. In total, the cost was able to go from $189,351.86 to $187,324.34.

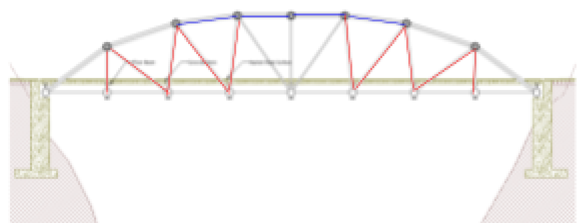
Anish - 4/11/21:



My initial modification to Kiki's bridge design was replacing members 9 through 12, as well as members 15 through 18 by making them thinner. I changed them so that instead of 100mm*100mm*5m, they were 90mm*90mm*5m. This change helped in reducing the amount of material needed, and in turn reduced the total cost of the bridge. The second modification I made was replacing members 19 through 21 with carbon steel material, as opposed to quenched and tempered steel. Using carbon steel reduced the cost of the three members, which further reduced the total cost of the design. By applying these modifications, I was able to decrease the cost from $189,351.86 to $183,216.54. (Members 9-12 and 15-18 outlined in red, members 19-21 outlined in blue)

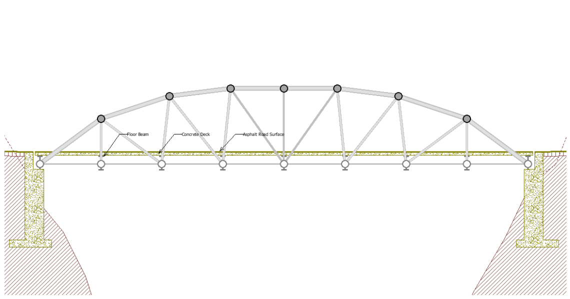
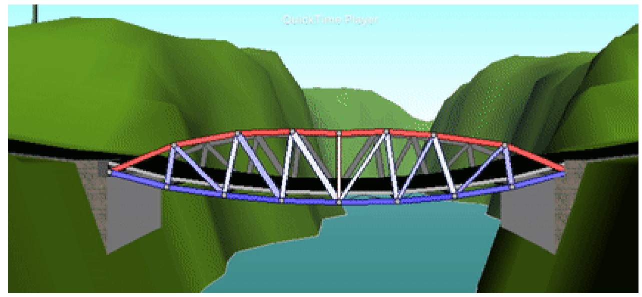
Sruti - 4/12/21:

The first modification I made to Kiki's second design is that I decreased the size of members 9-18 (marked in red) from 110mm to 100mm and this decreased the cost from $189,351.86 to $188,232.50. The second modification I made to Kiki's second design is that I decreased members 3-6 (marked in blue) from 200mm to 190mm which reduced the cost from $188,232.50 to $187,323.62. The final cost was $187,323.62. After making these two modifications, the bridge still passed the truss and load test, so these modifications were effective in reducing the cost of the bridge while maintaining the efficiency.



Final Design Description

[Slide Deck](#)

This bridge has a 12m deck, no abutments, no piers, no cable anchorages, medium strength, standard loading, and is made entirely of quenched and tempered steel. The cost of the bridge is $182,970.52 and uses mostly hollow tubes rather than solid bars. The load test shows that the bridge is fairly stable and can withstand the weight of the truck passing through.

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	QTS	Hollow Tube	200x200x10	5.00	1927.02	2173.07	OK	0.00	3501.70	OK
2	QTS	Hollow Tube	200x200x10	4.74	1925.93	2266.97	OK	0.00	3501.70	OK
3	QTS	Hollow Tube	190x190x9	4.03	2016.35	2100.56	OK	0.00	3002.25	OK
4	QTS	Hollow Tube	190x190x9	3.50	2100.79	2263.27	OK	0.00	3002.25	OK
5	QTS	Hollow Tube	190x190x9	3.50	2100.79	2263.27	OK	0.00	3002.25	OK
6	QTS	Hollow Tube	190x190x9	3.54	2003.81	2252.74	OK	0.00	3002.25	OK
7	QTS	Hollo	200x2	5.22	1916.9	2091.8	OK	0.00	3501.7	OK

		w Tube	00010		4	9			0	
8	QTS	Hollow Tube	200x200010	5.00	1860.54	2173.07	OK	0.00	3501.70	OK
9	QTS	Hollow Tube	100x100x5	3.00	0.00	451.00	OK	618.78	875.43	OK
10	QTS	Hollow Tube	100x100x5	5.00	0.00	179.21	OK	465.96	875.43	OK
11	QTS	Hollow Tube	100x100x5	4.53	56.59	218.55	OK	341.95	875.43	OK
12	QTS	Hollow Tube	100x100x5	5.70	0.00	137.85	OK	469.56	875.43	OK
13	QTS	Hollow Tube	100x100x5	5.02	127.30	177.44	OK	264.53	875.43	OK
14	QTS	Hollow Tube	100x100x5	5.02	67.44	177.44	OK	361.12	875.43	OK
15	QTS	Hollow Tube	100x100x5	5.41	69.15	153.17	OK	370.38	875.43	OK
16	QTS	Hollow Tube	100x100x5	4.61	81.57	210.84	OK	367.44	875.43	OK
17	QTS	Hollow Tube	100x100x5	3.00	0.00	451.00	OK	618.78	875.43	OK
18	QTS	Hollow Tube	100x100x5	5.00	0.00	179.21	OK	509.74	875.43	OK
1	QTS	Solid	75x75	6.10	49.70	110.66	OK	429.73	2591.7	OK

9		Bar							2	
20	QTS	Solid Bar	70x70	5.00	3.64	125.12	OK	0.00	2257.67	OK
21	QTS	Solid Bar	75x75	6.10	98.40	110.66	OK	381.04	2591.72	OK
22	QTS	Solid Bar	65x65	4.00	0.00	145.35	OK	1541.62	1946.67	OK
23	QTS	Solid Bar	65x65	4.00	0.00	145.35	OK	1541.62	1946.67	OK
24	QTS	Solid Bar	65x65	4.00	0.00	145.35	OK	1789.34	1947.74	OK
25	QTS	Solid Bar	65x65	4.00	0.00	145.35	OK	1810.12	1947.74	OK
26	QTS	Solid Bar	65x65	4.00	0.00	145.35	OK	1488.43	1947.74	OK
27	QTS	Solid Bar	65x65	4.00	0.00	145.35	OK	1488.43	1947.74	OK
28	QTS	Solid Bar	70x70	4.00	0.00	195.50	OK	1975.88	2257.67	OK
29	QTS	Solid Bar	70x70	4.00	0.00	195.50	OK	1947.74	2257.67	OK

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Quenched & Tempered Steel Bar	(1835.0 kg) x ($6.00 per kg) x (2 Trusses) =	$22,020.37
	Quenched & Tempered Steel Hollow Tube	(2626.6 kg) x ($7.70 per kg) x (2 Trusses) =	$40,450.15
Connection Cost (C)		(16 Joints) x (400.0 per joint) x (2 Trusses) =	$12,800.00
Product Cost (P)	6 - 65x65 mm	($1,000.00 per	$1,000.00

	Quenched & Tempered Steel Bar	Product) =	
Site Cost (S)	3 - 70x70 mm Quenched & Tempered Steel Bar	($1,000.00 per Product) =	$1,000.00
Total Cost	2 - 75x75 mm Quenched & Tempered Steel Bar	($1,000.00 per Product) =	$1,000.00
	10 - 100x100x5 mm Quenched & Tempered Steel Tube	($1,000.00 per Product) =	$1,000.00
	4 - 190x190x9 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
Site Cost (S)	Deck Cost	(8 4-meter panels) x ($4,700.00 per panel) =	$37,600.00
	Excavation Cost	(54,100 cubic meters) x ($1.00 per cubic meter) =	$54,100.00
	Abutment Cost	(2 standard abutments) x ($5,000.00 per abutment) =	$10,000.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	M + C + P + S	$62,470.52 + $12,800.00 + $6,000.00 + $101,700.00 =	$182,970.52

Final Design Evaluation

Our design was able to perform very well for its price. Even with the minimal and thin members that we used to construct the bridge, it is still able to hold itself up when under the pressure of a vehicle. This design mostly consisted of hollow parts since they were the cheapest and able to compress when under pressure. The bottom and several middle supports were replaced with solid members in order for the bridge to not collapse or cave in.

The bridge is able to be used in the real world as a cheap alternative to modern day bridges. This can be used to cross trenches, rivers, or any location that may need an elevated bridge around twelve meters. In comparison to a simple bridge which averages about $250,000, ours is much more affordable and a better option. If our bridge were to be implemented and used throughout the world, not only will the cost of building decrease, but the amount of waste will decrease as well. This is due to the fact the quenched and tempered steel is recyclable. Rather than using materials that are unrecyclable like concrete and asphalt that are common in modern bridges, creating one that is recyclable can help our planet (Perdomo, L).

Overall, our final design ended up being both economically viable and sturdy. This could help communities all over the world cut costs while being able to build a reliable bridge for people to use. The type of force exerted on each member helped us decide which type of member to use. For example, if a certain member was under a heavy compression force, we switched that member to a hollow bar. Also, if a certain member was under heavy tension forces, we used solid bars for those members. This is because hollow bars are more effective at combating compression, and solid bars are more efficient at dealing with tension.

In order to optimize the cost of our design, we ran several tests by making each member thinner in size in order to save material, which would decrease the total cost. We found that the thinner the material, the less force each member could withstand, so we had to run several load tests using different member sizes, until we developed a solution that was reliably sturdy, and at the same time using members as thin as possible in order to save costs.

One constraint that stopped us from saving even more money was the deck constraint. If we were able to lower the bridge deck to 0m, the money saved by using less material would have outweighed the cost of digging the lower deck, which would have brought the cost down to $178k. With more time to work on the design and modify each member carefully, we could have brought the total cost even below that.

References

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Perdomo, L. (2018, September 14). Steel Environmental Benefits Can Save Communities Money. Retrieved from https://usbridge.com/environmental-benefits-steel-bridges/