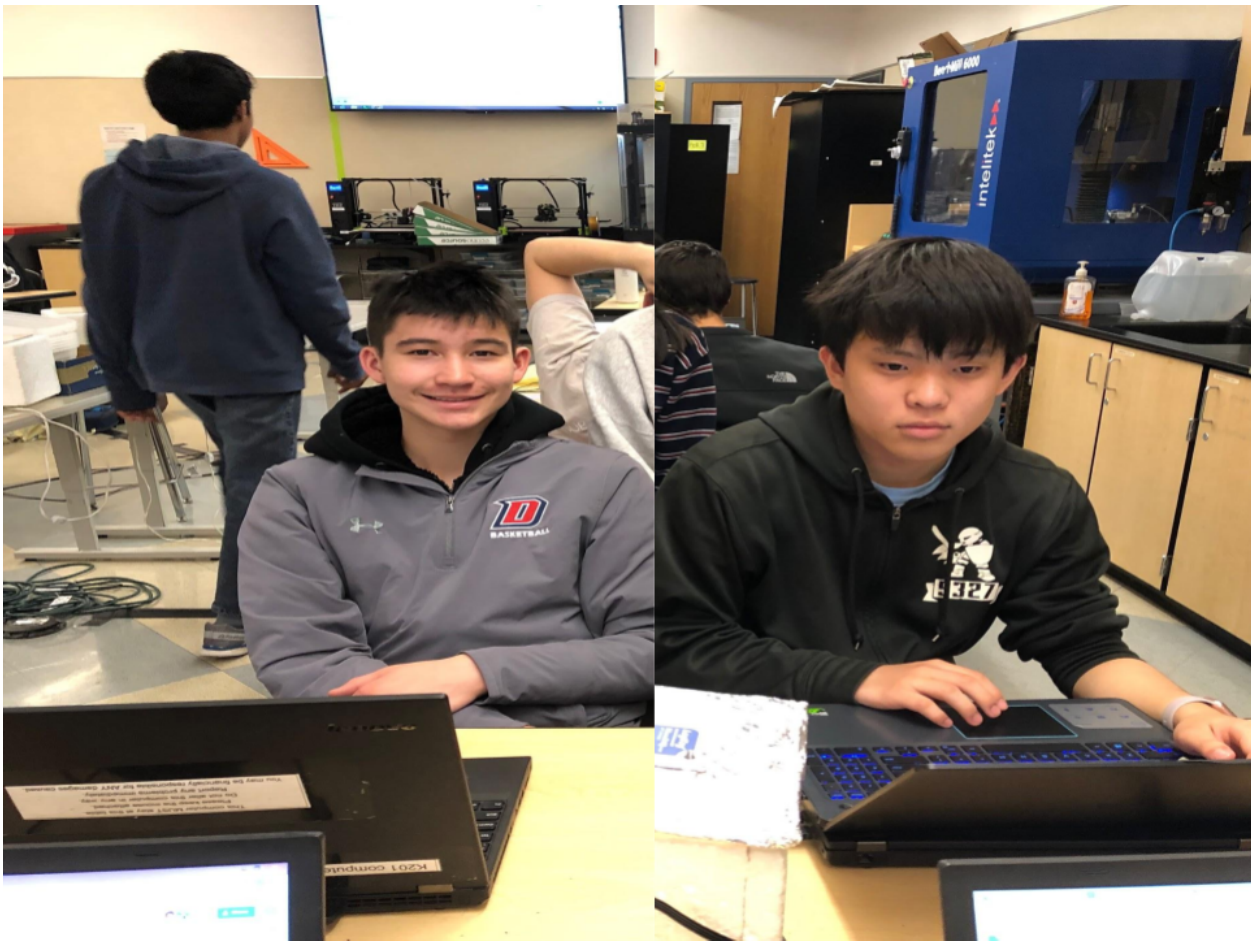
P2_3_2 West Point Bridge Design



Team KJ
Koji Hirai and TJ Meagher
Chou POE 6
March 7, 2019 - March 18, 2019

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Design Brief

Client: American Bridge Company

Problem Statement: People need to cross the Trinity River but are not able to. Trucks need to be able to cross the river.

Design Statement: We will create a cost-effective, stable bridge that spans the length over the Trinity River to allow people and trucks to cross.

Constraints:

- Designed using West Point Bridge Design 2016 Software
- Cost must be under $300,000
- Bridge deck elevation must be between 12 to 24 meters above water level
- Up to 50 joints and no more than 120 members
- Members will be made of carbon steel, quenched and tempered steel, or high-strength low alloy steel
- Allow for two lanes with standard 225kN Permit Loading
- Comply with 1994 LRFD AASHTO Bridge Design Specifications

Team Deliverables:

- Design Brief: Include all parts of a design brief
- Research Summary: Research materials and truss design,
- Brainstorming Sketches & Decision Matrix: Team's four brainstorming sketches. Decision matrix used to determine the design with explanations
- Modification Sketches: Record major modifications and explanation of the modification
- Final Bridge Design: Final design with load test results report, member property reports
- Final Design Justification: Justification for material selection and truss configuration.
- References: Use APA format to list all sources

Individual Deliverables:

- Design Brief Notes.
- Investigation Tables
- Project Log with specific details about personal contributions
- Conclusion Question Conclusion question answered thoroughly and correctly

Research Summary

Materials

Carbon Steel: (www.metalsupermarkets.com)

- Combination of steel with 2.1% carbon content by weight
- Stronger as carbon percentage increases
- Steel can become harder and stronger with heat

  Low Carbon Steel
  - Typically contain 0.04% to 0.30% carbon
  - Many Shapes
  - Element contents are changed based on desired properties

  Medium Carbon Steel
  - Typically carbon range of 0.31% to 0.60%
  - Difficult to form, weld and cut

  High Carbon Steel
  - Carbon range between 0.61% and 1.50%.
  - Very difficult to cut, bent and weld
  - Hard and brittle

Quenched and Tempered Steel: (www.shapecut.com.au)

- Quenching and tempering strengthen steel and other alloys
- More weldable and ductile than carbon steel
- Less brittle and more ductile without sacrificing hardness
- Greater resistance to wear and abrasion

High-Strength Low-Alloy Steel: (www.metalsupermarkets.com)

- Carbon Steel with small amounts of alloying elements added to the chemical composition
- Increases the strength and hardness
- Increased corrosion resistance like iron oxide

Types of Bridges

Arch Bridge: (www.naturebridges.com)

- Arch found at bottom of the bridge
- Supported by compression forces
- Some tension under the arch

Beam Bridge: (www.naturebridges.com)

- Short length
- Cost effective to build
- Support is located toward the edges

Cantilever Bridge: (howbridgeswork.weebly.com)

- Similar Beam Bridge
- Uses horizontal structures that are supported only on one end.

Suspension Bridge: (www.naturebridges.com)

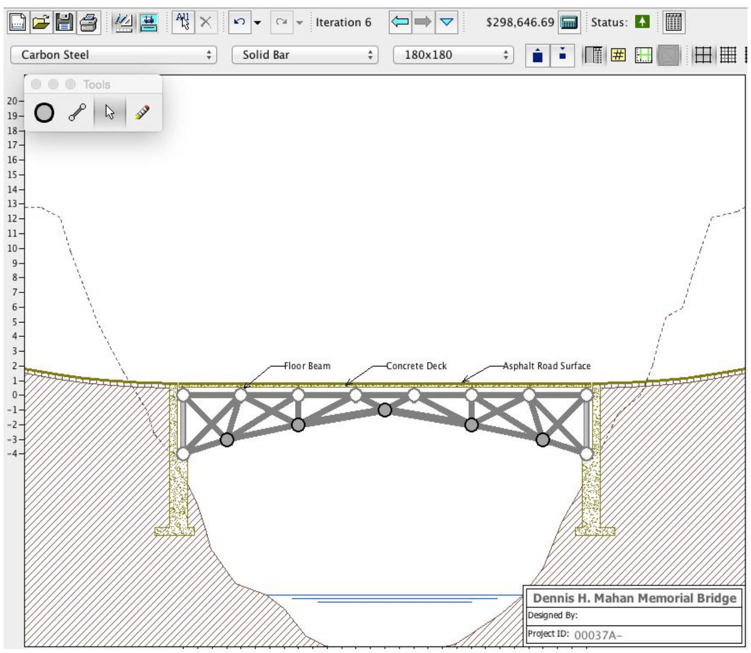
- Suspension cables connect between towers
- Can be made with longer spans
- Less material -> less expensive

Cable-Stayed Bridge: (www.naturebridges.com)

- Kind of a suspension bridge but shorter distance
- Cables connect to columns in two ways

Brainstorming Sketches

TJ’s First Design

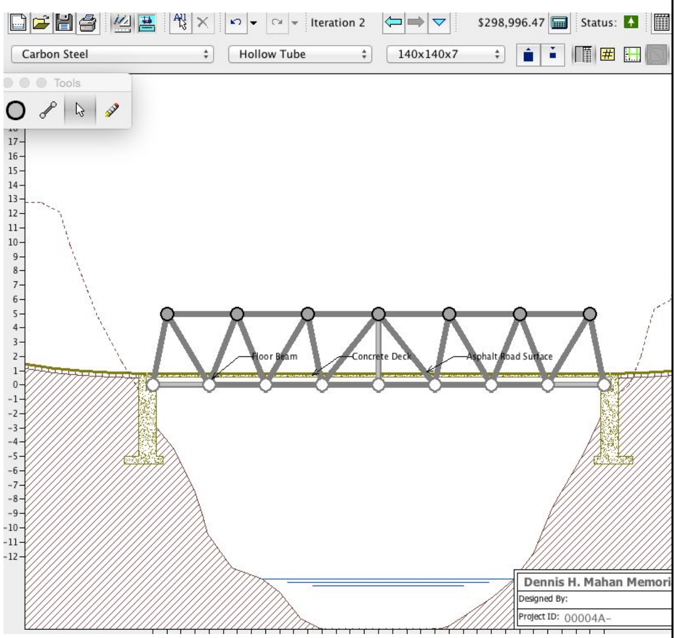


Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Tube	140	4.00	73.57	0.63	0.01
2	CS	Bar	140	4.00	98.97	0.03	0.03
3	CS	Bar	140	4.00	98.97	0.28	0.00
4	CS	Bar	140	4.00	98.97	0.62	0.00
5	CS	Bar	140	4.00	98.97	0.63	0.00
6	CS	Bar	140	4.00	98.97	0.30	0.00
7	CS	Bar	140	4.00	98.97	0.02	0.02
8	CS	Tube	140	4.00	73.57	0.40	0.00
9	CS	Bar	140	2.24	55.33	0.11	0.05
10	CS	Bar	140	2.24	55.33	0.13	0.03
11	CS	Bar	140	2.00	49.49	0.02	0.06
12	CS	Bar	140	4.47	110.66	0.46	0.00
13	CS	Bar	140	4.47	110.66	0.41	0.00
14	CS	Bar	140	2.00	49.49	0.03	0.05
15	CS	Bar	140	4.47	110.66	0.03	0.05
16	CS	Bar	140	5.66	139.97	0.60	0.00
17	CS	Bar	140	3.16	78.25	0.00	0.06
18	CS	Bar	140	4.47	110.66	0.02	0.06
19	CS	Bar	140	4.24	104.98	0.08	0.02
20	CS	Bar	140	5.66	139.97	0.59	0.00
21	CS	Bar	140	3.16	78.25	0.61	0.00
22	CS	Bar	140	3.16	78.25	0.00	0.05
23	CS	Bar	140	4.24	104.98	0.06	0.01
24	CS	Bar	140	3.16	78.25	0.61	0.00
25	CS	Bar	140	5.83	144.28	0.72	0.00
26	CS	Bar	140	5.83	144.28	0.68	0.00
27	CS	Bar	140	4.00	98.97	0.69	0.00
28	CS	Bar	140	5.10	126.17	0.69	0.00
29	CS	Bar	180	6.08	117.06	0.20	0.00
30	CS	Bar	180	6.08	117.06	0.20	0.00
31	CS	Bar	140	5.10	126.17	0.69	0.00

This bridge design has many different features that make it unique. This bridge design has a deck elevation of 12 meters over the water and has a support configuration of 4 meter high arch abutments, no pier, and no cable anchorages. This bridge design is consisted entirely of carbon steel members with the size of the members being 140mm or 180mm. The carbon steel members are cheap and are able to hold enough weight to make the bridge stable. Also, all of the members are of a solid bar except for two of the members. The solid bar allows for greater strength for the bridge. Making the two members hollow tubes decreases the price, but does not affect the overall stability of the bridge dramatically. The members are located below the road of the bridge because with the arch abutments, the members create support from underneath to hold the weight of multiple trucks. The cost of this bridge is roughly $298,000 which is $2,000 below the budget. The cost makes it difficult to make necessary modifications to improve the design without going over budget.

TJ’s Second Design

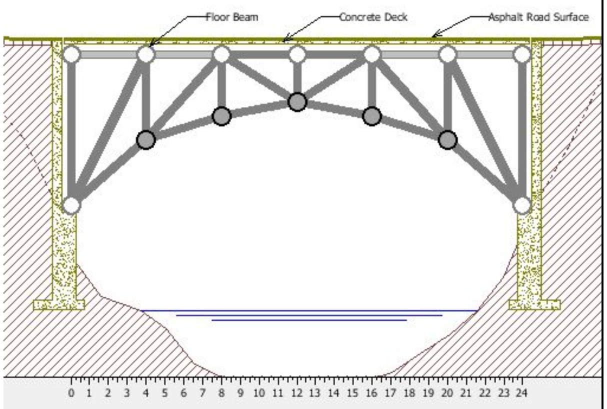


Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Streng
1	CS	Tube	140	4.00	73.57	0.00	0.29
2	CS	Bar	140	4.00	98.97	0.00	0.29
3	CS	Bar	140	4.00	98.97	0.00	0.43
4	CS	Bar	140	4.00	98.97	0.00	0.49
5	CS	Bar	140	4.00	98.97	0.00	0.49
6	CS	Bar	140	4.00	98.97	0.00	0.43
7	CS	Bar	140	4.00	98.97	0.00	0.28
8	CS	Tube	140	4.00	73.57	0.00	0.28
9	CS	Bar	140	5.10	126.17	0.67	0.00
10	CS	Bar	140	5.00	123.72	0.51	0.00
11	CS	Bar	140	5.00	123.72	0.87	0.00
12	CS	Bar	150	5.00	115.47	0.85	0.00
13	CS	Bar	150	5.00	115.47	0.84	0.00
14	CS	Bar	140	5.00	123.72	0.85	0.00
15	CS	Bar	140	5.00	123.72	0.49	0.00
16	CS	Bar	140	5.10	126.17	0.65	0.00
17	CS	Bar	140	5.83	144.28	0.00	0.30
18	CS	Bar	140	5.39	133.25	0.58	0.00
19	CS	Bar	140	5.39	133.25	0.00	0.21
20	CS	Bar	140	5.10	126.17	0.00	0.13
21	CS	Bar	140	5.83	144.28	0.50	0.00
22	CS	Bar	140	6.40	158.44	0.34	0.02
23	CS	Bar	140	6.40	158.44	0.38	0.01
24	CS	Bar	140	5.10	126.17	0.00	0.14
25	CS	Bar	140	5.83	144.28	0.53	0.00
26	CS	Bar	140	5.39	133.25	0.00	0.22
27	CS	Bar	140	5.39	133.25	0.60	0.00
28	CS	Bar	140	5.83	144.28	0.00	0.31
29	CS	Tube	140	5.00	91.96	0.00	0.71

This bridge design also has different features that make it unique. This bridge design also has a deck elevation of 12 meters over the water and has a support configuration of standard abutments, no pier, and no cable anchorages. This bridge is consisted of carbon steel members for its durability and strength for a reasonable price. The tubes of the members are 140 to 150mm in size and are all solid bars except for three hollow tube members. 140mm tubes are used because they are inexpensive but still provide the stability and strength to hold the weight of objects going over the bridge. Solid bars are used as they provide enough strength to make our bridge safe to drive across. The hollow tubes are inserted where they are because these members experienced the least amount of force, and we needed to lower the price. The members are located above the road as there aren’t a pier or arch abutments to support members from beneath the road. Therefore, we added the members above and attached them to joints diagonally to help keep the bridge stable. The estimated cost of this bridge was around $299,000. This bridge is barely below the budget, but does not allow us to make adjustments to the bridge without going over the budget.

Koji’s First Design



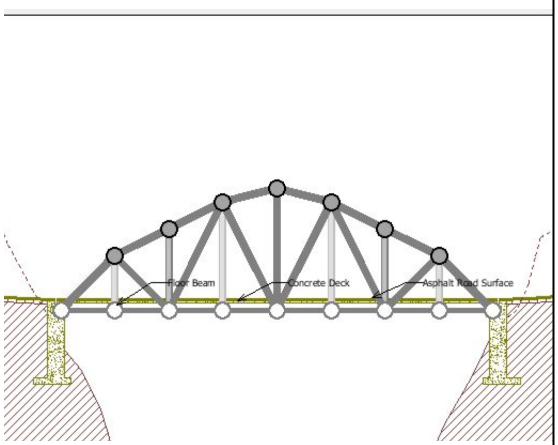
Member List | Member Details

Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Streng
1	CS	Bar	150	5.32	122.75	0.44	0.00
2	CS	Bar	140	4.19	103.69	0.18	0.00
3	CS	Bar	140	4.07	100.70	0.17	0.00
4	CS	Bar	150	5.32	122.75	0.45	0.00
5	CS	Bar	140	3.25	80.42	0.01	0.00
6	CS	Bar	140	2.50	61.86	0.17	0.00
7	CS	Bar	140	3.25	80.42	0.01	0.00
8	CS	Tube	150	4.00	68.44	0.00	0.00
9	CS	Tube	150	4.00	68.44	0.46	0.00
10	CS	Bar	140	4.00	98.97	0.37	0.00
11	CS	Bar	140	4.00	98.97	0.37	0.00
12	CS	Tube	150	4.00	68.44	0.43	0.00
13	CS	Tube	150	4.00	68.44	0.00	0.00
14	CS	Bar	150	8.00	184.75	0.68	0.00
15	CS	Bar	150	8.00	184.75	0.27	0.00
16	CS	Bar	170	8.94	182.26	0.42	0.00
17	CS	Bar	170	8.94	182.26	0.40	0.00
18	CS	Bar	150	6.02	139.04	0.48	0.00
19	CS	Bar	160	6.02	130.35	0.34	0.00
20	CS	Bar	140	4.50	111.35	0.06	0.03
21	CS	Bar	140	4.50	111.35	0.06	0.03
22	CS	Bar	140	4.72	116.72	0.01	0.12
23	CS	Bar	140	4.72	116.72	0.04	0.10
24	CS	Bar	140	4.07	100.70	0.16	0.00
25	CS	Bar	140	4.19	103.69	0.17	0.00

This bridge design also contains unique features. This bridge has a deck elevation of 12 meters and has a support configuration of 8 meter high arch abutments, no pier and no cable anchorages. This bridge consists of 25 carbon steel members. The carbon steel provides a great deal of strength and resistance for its reasonable cost. The tubes of the members vary from 140 to 170mm throughout the bridge. Different areas on the bridges experience different amounts of force. The size of the tubes correlate with the different areas of force as the larger tubes are put where the bridge experiences the most force and the smaller tubes are put where the bridge experiences the least amount of force. Because of its arch abutments, the members are placed under the bridge to help keep the bridge stable. Of the 25 members, 21 of them are made out of solid bars, and 4 of them are used as hollow tubes. As stated before, the solid bars are very strong, and deal with most of the force on the bridge, while the 4 hollow tubes are there to reduce cost while still being able to hold a great deal of force. The estimated cost for this design is a couple hundred dollars below $300,000. This design was the closest to the budget, and this nearly makes it impossible to make major modifications to the bridge without completely changing up the bridge all together.

Koji’s Second Design



Member List | Member Details

Load Test Results

#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Bar	160	5.66	122.47	0.68	0.00
2	CS	Bar	150	4.47	103.28	0.56	0.00
3	CS	Bar	150	4.47	103.28	0.56	0.00
4	CS	Bar	150	4.12	95.22	0.42	0.00
5	CS	Bar	150	4.12	95.22	0.42	0.00
6	CS	Bar	150	4.47	103.28	0.54	0.00
7	CS	Bar	150	4.47	103.28	0.54	0.00
8	CS	Bar	160	5.66	122.47	0.66	0.00
9	QTS	Tube	140	4.00	73.57	0.00	0.36
10	CS	Tube	140	6.00	110.35	0.03	0.00
11	QTS	Tube	140	8.00	147.13	0.00	0.36
12	CS	Bar	140	9.00	222.69	0.00	0.13
13	QTS	Tube	140	8.00	147.13	0.00	0.36
14	CS	Tube	140	6.00	110.35	0.03	0.00
15	QTS	Tube	140	4.00	73.57	0.00	0.36
16	CS	Bar	150	8.94	206.56	0.39	0.01
17	CS	Bar	150	8.94	206.56	0.47	0.01
18	CS	Bar	140	8.94	221.31	0.00	0.11
19	CS	Bar	140	5.66	139.97	0.03	0.07
20	CS	Bar	140	8.94	221.31	0.00	0.10
21	CS	Bar	140	5.66	139.97	0.01	0.08
22	CS	Bar	110	4.00	125.97	0.00	0.44
23	CS	Bar	110	4.00	125.97	0.00	0.44
24	CS	Bar	110	4.00	125.97	0.00	0.47
25	CS	Bar	110	4.00	125.97	0.00	0.47
26	CS	Bar	110	4.00	125.97	0.00	0.46
27	CS	Bar	110	4.00	125.97	0.00	0.46
28	CS	Bar	110	4.00	125.97	0.00	0.42
29	CS	Bar	110	4.00	125.97	0.00	0.42

This bridge design is very aesthetically different and incorporates unique features as well. This design was inspired by a traditional bridge that has one big arch to support the entire bridge. The bridge has a deck elevation of 12 meters and has a support configuration of standard abutments, no pier, and no cable anchorages. This bridge consists of 25 carbon steel members and 4 quenched and tempered steel members. The carbon steel is an affordable metal that also has great strength. Quenched and tempered steel, on the other hand, is a little more expensive than carbon steel but has greater strength and is a better metal for more stable bridges. The tubes of the members ranged in sizes from 110, 140, 150, and 160mm. The different sizes of the members were used to hold different amounts of force. Also, 6 members were hollow tubes, and 23 members were solid bars. Solid bars allow for greater strength but are more expensive than hollow tubes. Hollow tubes are used for areas that receive very little amounts of force, as they are significantly cheaper than solid bars. The estimated cost for this design is roughly $299,000. This cost is below the budget which is one of the constraints for the design, but the cost does not allow for easy modifications as the budget is very strict.

Decision Matrix

Design	Complexity	Price (Cost)	Stability	Aesthetic	Total
Koji 1	2	2	2	3	9
Koji 2	3	2	1	2	8
TJ 1	1	3	2	2	8
TJ 2	3	2	1	1	7

Scale:

Complexity

1 - Most Complex, may not reproducible in the real world
2 - Mostly simple but somewhat complex
3 - Not very complex, very simple

Price

1 - Over the cost
2 - Not very expensive or cheap, meets the cost limit
3 - Lowest cost possible

Stability

1 - Not stable, breaks or has many bold color members
2 - Mostly stable, but with a little wobbliness
3 - Very stable, not much movement, no bold colors in testing

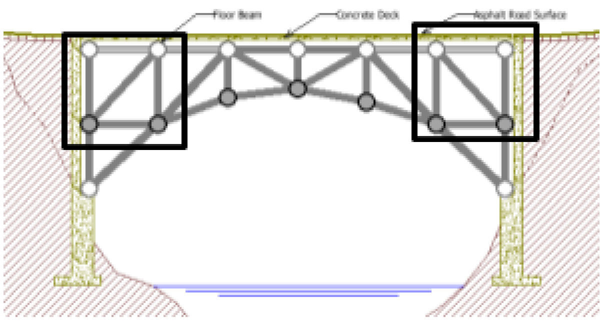
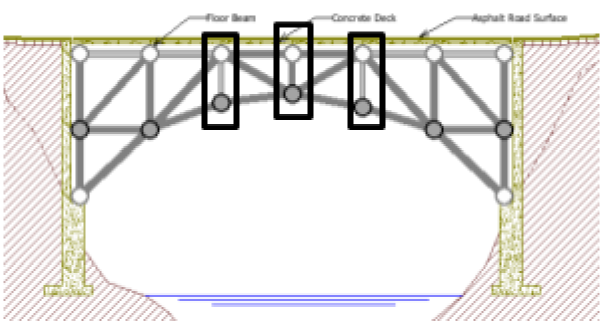
Aesthetic

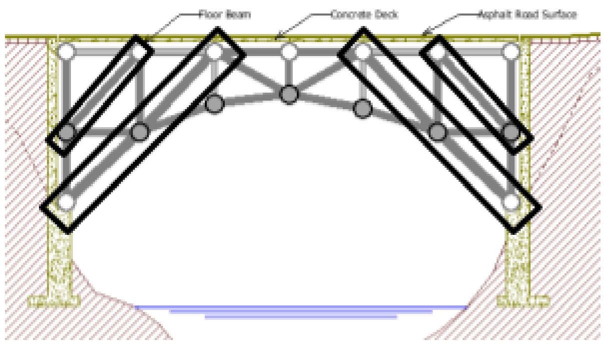
1 - The bridge doesn't look good, not appealing
2 - Mostly good looking, is not best looking, seems common/generic
3 - Best looking bridge, unique

Decision Matrix Paragraph

When thinking of ideas for the decision matrix, we thought of four main ideas that relate to the construction of the bridge. These four ideas are complexity, stability, price, and aesthetics. Instead of ranking each brainstorm sketch from 1-4 in each category, we had three options ranking from less appealing to our design as a 1 to a more appealing solution to our design as 3. When looking at the four categories and the four brainstorm sketches, whichever one added up to the highest total number at the end, was the design that we chose. From the results of the decision matrix, Koji's first brainstorm was the best choice. His design was mostly simple, but somewhat complex. This would receive a two on our decision matrix. His design can be put into the real world but it is complex because the members are underneath the bridge. His design was also not expensive, but also not cheap. This would receive another two, as the design met the cost limit at around $299,000. Koji's design was also the most stable during the simulation as it still received a 2 because there was still a little bit of wobbliness when the truck drove over the bridge. Lastly for aesthetics, Koji's design was the most unique and also was aesthetically pleasing to the eye because of its symmetrical nature, therefore receiving a 3. When adding up all of the points Koji's design was the one with the highest number. The decision matrix makes sense, as Koji's design was the most stable, cost-efficient appealing bridge compared to all of the other models. This design is cost-efficient because the hollow tubes reduce the price of the bridge. This design is also the most appealing to the eye because of how symmetrical it is compared to the other designs. This design does not have sharp edges but has a nice, smooth arch that makes it appealing. Also this design is simple, as there have been real-world examples of bridges built with the same format. But there is some complexity as the arch abutments makes its structure need multiple diagonal members to support the bridge. Lastly, this design is the most stable because the use of the carbon steel members along with the 8-meter high arch abutments stability and support to the bridge.

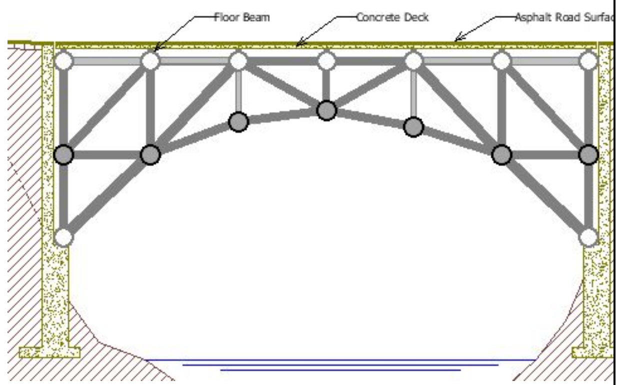
Modifications

Modification	Description
 (The black boxes are the modified members)	Since the bridge design was already around $295,000 there was not much money left to make much modifications. However, we noticed that the side sections of the bridge were structurally weak because of long members. Instead, we added more short vertical and horizontal members and one shorter slanted member. Increasing the number of members made it possible to shrink the sections without much force while increasing the size of areas that need more strength.
 (The black boxes are the modified members)	After our first modification, instead of looking for major design changes, we looked for areas we could change solid bar to hollow, and reduce costs for areas that do not experience that much force. Many of the vertical members were changed to hollow tubes to reduce the cost and weight of the bridge. We also looked at forces that each member was experiencing and changed members with compression forces to hollow tubes, while we kept solid bars for members with tension forces.

 (The black boxes are the modified members)	After our second modification, we reviewed the overall bridge with the load test simulations. We found that some of the slanted members on the side were experiencing a lot of force, so we increased the size of the members. This was the last modification for our final design.

Final Bridge Design

Final Design



Load Test Results

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	CS	Bar	140	4.03	99.74	508.84	2612.49	OK	0.00	4655.00	OK
2	CS	Bar	140	4.07	100.70	521.22	2586.32	OK	0.00	4655.00	OK
3	CS	Bar	180	5.48	105.52	1167.11	4057.46	OK	0.00	7695.00	OK
4	CS	Bar	140	4.27	105.70	539.25	2449.45	OK	0.00	4655.00	OK
5	CS	Bar	140	4.19	103.69	536.73	2504.31	OK	0.00	4655.00	OK
6	CS	Bar	180	5.48	105.52	1167.11	4057.46	OK	0.00	7695.00	OK
7	CS	Tube	150	4.00	68.44	280.12	704.11	OK	4.42	950.95	OK
8	CS	Tube	140	4.00	73.57	280.12	630.23	OK	4.42	884.45	OK
9	CS	Bar	150	4.00	92.38	951.40	3230.99	OK	0.00	5343.75	OK
10	CS	Bar	150	4.00	92.38	951.40	3230.99	OK	0.00	5343.75	OK
11	CS	Tube	140	4.00	73.57	285.20	630.23	OK	18.81	884.45	OK
12	CS	Tube	150	4.00	68.44	0.00	704.11	OK	0.00	950.95	OK
13	CS	Bar	150	4.25	98.15	326.22	3049.26	OK	0.00	5343.75	OK
14	CS	Tube	110	3.00	69.91	55.30	365.35	OK	3.38	498.75	OK
15	CS	Bar	120	2.25	64.95	627.77	2594.93	OK	0.00	3420.00	OK
16	CS	Tube	110	2.75	64.08	117.47	380.67	OK	0.00	498.75	OK
17	CS	Bar	150	4.25	98.15	623.31	3049.26	OK	0.00	5343.75	OK
18	CS	Bar	170	5.84	118.93	840.38	3089.07	OK	0.00	6863.75	OK
19	CS	Bar	170	5.84	118.93	805.68	3089.07	OK	0.00	6863.75	OK
20	CS	Bar	140	4.59	113.56	107.36	2237.25	OK	471.39	4655.00	OK
21	CS	Bar	140	4.59	113.56	41.34	2237.25	OK	617.72	4655.00	OK
22	CS	Bar	150	4.25	98.15	644.57	3049.26	OK	0.00	5343.75	OK
23	CS	Bar	150	3.75	86.60	658.00	3411.55	OK	0.00	5343.75	OK
24	CS	Bar	150	4.25	98.15	205.94	3049.26	OK	0.00	5343.75	OK
25	CS	Bar	150	3.75	86.60	528.34	3411.55	OK	0.00	5343.75	OK
26	CS	Bar	140	4.00	98.97	0.00	2633.62	OK	0.00	4655.00	OK
27	CS	Bar	140	5.84	144.41	6.45	1469.30	OK	408.72	4655.00	OK
28	CS	Bar	140	4.00	98.97	18.81	2633.62	OK	285.20	4655.00	OK
29	CS	Bar	140	5.84	144.41	416.13	1469.30	OK	27.45	4655.00	OK

Cost Calculations

Cost Calculations Report

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(18419.4 kg) x ($4.30 per kg) x (2 Trusses) =	$158,406.57
	Carbon Steel Hollow Tube	(580.1 kg) x ($6.30 per kg) x (2 Trusses) =	$7,309.35
Connection Cost (C)		(16 Joints) x (400.0 per joint) x (2 Trusses) =	$12,800.00
Product Cost (P)	2 - 110x110x5 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	1 - 120x120 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	10 - 140x140 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 140x140x7 mm Carbon Steel Tube	($1,000.00 per Product) =	$1,000.00
	8 - 150x150 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 - 170x170 mm Carbon Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 180x180 mm Carbon Steel Bar	($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	(54,100 cubic meters) x ($1.00 per cubic meter) =	$54,100.00
	Abutment Cost	(2 arch abutments) x ($15,550.00 per abutment) =	$31,100.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	**M + C + P + S**	**$165,715.92 + $12,800.00 + $8,000.00 + $113,400.00 =**	**$299,915.92**

Member Details (Grouped by size, type, and material)

Member List | Member Details

Members 1,2,4,5,20... | Members 3,6 | Members 7,12 | Members 8,11 | Members 9,10,13,17... | M...

Material Properties:

Material	Carbon Steel
Yield Stress (Fy)	250000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

Dimensions:

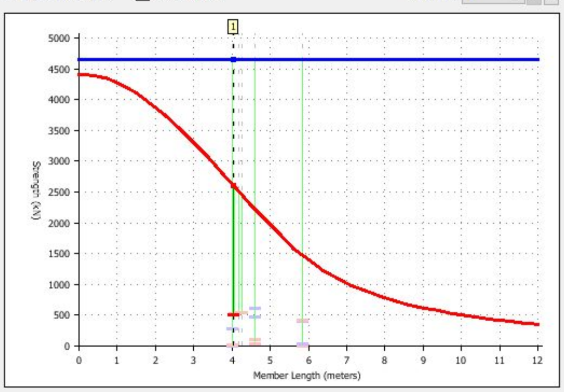
Cross-Section Type	Solid Bar
Cross-Section Size	140x140
Area	0.0196 sq. meters
Moment of Inertia	3.20E-05 meters^4
Member Length	--

Section (mm): 140 × 140

Cost:

Unit Cost	$661.60 per meter
Member Cost	--

Strength vs. Length: Graph all tabs — Member: 1



Member List | Member Details

Members 1,2,4,5,20... | Members 3,6 | Members 7,12 | Members 8,11 | Members 9,10,13,17... | M...

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:

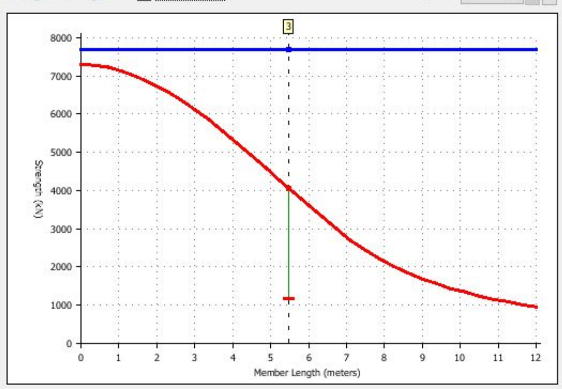
Cross-Section Type	Solid Bar
Cross-Section Size	180x180
Area	0.0324 sq. meters
Moment of Inertia	8.75E-05 meters^4
Member Length	--

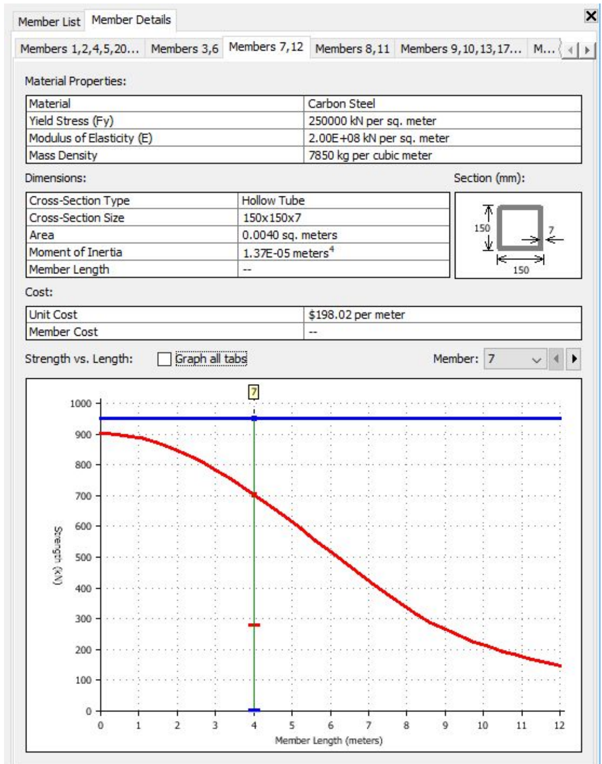
Section (mm): 180 × 180

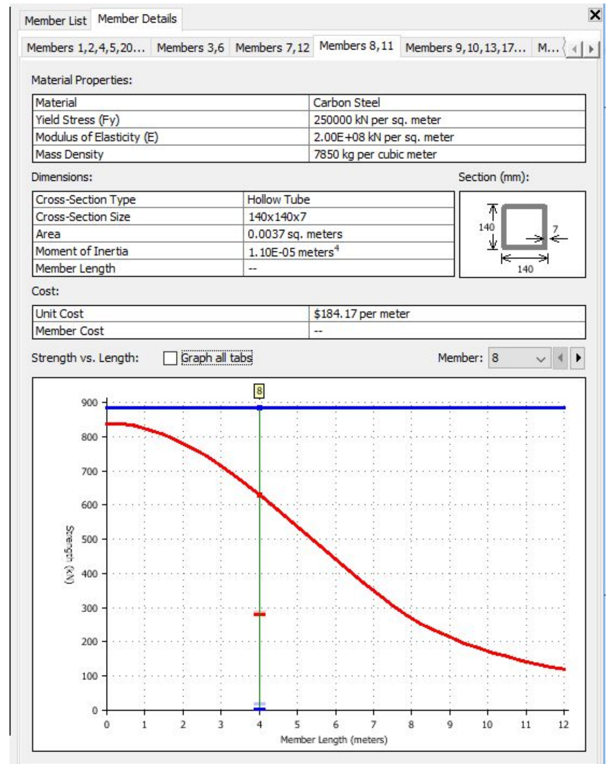
Cost:

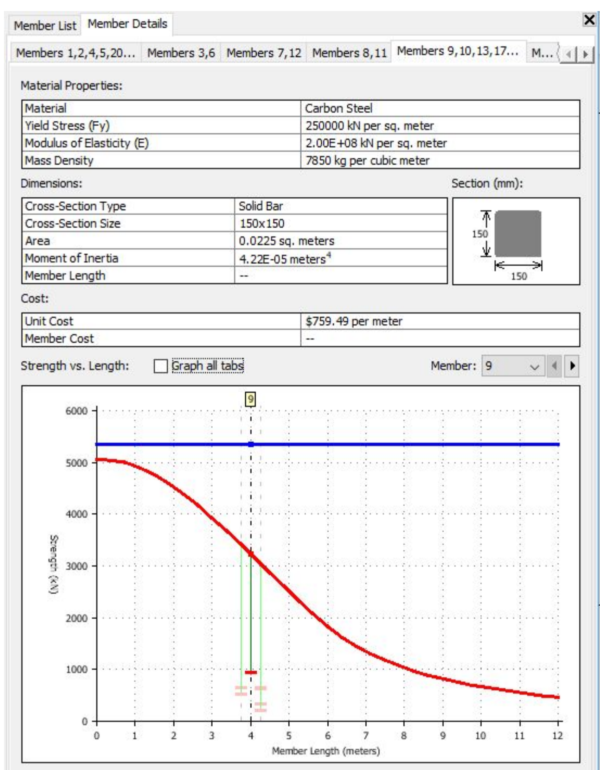
Unit Cost	$1093.66 per meter
Member Cost	--

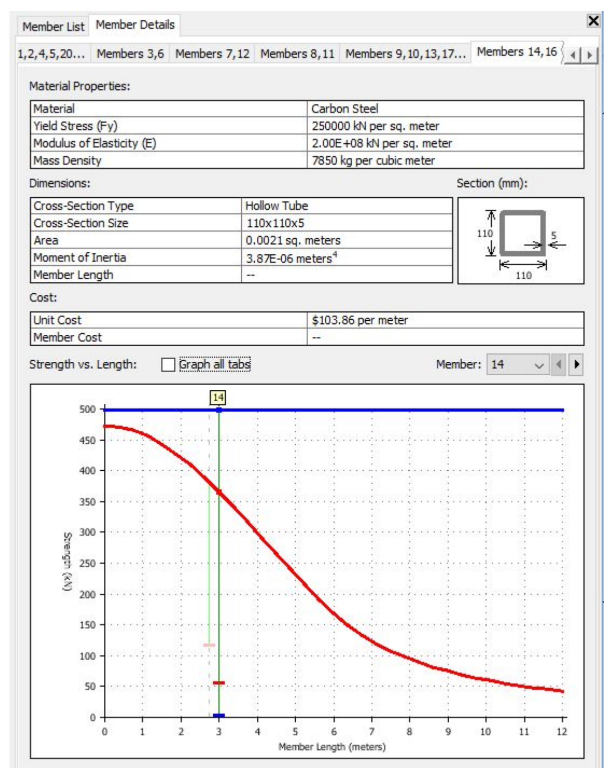
Strength vs. Length: Graph all tabs — Member: 3

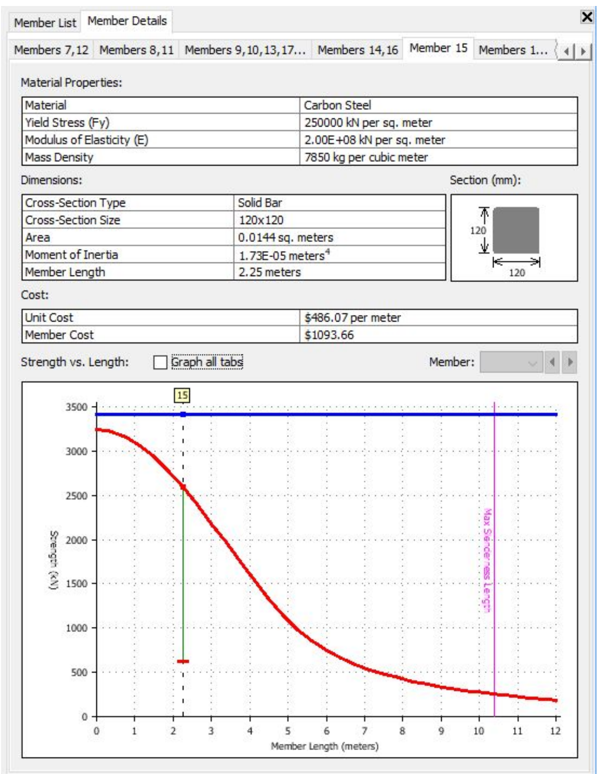


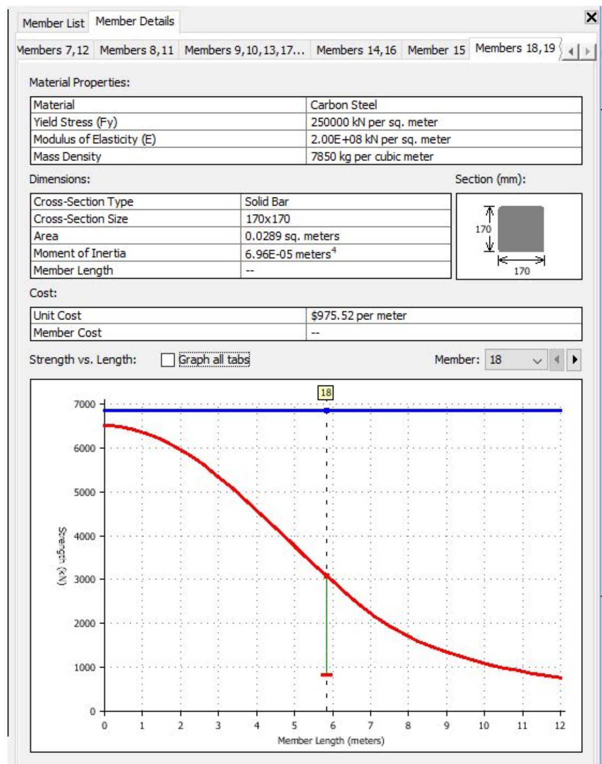

Member List
Member Details
Members 1,2,4,5,20...
Members 3,6
Members 7,12
Members 8,11
Members 9,10,13,17...
M...
Material Properties:
Material | Carbon Steel
Yield Stress (Fy) | 250000 kN per sq. meter
Modulus of Elasticity (E) | 2.00E+08 kN per sq. meter
Mass Density | 7850 kg per cubic meter
Dimensions:
Section (mm):
Cross-Section Type | Hollow Tube
Cross-Section Size | 150x150x7
Area | 0.0040 sq. meters
Moment of Inertia | 1.37E-05 meters4
Member Length | --
150
7
150
Cost:
Unit Cost | $198.02 per meter
Member Cost | --
Strength vs. Length:
Graph all tabs
Member: 7
7
Strength (kN)
Member Length (meters)


Member List
Member Details
Members 1,2,4,5,20...
Members 3,6
Members 7,12
Members 8,11
Members 9,10,13,17...
M...
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:
Section (mm):
Cross-Section Type | Hollow Tube
Cross-Section Size | 140x140x7
Area | 0.0037 sq. meters
Moment of Inertia | 1.10E-05 meters4
Member Length | --
140
7
140
Cost:
Unit Cost | $184.17 per meter
Member Cost | --
Strength vs. Length:
Graph all tabs
Member: 8
8
Strength (kN)
Member Length (meters)


Member List
Member Details
Members 1,2,4,5,20...
Members 3,6
Members 7,12
Members 8,11
Members 9,10,13,17...
M...
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:
Section (mm):
Cross-Section Type | Solid Bar
Cross-Section Size | 150x150
Area | 0.0225 sq. meters
Moment of Inertia | 4.22E-05 meters4
Member Length | --
150
150
Cost:
Unit Cost | $759.49 per meter
Member Cost | --
Strength vs. Length:
Graph all tabs
Member: 9
9
Strength (kN)
Member Length (meters)


Member List
Member Details
1,2,4,5,20...
Members 3,6
Members 7,12
Members 8,11
Members 9,10,13,17...
Members 14,16
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:
Section (mm):
Cross-Section Type | Hollow Tube
Cross-Section Size | 110x110x5
Area | 0.0021 sq. meters
Moment of Inertia | 3.87E-06 meters4
Member Length | --
110
5
110
Cost:
Unit Cost | $103.86 per meter
Member Cost | --
Strength vs. Length:
Graph all tabs
Member: 14
14
Strength (kN)
Member Length (meters)


Member List
Member Details
Members 7,12
Members 8,11
Members 9,10,13,17...
Members 14,16
Member 15
Members 1...
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:
Section (mm):
Cross-Section Type | Solid Bar
Cross-Section Size | 120x120
Area | 0.0144 sq. meters
Moment of Inertia | 1.73E-05 meters⁴
Member Length | 2.25 meters
120
120
Cost:
Unit Cost | $486.07 per meter
Member Cost | $1093.66
Strength vs. Length:
Graph all tabs
Member:
15
Strength (kN)
Member Length (meters)
Max Slenderness Length


Member List
Member Details
Members 7,12
Members 8,11
Members 9,10,13,17...
Members 14,16
Member 15
Members 18,19
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:
Section (mm):
Cross-Section Type | Solid Bar
Cross-Section Size | 170x170
Area | 0.0289 sq. meters
Moment of Inertia | 6.96E-05 meters⁴
Member Length | --
170
170
Cost:
Unit Cost | $975.52 per meter
Member Cost | --
Strength vs. Length:
Graph all tabs
Member: 18
18
Strength (kN)
Member Length (meters)

Final Design Justification

Our final design is based on Koji Design #1 with some modifications to increase the strength of the bridge. We chose this design because of its overall complexity and stability as well as its appearance. Our bridge uses a 12 feet deck elevation with 8 feet arch abutments because the lower deck elevation will reduce the length (the span of the bridge) which will help reduce the number of members and materials needed, ultimately reducing cost. The arch abutments allowed use to anchor members to the side towers, which enabled us to create arches in our design. The design is an arch bridge, with minimal members which lead to the reduction of costs. During our brainstorming phase, we found that the arch bridge exerts a lot of compression forces on the lower curve part of the bridge. In order to minimize the compression force that acts on the arch section, we strengthened the members that support the arch to the surface, and also increased the thickness of the arch. We also found that hollow tubes are effective for compression forces, however, after experimenting with modifications, we found that the force acting on the arch members did not change much. The arch was kept at solid bars, but many of the vertical members near the center of the bridge were changed from solid to smaller hollow tubes since we found that they were not experiencing much force. We also used more short members rather than fewer long members since we found that longer members are more vulnerable to high tension and compression forces. This is why the long members on the side of the bridges near the arch abutments were replaced with 3 shorter members. This also allowed us to make some parts (like the slanted member) thicker so it can withstand the forces being applied. We found that quenched and tempered steel and High-Strength Low-Alloy Steel was significantly stronger, however, the price to performance was not as great as carbon steel. We ultimately decided that slightly larger carbon steel members were more cost effective than changing materials. We also did not have a budget large enough to create an entire bridge with another material besides carbon steel. This also relates to real life building since joints with different materials are usually not strong and could result in one part breaking before another due to the difference in properties of the metals.

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