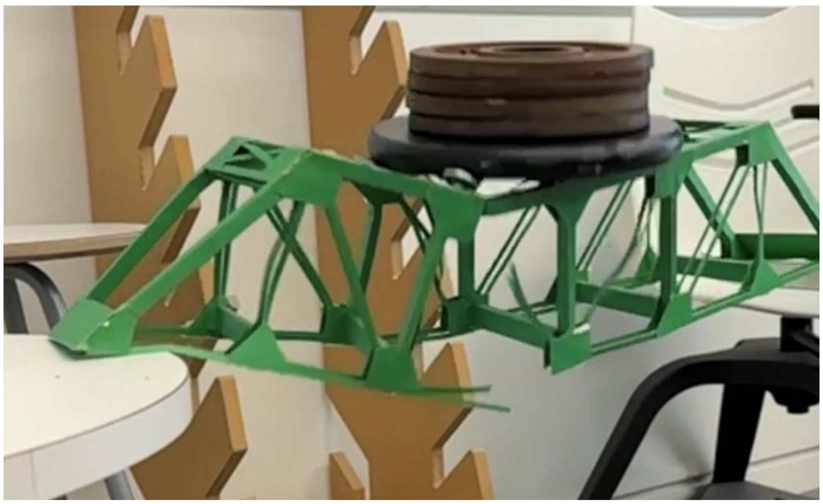
Neil Hasenstaub
EGN2001C

Bridge Project Report and Calculations

A. The Reflection

The Grant Road Truss bridge was a huge success. Our team efforts lead to a bridge that exceeded its requirements.

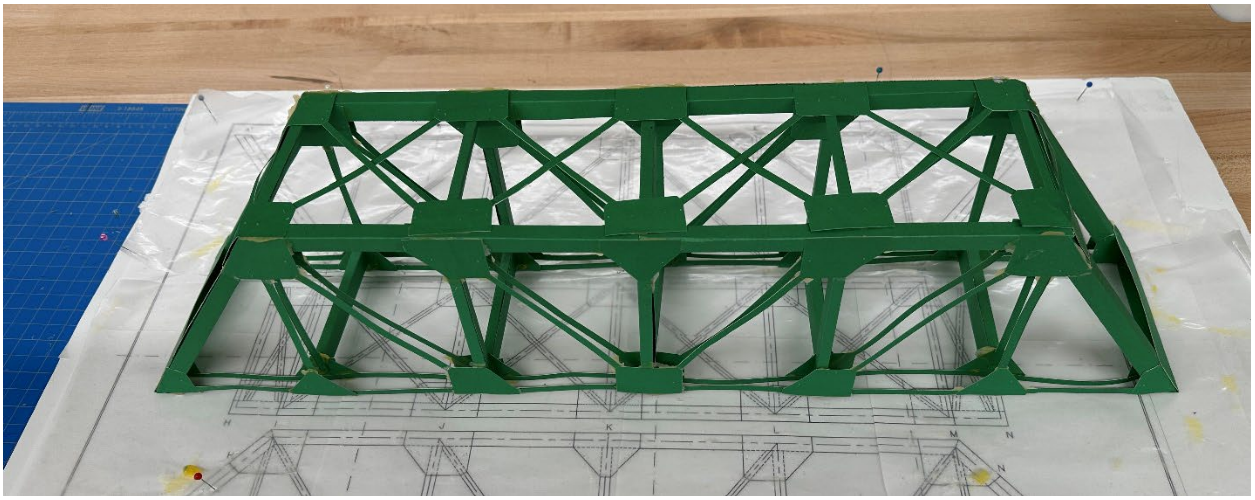
The bridge met the 5-kilogram load expectation. It continued to support loading until it reached 9.5kg, or about 19lb. Examining high-speed footage of the failure shows that it began with complete fracture of some of the bars, followed by shearing of the top chord members, and finally complete failure of the top chords as the weight caused both ends to separate.



THE BRIDGE FAILING UNDER ITS MAXIMUM LOAD. NOTE THE BARS AT THE BOTTOM AND MIDDLE THAT ARE COMPLETELY SEPARATED, AND THE BENDING OF THE TOP CHORDS.

The outcome of the bridge loading can be attributed to the smoothness of the construction process. We, as bridge contractors, recognized the importance and effect of quality work on the result. Time and care were taken to create the components without cutting corners while not sacrificing too much time in order to meet the weekly pacing. Specifically, the creation of the bars probably took longer than average, since cut members were trashed if they were not straight enough. The tubes also took some time to make sure they were evenly cemented together and mostly square. We also spent a lot of time making sure the joints between members and gussets were set correctly and with enough adhesive.

We must also recognize the impact of the team dynamics on the outcome. Tasks were evenly distributed among all *participating* members (more on this later), with progress being made at our own pace. Strong communication allowed us to monitor completion of milestones, and the organizational structure we created, which did not include a defined leader, allowed us each take charge of issues or request a status report, much like a system of checks and balances.



THE COMPLETED BRIDGE. NOTE THE SPOTS AROUND THE GUSSETS WITH VISIBLE GLUE, MISALIGNED BARS, AND CROOKED TOP GUSSETS.

It is worth noting, however, that with our prioritization of the quality of the bridge mechanics and components, its appearance did suffer. Most notably, the floor beams were not parallel, and some of the top chords had rubber cement residue from their construction process. Additionally, some of the glue joints were “overflowing” as a consequence of too much glue being applied, however this was a benign feature. We do believe, however, that this tradeoff is justified. The bridge’s performance far exceeded our expectations, and most of the problems with appearance are purely cosmetic. Advanced analysis of the internal forces would be needed to determine the structural impact of misaligned floor beams. We do not think that the compromises made with the bridge’s appearance had a major impact on its performance under heavy loading.

B. The Need (For a New Bridge)

We unfortunately heard the news of the untimely collapse of our bridge the day it happened. A collision with a heavy tractor trailer has severely damaged the bridge and compromised its structural integrity. As such, Echo and Sons have been contracted once again to provide a new design, with several considerations to keep in mind.

This bridge will be a deck truss designed with a 20% higher load capacity in mind, per the Town Engineer's comment that heavy vehicle traffic is increasing. The deck will also need to be wider to accommodate the size of such vehicles. The factor of safety will be 2.0 for all structural members in our design, all of which will be made of steel of varying grades and cross-sections.

C. Design Requirements

After reviewing the comments made by various individuals from Hauptville, we have determined how we will weigh the considerations for the bridge. First, we think that prioritizing the strength of the bridge is very important. The bridge must not be susceptible to critical damage, leading to our assessment of a deck truss with a minimum factor of safety of 2.0 for all members. We are extending this requirement to make all members have a minimum factor of safety of 2.5 to increase the bridge's capacity. We will also prioritize having the construction of the bridge done in a timely manner by partnering with contractors for a design-build system, without compromising the quality of any part of the bridge, from fabrication of the members to the construction of the joints.

On the other hand, we are not prioritizing the appearance of the bridge very much. We think that the need for structural performance in a bridge vastly outweighs the need for it to look nice. However, we are still choosing to move forward with a symmetric design. Note that this take on appearance does *not* relate to the quality of the bridge itself, meaning the quality of construction and thus the appearance of the construction, one of the issues with the previous bridge, will not be a problem this time. Finally, we are choosing to mostly ignore the need for an inexpensive bridge. We believe that a quality bridge with a guarantee on its loading capacity and performance *cannot* be done by focusing on minimizing cost. Our proposal has this bridge being done with no regard to cost.

In summary, we are choosing to put bridge performance and design first, at the expense of appearance (to an extent) and cost.

D. The Proposal

The town of Hauptville deserves a final solution to the Grant Road Bridge problem. Our proposal aims to be that final solution. We seek to achieve a bridge of this status by prioritizing one thing and one thing only: strength. We saw what happened to the old bridge, and with the model we will present, we can *guarantee* that will not happen again. Our approach will be a strong, high-quality bridge that stops at no compromise.

This idea may seem extreme, and that's because it is. Based on the townspeople's comments, we have decided to prioritize the loading strength and design of the bridge over its aesthetics and cost. This town does not need to be plagued by lack of access to other parts of the county, nor does its reputation need to suffer. Our design calls for a 20% higher rated capacity to allow for more heavy traffic in the future. In achieving this high capacity, we are extending the minimum factor of safety from 2.0 to 2.5 to prevent overloading scenarios and instill higher confidence in the bridge's performance.

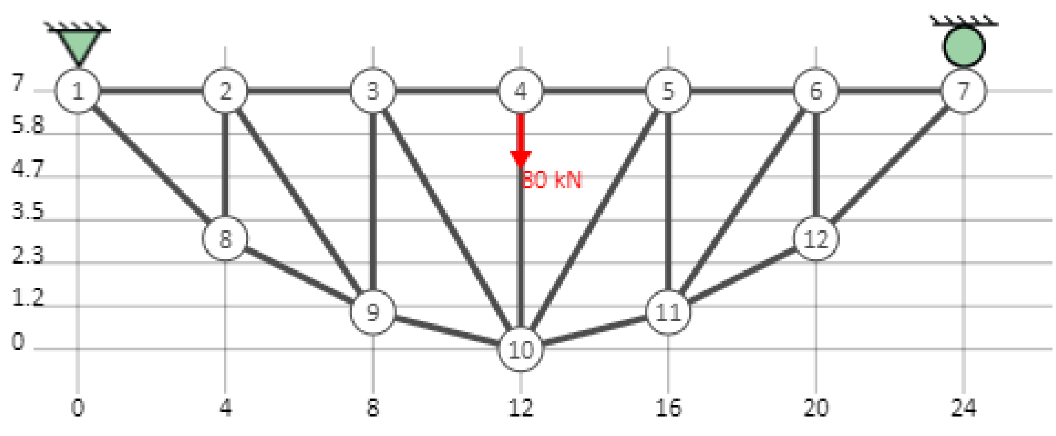
As such, in focusing on the performance and structure of the bridge itself, we have decided to do this at the expense of the appearance and cost of the bridge. A bridge such as we have described cannot be built cheaply, and despite some wishes that the cost be kept down, we have determined that this is simply not possible. A bridge that will be built to last will be expense to put it bluntly. We think this tradeoff is very much worth it in the long run, since it will eliminate the financial burden of having to build another bridge if this one were to fail.

Unfortunately, the aesthetics of the bridge will also not be as nice as the previous bridge. Since it is a deck truss, all of its structural members will be under the deck and out of view for vehicles and pedestrians. We are also not adding any kind of embellishments or decorations to the bridge to prevent structural compromises and to keep down the already high cost. We can say, however, that the bridge will still be symmetrical and painted to the town's choosing, so that the bridge is not completely lifeless.

In conclusion, we hope that the town of Hauptville will consider our proposal for the Grant Road bridge. We will aim to make our design the final bridge, a bridge that will last.

E. The Truss Designs

Neil Hasenstaub:

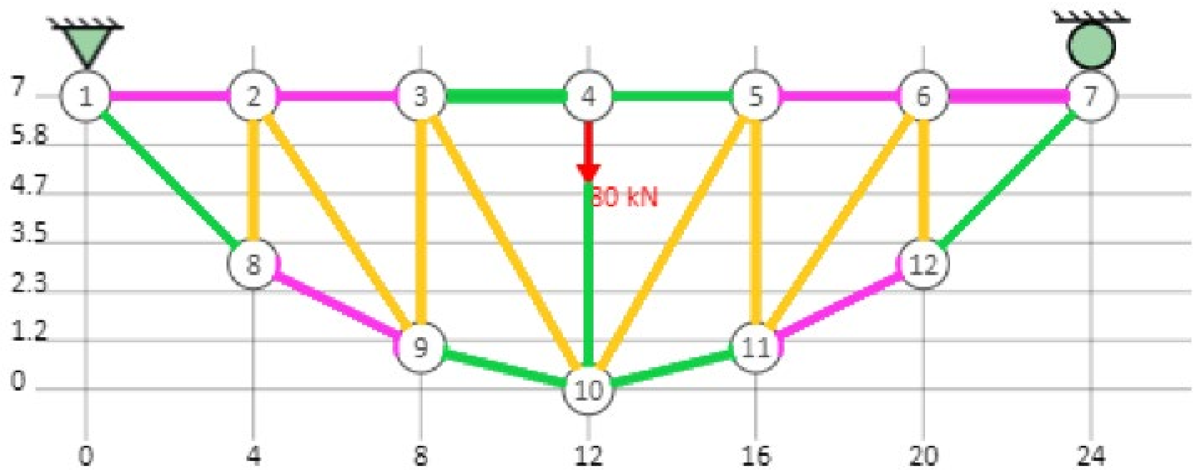


This design was chosen for its capability of strength and performance while retaining some aesthetic quality. It is a Howe design with curved top chords, which gives it a nice, rounded shape. A symmetric design was chosen for its appearance and ease of modification during optimization.

As seen in the analysis below, force was concentrated in the deck members and top chords. As such, these members were given higher steel grades and larger cross sections to handle the force with acceptable factor of safety. The factor of safety itself in this model was to have a minimum of 2.5 over the given minimum of 2.0 to increase its loading capacity and tolerance to oversize loads.

This design yielded a final mass of 480.59kg and a cost of $164.03. While little mind was given to either of these values based on our ranking of considerations, for the level of safety and strength the bridge provides, they are not relatively high. They were increased by the choice to increase the minimum factor of safety, but not to a concerning point.

Design with Member Properties:



Properties Used:

Property #	Type of Steel	Modulus of Elasticity (E)	Type of I-Beam	Cross Sectional Area (A)	Density (kg/m^3)	Cost ($/metric ton)
1	S275	275	IPE 220	426	8010	810
2	S275	275	IPE 240	501	8010	810
3	S355	355	IPE 300	744	8090	955

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Member Forces and Directions:

member	force	direction			
1-2	40	compression	11-12	44.72	tension
2-3	53.33	compression	12-7	56.57	tension
3-4	68.57	compression	8-2	20	compression
4-5	68.57	compression	9-3	26.67	compression
5-6	53.33	compression	10-4	80	compression
6-7	40	compression	11-5	26.67	compression
1-8	56.57	tension	12-6	20	compression
8-9	44.72	tension	2-9	24.04	tension
9-10	54.97	tension	3-10	30.71	tension
10-11	54.97	tension	10-5	30.71	tension
			6-11	24.04	tension

Individual Member Properties:

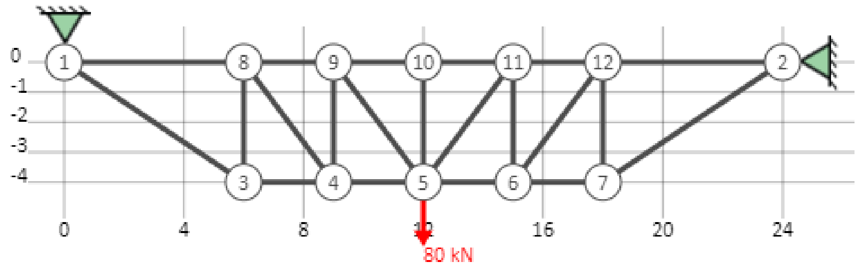
Member Properties									
Member	Structural Steel (EU Grade)	Cross-Section (mm^2)	Cross-Section (m^2)	Length (m)	Volume (m^3)	Mass (kg)	Yield Strength (Mpa)	Cost ($/metric ton)
1->2	S275	501	0.000501	4	0.002004	16.05204	275	810
2->3	S275	501	0.000501	4	0.002004	16.05204	275	810
3->4	S355	744	0.000744	4	0.002976	24.07584	355	955
4->5	S355	744	0.000744	4	0.002976	24.07584	355	955
5->6	S275	501	0.000501	4	0.002004	16.05204	275	810
6->7	S275	501	0.000501	4	0.002004	16.05204	275	810
1->8	S355	744	0.000744	5.656854	0.004209	34.04837945	355	955
8->9	S275	501	0.000501	4.472136	0.002241	17.94672631	275	810
9->10	S355	744	0.000744	4.123106	0.003068	24.81680784	355	955
10->11	S355	744	0.000744	4.123106	0.003068	24.81680784	355	955
11->12	S275	501	0.000501	4.472136	0.002241	17.94672631	275	810
12->7	S355	744	0.000744	5.656854	0.004209	34.04837945	355	955
8->2	S275	426	0.000426	4	0.001704	13.64904	275	810
9->3	S275	426	0.000426	6	0.002556	20.47356	275	810
10->4	S355	744	0.000744	7	0.005208	42.13272	355	955
11->5	S275	426	0.000426	6	0.002556	20.47356	275	810
12->6	S275	426	0.000426	4	0.001704	13.64904	275	810
2->9	S275	426	0.000426	7.211103	0.003072	24.60615679	275	810
3->10	S275	426	0.000426	8.062258	0.003435	27.51051962	275	810
10->5	S275	426	0.000426	8.062258	0.003435	27.51051962	275	810
6->11	S275	426	0.000426	7.211103	0.003072	24.60615679	275	810
						Total Weight (kg):		
						480.59494		

Factor of Safety and Costs:

Member Lengths	
Member	Length (m)
Deck Beams	4
8->2,12->6	4
9->3,11->5	6
10->4	7
1->8,12->7	5.65685425
9->2,11->6	7.21110255
10->3,10->5	8.06225775
8->9,11->12	4.47213595
9->10,10->11	4.12310563

Member Calculations				
Member	Force (N)	Stress (MPa)	Factor of Safety	Cost ($)
1->2	40000	79.84032	3.444375	4.865863
2->3	53330	106.4471	2.583443	4.865863
3->4	68570	92.16398	3.85183	9.421212
4->5	68570	92.16398	3.85183	9.421212
5->6	53330	106.4471	2.583443	4.865863
6->7	40000	79.84032	3.444375	4.865863
1->8	56570	76.03495	4.668906	13.32361
8->9	44720	89.26148	3.080836	5.4402
9->10	54970	73.88441	4.804803	9.711163
10->11	54970	73.88441	4.804803	9.711163
11->12	44720	89.26148	3.080836	5.4402
12->7	56570	76.03495	4.668906	13.32361
8->2	20000	46.94836	5.8575	4.13744
9->3	26670	62.60563	4.392576	6.206161
10->4	80000	107.5269	3.3015	16.48712
11->5	26670	62.60563	4.392576	6.206161
12->6	20000	46.94836	5.8575	4.13744
2->9	24040	56.43192	4.873128	7.458877
3->10	30710	72.0892	3.814718	8.339278
10->5	30710	72.0892	3.814718	8.339278
6->11	24040	56.43192	4.873128	7.458877
				Total Cost:
				164.03

Blayne Rutz:



The design was chosen through trial and error, to improve cost, strength, and distribution of force. The bridge has an upside-down and symmetrical Howe design. The decision to turn the bridge upside-down was to reduce the stress on members, 4-5 and 5-6.

The members with higher applied forces were given larger cross-sections and mother strength material respectively. The process was repeated for each member until a safety rating of at least 2 was reached for all members.

The bridge has a total mass of 227.2448 kg, and a cost of $197.41. The bridge is much lighter, but comes at a higher cost than the one provided by Neil, while also having lower safety ratings than Neil's bridge.

Properties Used:

Material	Yield Strength	Modulus of Elasticity (E)	Density (kg/m^3)	Cost ($/ metric ton)
S235	235	235	7850	720
S275	275	270	8010	810
S355	355	355	8090	955

I-Beam	Cross-section area (mm^2)
IPE 140	203
IPE 180	305
IPE 220	426
IPE240	501
IPE 300	744

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Member Forces and Directions:

Members	Force (kN)	Direction
1->8	16.4	T
1->3	72.11	T
3->4	60	T
4->5	90	T
5->6	90	T
6->7	60	T
7->2	72.11	T
8->9	13.6	C
9->10	43.6	C
10->11	43.6	C
11->12	13.6	C
12->2	16.4	T
3->8	40	C
4->9	40	C
5->10	0	Zero
6->11	40	C
7->12	40	C
4->8	50	T
5->9	50	T
5->11	50	T
6->12	50	T

Individual Member Properties:

Members	Material Grade (EU Grade)	Cross Section (mm^2)	Length (m)	Volume (m^3)	Mass (kg)	Yield Strength
1->8	S235	203	4	0.812	6374.2	235
1->3	S355	426	7.2111	3.0719286	24851.9	355
3->4	S275	501	3	1.503	12039.03	275
4->5	S275	744	3	2.232	17878.32	275
5->6	S275	744	3	2.232	17878.32	275
6->7	S275	501	3	1.503	12039.03	275
7->2	S355	426	7.2111	3.0719286	24851.9	355
8->9	S235	203	3	0.609	4780.65	235
9->10	S355	305	5	1.525	12337.25	355
10->11	S355	305	3	0.915	7402.35	355
11->12	S235	203	3	0.609	4780.65	235
12->2	S235	203	4	0.812	6374.2	235
3->8	S275	305	3	0.915	7329.15	275
4->9	S275	305	3	0.915	7329.15	275
5->10	S235	203	3	0.609	4780.65	235
6->11	S275	305	3	0.915	7329.15	275
7->12	S275	305	4	1.22	9772.2	275
4->8	S355	305	4	1.22	9869.8	355
5->9	S355	305	4	1.22	9869.8	355
5->11	S355	305	4	1.22	9869.8	355
6->12	S355	305	4	1.22	9869.8	355

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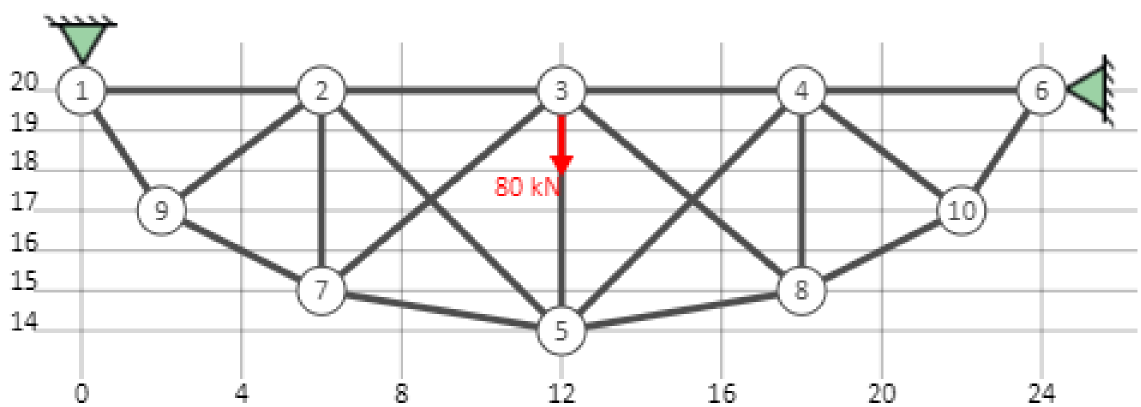
Factor of Safety and Costs:

Members	Length (m)		Members	Force (kN)	Stress (MPa)	Factor of Safety	Cost ($)
1->8	4		1->8	16.4	80.78817734	2.908841463	4.589424
1->3	7.2111		1->3	72.11	169.2723005	2.097212592	17.89336971
3->4	3		3->4	60	119.760479	2.29625	8.6681016
4->5	3		4->5	90	120.9677419	2.273333333	12.8723904
5->6	3		5->6	90	120.9677419	2.273333333	12.8723904
6->7	3		6->7	60	119.760479	2.29625	8.494956
7->2	7.2111		7->2	72.11	169.2723005	2.097212592	17.89336971
8->9	3		8->9	13.6	66.99507389	3.507720588	3.442068
9->10	5		9->10	43.6	142.9508197	2.48337156	8.79498
10->11	3		10->11	43.6	142.9508197	2.48337156	5.329692
11->12	3		11->12	13.6	66.99507389	3.507720588	3.442068
12->2	4		12->2	16.4	80.78817734	2.908841463	4.589424
3->8	3		3->8	40	131.147541	2.096875	5.276988
4->9	3		4->9	40	131.147541	2.096875	5.276988
5->10	3		5->10	0	0	0	3.442068
6->11	3		6->11	40	131.147541	2.096875	5.276988
7->12	4		7->12	40	131.147541	2.096875	7.035984
4->8	4		4->8	50	163.9344262	2.1655	7.106256
5->9	4		5->9	50	163.9344262	2.1655	7.106256
5->11	4		5->11	50	163.9344262	2.1655	7.106256
6->12	4		6->12	50	163.9344262	2.1655	7.106256
						Total Cost ($)=	163.6162738

Christian Burton:



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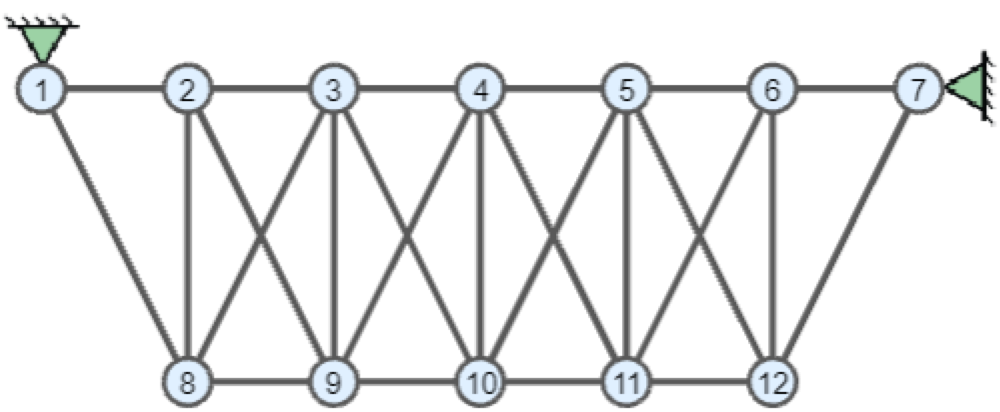
Member	Load (kN)	Direction	Material Grade	Cross Sectional Area (mm^2)	Stress	Yield Strength	Factor of Safety	Length (m)	Volume (m^3)	Density	Mass (kg)	Cost ($)
1-2	18.3	T	S235	305	60.00	235	3.917	6	0.183	7850	1436.55	1034.316
1-9	48.07	T	S235	426	112.84	235	2.083	3.60555	0.15359643	7850	1205.73198	868.127
2-7	0.73	T	S235	305	2.39	235	98.185	5	0.1525	7850	1197.125	861.93
2-3	18.3	C	S235	305	60.00	235	3.917	6	0.183	7850	1436.55	1034.316
2-5	21.6	T	S235	305	70.82	235	3.318	8.48258	0.25871869	7850	2030.94172	1462.278
7-5	65.62	T	S235	744	88.20	235	2.664	6.08276	0.452557344	7850	3552.57515	2557.854
3-5	52.12	C	S235	501	104.03	235	2.259	6	0.3006	7850	2359.71	1698.991
3-4	18.3	C	S235	305	60.00	235	3.917	6	0.183	7850	1436.55	1034.316
5-4	21.6	T	S235	305	70.82	235	3.318	8.48258	0.25871869	7850	2030.94172	1462.278
4-6	18.3	T	S235	305	60.00	235	3.917	6	0.183	7850	1436.55	1034.316
6-10	48.07	T	S235	501	95.95	235	2.449	3.60555	0.180638055	7850	1418.00873	1020.966
5-8	65.62	T	S235	744	88.20	235	2.664	6.08276	0.452557344	7850	3552.57515	2557.854
4-8	0.73	T	S235	203	3.60	235	65.349	5	0.1015	7850	796.775	573.678
3-7	21.77	C	S235	305	71.38	235	3.292	7.81025	0.238212625	7850	1869.96911	1346.378
3-8	21.77	C	S235	305	71.38	235	3.292	7.81025	0.238212625	7850	1869.96911	1346.378
9-2	26.67	C	S235	305	87.44	235	2.687	5	0.1525	7850	1197.125	861.93
9-7	53.67	T	S235	501	107.13	235	2.194	4.47214	0.224054214	7850	1758.82558	1266.354
10-8	53.67	T	S235	501	107.13	235	2.194	4.47214	0.224054214	7850	1758.82558	1266.354
4-10	26.67	C	S235	305	87.44	235	2.687	5	0.1525	7850	1197.125	861.93

I arrived at this bridge design through a process of trial and error. I started with a bowstring design, but there were not enough nodes and truss members to comfortably handle the 80 kN load. I went back and reconfigured the placement of the nodes while adding 2 more, which allowed me to add more truss members increasing the structural integrity of the bridge. When it came time for material selection I chose S235 steel, and I used different I beam cross sections for different members until I reached a design that met the criteria of a safety factor of at least 2 for each truss member. This design is structurally stable, affordable, and still retains aesthetics. It is also a 24-meter long deck truss bridge as the town requested. All in all, this bridge design is a good fit for the town's new bridge, as I believe it does a good job of fulfilling the requirements of the town.

Zachary Alexander:



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Properties Used:

Type of Steal	Modulus of Elasticity (E)	Density (kg/m^3)	Cost ($/metric ton)
S235	235	7850	720
S275	275	8010	810
S355	355	8090	955

I-beam	Cross-section area (mm^2)
IPE 140	203
IPE 180	305
IPE 220	426
IPE 240	501
IPE 300	744

Member Forces and Direction:

Members	Type	Length (m)	Force (kN)		Stress(MPa)	Cross-section area (mm^2)	Volume (m^3)	Density	Mass (kg)	Factor of Safety	Cost ($)
1->2	235	4	17.21	tension	56.42622	305	0.122	7850	957.7	4.164731	689.544
1->8	355	7.211103	48.07	tension	64.610215	744	0.537	8090	4344.33	5.494487	4148.835
2->3	235	4	3.61	tension	11.836065	305	0.122	7850	957.7	19.85457	689.544
2->8	275	6	20.41	compression	40.738522	501	0.301	8010	2411.01	6.750368	1952.918
2->9	275	7.211103	24.52	tension	48.942115	501	0.361	8010	2891.61	5.618883	2342.204
3->4	275	4	20.82	compression	41.556886	501	0.2	8010	1602	6.617435	1297.62
3->8	275	7.211103	23.55	compression	47.005988	501	0.361	8010	2891.61	5.850318	2342.204
3->9	235	6	2.55	tension	8.360655	305	0.183	7850	1436.55	28.10785	1034.316
3->10	275	7.211103	20.48	tension	40.878243	501	0.361	8010	2891.61	6.727295	2342.204
4->5	275	4	20.82	compression	41.556886	501	0.2	8010	1602	6.617435	1297.62
4->9	275	7.211103	27.59	compression	55.06986	501	0.361	8010	2891.61	4.993657	2342.204
4->10	275	6	34.08	compression	68.023952	501	0.301	8010	2411.01	4.042694	1952.918
4->11	275	7.211103	27.59	compression	55.06986	501	0.361	8010	2891.61	4.993657	2342.204
5->6	235	4	3.61	tension	11.836065	305	0.122	7850	957.7	19.85457	689.544
5->10	275	7.211103	20.48	tension	40.878243	501	0.361	8010	2891.61	6.727295	2342.204
5->11	235	6	2.55	tension	8.360655	305	0.183	7850	1436.55	28.10785	1034.316
5->12	275	7.211103	23.55	compression	47.005988	501	0.361	8010	2891.61	5.850318	2342.204
6->7	235	4	17.21	tension	56.42622	305	0.122	7850	957.7	4.164731	689.544
6->11	275	7.211103	24.52	tension	48.942115	501	0.361	8010	2891.61	5.618883	2342.204
6->12	275	6	20.41	compression	40.738522	501	0.361	8010	2891.61	6.750368	2342.204
7->12	355	7.211103	48.07	tension	64.610215	744	0.537	8090	4344.33	5.494487	4148.835
8->9	275	7.211103	39.73	tension	79.301397	501	0.361	8010	2891.61	3.467783	2342.204
9->10	355	7.211103	68.64	tension	92.526881	744	0.537	8090	4344.33	3.836723	4148.835
10->11	355	7.211103	68.64	tension	92.526881	744	0.537	8090	4344.33	3.836723	4148.835
11->12	275	7.211103	39.73	tension	79.301397	501	0.361	8010	2891.61	3.467783	2342.204
								Total mass (kg) =	63914.95	Total cost ($) =	53687.47

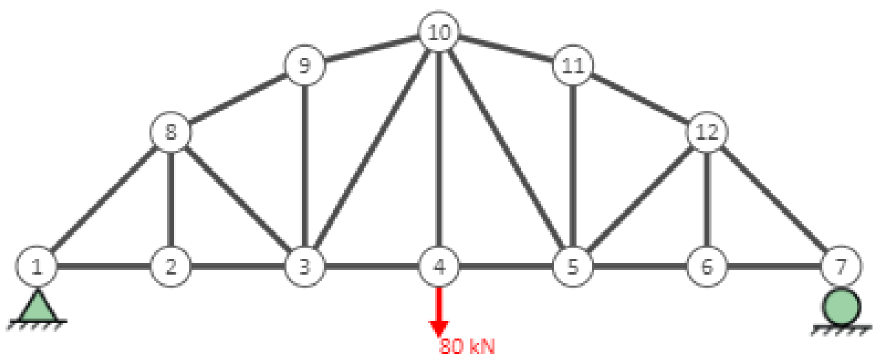
The bridge design is a truss bridge with a X beam pattern. The main purpose of this was to make sure that the bridge can withstand enough force for the bridge to be completely reliable. Which is shown by the factor of safety. However the cost and mass of the bridge are high as a result of the safety. While the cost and mass of the bridge could have been lower if some parts were changed, the whole purpose of this design is to make sure the bridge is going to hold, even in the worst circumstances.

Based on these designs, we are moving forward with Neil's truss. We think it best represents our prioritization of strength, as shown by its design being performance first with high factors of safety. We also think it will appeal to aesthetics, even though this was not as much of a priority.

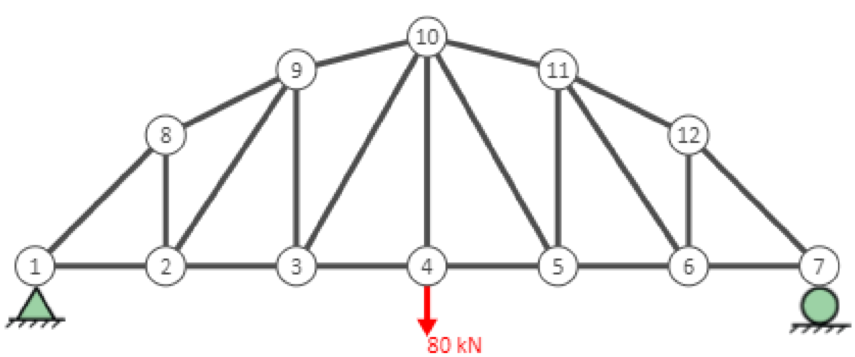
F. Design Reports

Neil Hasenstaub:

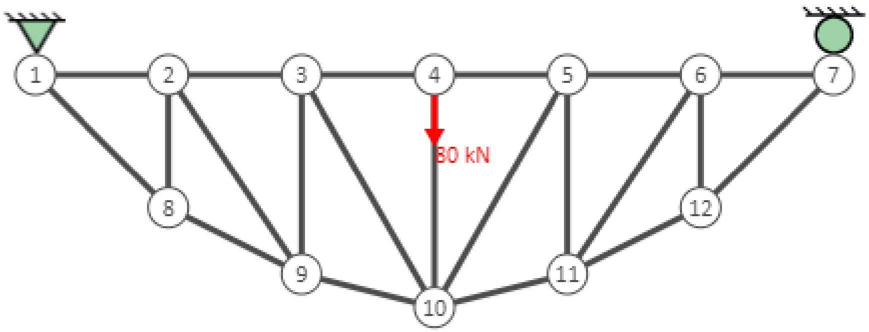
The bridge design began as a thought of what shape the bridge should be. After considering the relatively standard and uninteresting shape of the previous shape of the bridge, I went for a kind of bowstring truss. This might also be described as a Howe truss with curved top chords.



Soon after creating this design, however, I realized that members 8-2 and 12-6 will be zero force. This is because nodes 2 and 6 will only have one member with force in the y-direction, meaning those members must have zero force. To avoid wasting money and efficiency by having unforced members in the bridge, those members were removed and replaced with members 2-9 and 11-6.



These new members cause 8-2 and 12-6 to be nonzero force members, which allows for force to be distributed among more members. Considering the need for a deck truss, this same design was used, only having the structural members of the truss below the deck.



Do note the appearance of the roller support at node 7. While this might appear to be unsupported at this point, the analysis follows the assumption that the supports will be pointing the other way, as how the bridge would be supported at its ends.

Having settled on this design, I reviewed the force analysis of the members.

member	force	direction
1-2	40	compression
2-3	53.33	compression
3-4	68.57	compression
4-5	68.57	compression
5-6	53.33	compression
6-7	40	compression
1-8	56.57	tension
8-9	44.72	tension
9-10	54.97	tension
10-11	54.97	tension
11-12	44.72	tension
12-7	56.57	tension
8-2	20	compression
9-3	26.67	compression
10-4	80	compression
11-5	26.67	compression
12-6	20	compression
2-9	24.04	tension
3-10	30.71	tension
10-5	30.71	tension
6-11	24.04	tension

Since the bridge design is symmetrical, the forces in the members are also symmetrical. This made optimizing the members easier, as symmetric members can be modified in the same way.

To start optimizing the bridge members, the base property of the members was created:

Property #	Type of Steel	Modulus of Elasticity (E)	Type of I-Beam	Cross Sectional Area (A)	Density (kg/m^3)	Cost ($/metric ton)
1	S275	275	IPE 220	426	8010	810

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This used a cross-sectional area and steel grade that were in the middle of the range of combinations. This was to reflect the priority of strength; I would rather overcompensate to begin with than have many or most members be inadequate. Applying this property to all members yielded the following safety analysis:

Member	Force (N)	Stress (MPa)	Factor of Safety	Cost ($)
1->2	40000	93.89671	2.92875	4.13744
2->3	53330	125.1878	2.1967	4.13744
3->4	68570	160.9624	1.708473	4.13744
4->5	68570	160.9624	1.708473	4.13744
5->6	53330	125.1878	2.1967	4.13744
6->7	40000	93.89671	2.92875	4.13744
1->8	56570	132.7934	2.070886	5.851224
8->9	44720	104.9765	2.619633	4.625799
9->10	54970	129.0376	2.131162	4.264776
10->11	54970	129.0376	2.131162	4.264776
11->12	44720	104.9765	2.619633	4.625799
12->7	56570	132.7934	2.070886	5.851224
8->2	20000	46.94836	5.8575	4.13744
9->3	26670	62.60563	4.392576	6.206161
10->4	80000	187.7934	1.464375	7.240521
11->5	26670	62.60563	4.392576	6.206161
12->6	20000	46.94836	5.8575	4.13744
2->9	24040	56.43192	4.873128	7.458877
3->10	30710	72.0892	3.814718	8.339278
10->5	30710	72.0892	3.814718	8.339278
6->11	24040	56.43192	4.873128	7.458877

Only a few members were under the 2.0 factor of safety minimum previously established, indicated in black. Many more, however, were under the increased standard of 2.5. To meet this requirement, I created three more properties:

Property #	Type of Steel	Modulus of Elasticity (E)	Type of I-Beam	Cross Sectional Area (A)	Density (kg/m^3)	Cost ($/metric ton)
1	S275	275	IPE 220	426	8010	810
2	S275	275	IPE 240	501	8010	810
3	S355	355	IPE 300	744	8090	955
4	S235	235	IPE 140	203	7850	720

Properties 2 and 3 were designed with higher capacity in mind. Property 3, using the highest steel grade and large cross-section, was specifically for members that currently were under 2.0 in the factor of safety. Property 4 was created for any members that were greatly exceeding 2.0, but none currently were. Property 3 was thus assigned to members 3-4, 4-5, and 10-4, and Property 2 to members that were under 2.5. I did not pay too much attention to the costs, as this was not one of our priorities as stated before.

This was the resulting safety analysis with the new properties applied:

Member	Force (N)	Stress (MPa)	Factor of Safety	Cost ($)	Property #
1->2	40000	79.84032	3.444375	4.865863	2
2->3	53330	106.4471	2.583443	4.865863	2
3->4	68570	92.16398	3.85183	9.421212	3
4->5	68570	92.16398	3.85183	9.421212	3
5->6	53330	106.4471	2.583443	4.865863	2
6->7	40000	79.84032	3.444375	4.865863	2
1->8	56570	112.9142	2.435478	6.88137	3
8->9	44720	89.26148	3.080836	5.4402	2
9->10	54970	73.88441	4.804803	9.711163	3
10->11	54970	73.88441	4.804803	9.711163	3
11->12	44720	89.26148	3.080836	5.4402	2
12->7	56570	76.03495	4.668906	13.32361	3
8->2	20000	46.94836	5.8575	4.13744	1
9->3	26670	62.60563	4.392576	6.206161	1
10->4	80000	107.5269	3.3015	16.48712	3
11->5	26670	62.60563	4.392576	6.206161	1
12->6	20000	46.94836	5.8575	4.13744	1
2->9	24040	56.43192	4.873128	7.458877	1
3->10	30710	72.0892	3.814718	8.339278	1
10->5	30710	72.0892	3.814718	8.339278	1
6->11	24040	56.43192	4.873128	7.458877	1

All members had factors of safety of at least 2.5. Property 4 was not applied to any members but was still included in the list of properties to reflect its function as a fallback for unoptimized members. The final cost was $164.03 with a mass of 480.59kg.

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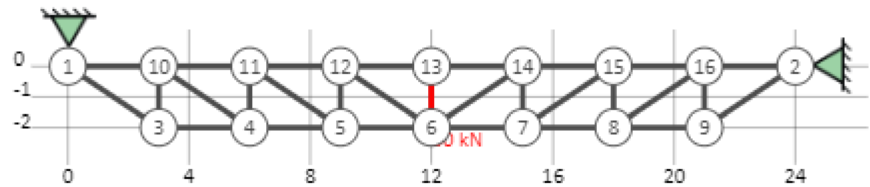
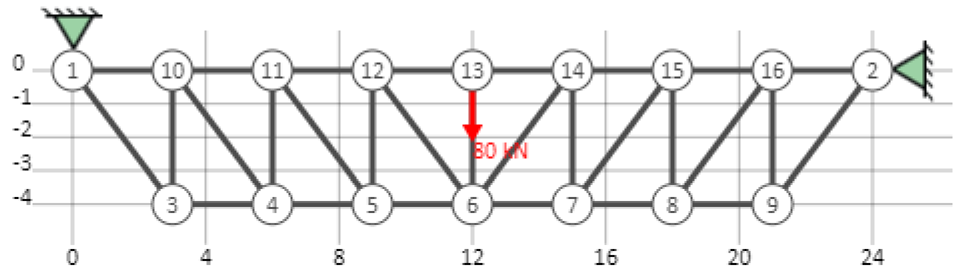
Blayne Rutz:

It started with an upright warren with vertical design with the vertical struts starting at 5 meters long. But, I thought having the vertical struts on the bottom looked nicer, and it helped with taking some force off members 5-6 6-7.



The vertical struts were shortened to 2 meters, to reduce cost, and I thought they would work better since there would be less stress caused by weight.



Members 5-6 and 6-7 had too big a force to compensate for with the size and material. So, I lengthened the vertical struts to 4 meters, which helped with reducing the load on 5-6 and 6-7 within a manageable amount.

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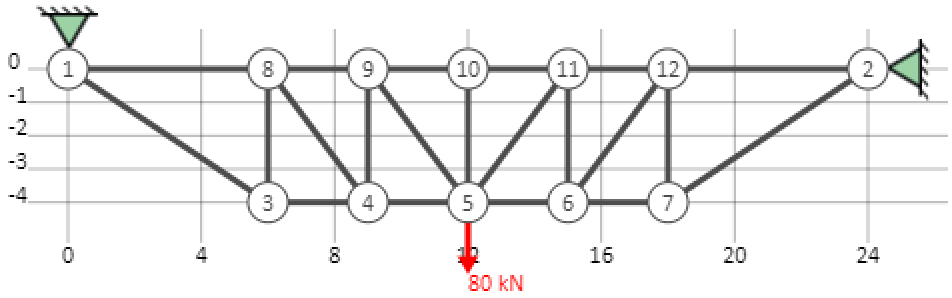

I removed nodes 3-10 and 9-16, because the members weren't under much stress, helping reduce the cost.

After designing the bridge, I switched focus towards the material and size of each member. This was probably the most time consuming part, since it would affect the forces on each member, as well as the weight of the bridge. To determine which combination was best, I used excel to find the factor of safety of each member, and plugged in the different values for the cross-section area and material to get the factor as close to 2 without going under. Once I had the sizes, I used excel to find the cost as well.

I used 15 versions for the properties, one for each combination, S235 with IPE40, S275 with IPE40, S355 with IPE40, S235 with IPE180, etc.

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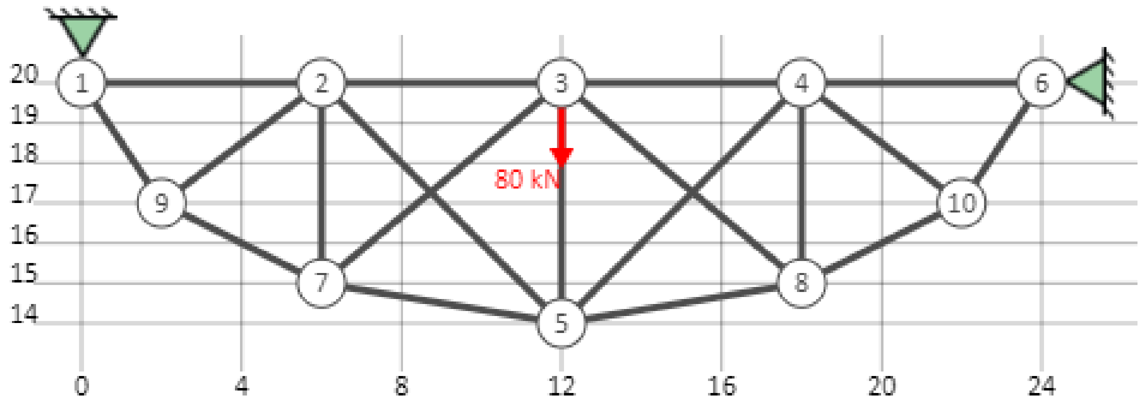
Members	Factor of Safety
1->8	2.908841463
1->3	2.097212592
3->4	2.29625
4->5	2.273333333
5->6	2.273333333
6->7	2.29625
7->2	2.097212592
8->9	3.507720588
9->10	2.48337156
10->11	2.48337156
11->12	3.507720588
12->2	2.908841463
3->8	2.096875
4->9	2.096875
5->10	0
6->11	2.096875
7->12	2.096875
4->8	2.1655
5->9	2.1655
5->11	2.1655
6->12	2.1655

Each member meets the minimum safety rating of 2 except for member 5-10 which had no force placed on it.

Christian Burton:



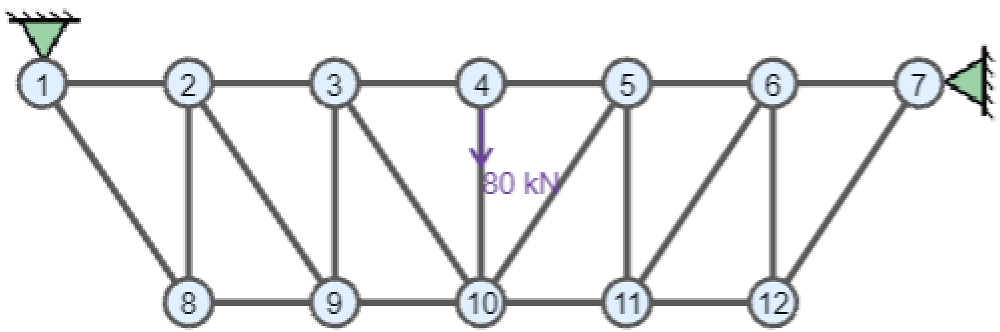
I originally started with an upside down tied arch design for the other truss members. I did this to still keep some aesthetic while also trying to design a material efficient bridge to keep costs down. I started with 6 nodes in a straight line along the top for the road, each spaced out 6 meters. I also added 3 more nodes in an arch. I then combined all of the nodes with truss members, but I realized that there were not enough joints for the bridge to meet the criteria of having a safety factor of 2 on every member. I went back and adjusted the amount of nodes and added 2 more nodes to the bottom arch. Now with 5 nodes on the bottom, I was able to add 4 more trusses, increasing the structural integrity of the bridge.

I chose S235 steel for all of the members using IPE 180 beams. Upon completing all of my calculations I realized that the safety factor on some of the members fell below the requirement. I went back to these members and changed them to either IPE 220, 240, and 300 beams accordingly. After redoing all my calculations every member exceeded the 2.0 requirement for the safety factor.

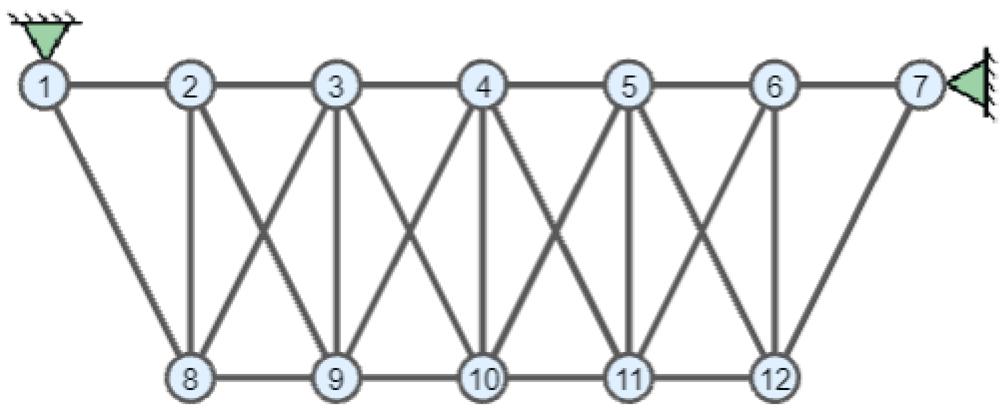
Neil Hasenstaub
EGN2001C

Zachary Alexander:

The first bridge idea was a parker bridge, however part way through the designing process it was changed to a truss bridge due to its simple design which is easier to work with.



While seeing how the force affected the bridge, the choice was made to change the design again to be more safe rather than care about design or cost. The result was a truss bridge with a X beam pattern to have a more sturdy design.



Then during the calculations, parts with more force on them were given stronger parts to make sure that the factor of safety didn't go below 2.5. Which shown in the calculations, they never did. Anything that was below 20 kN of force were given S235 steel and IPE 180 beams, anything between 20 kN and 40 kN were given S275 steel and IPE 240 beams and anything above 40 kN were given S355 steel and IPE 300 beams. This was to ensure that the bridge would hold plenty of weight.

Neil Hasenstaub
EGN2001C

G. Manual FBD Evaluation