Spaghetti Bridge Design

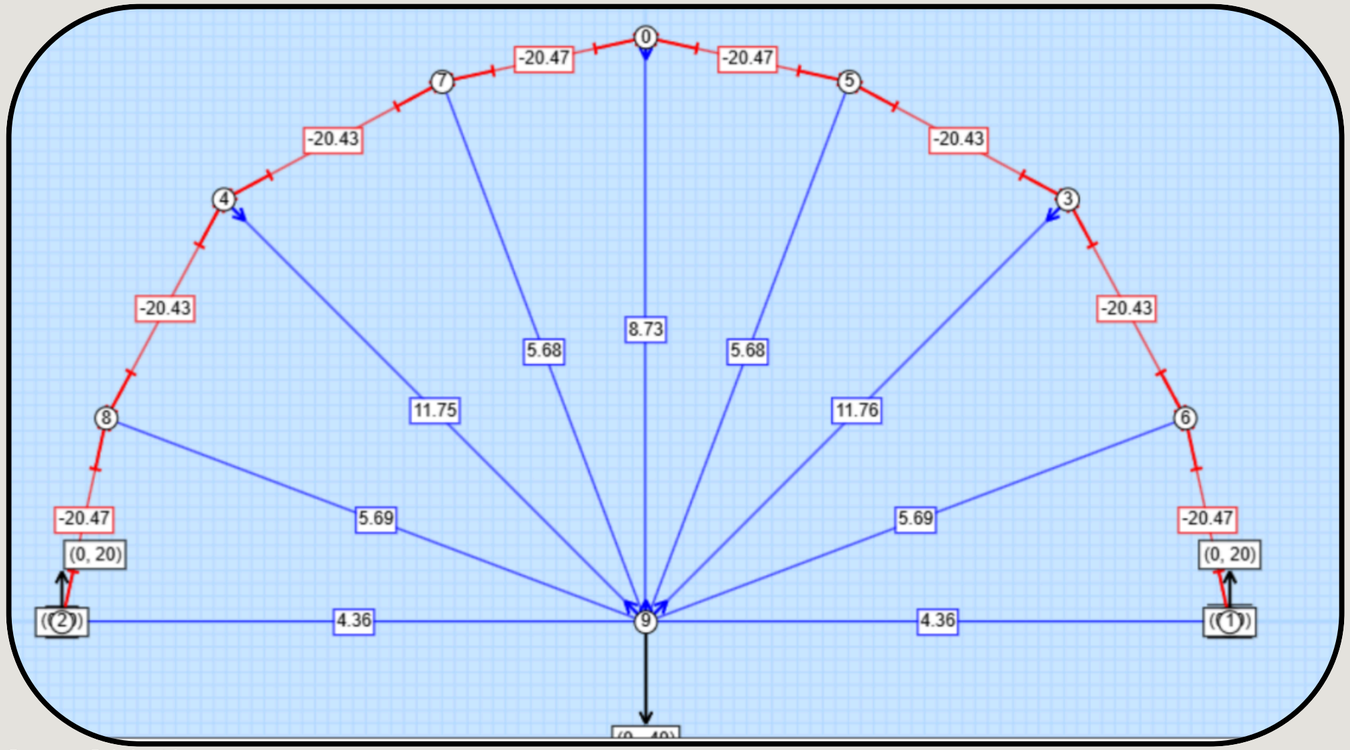


PRESENTED BY

Jeffrey, Aiden, Harry, Andy

Brainstorming - Everyone's Designs

Jeffery's Truss



Source: Original Image

Pros:

- Relatively simple to build & calculate forces as all the radius and arc lengths are the same
- Good force distribution

Cons:

- It's only 50 cm on the base to make the base only two spaghetti long, which is not enough to fit the gap

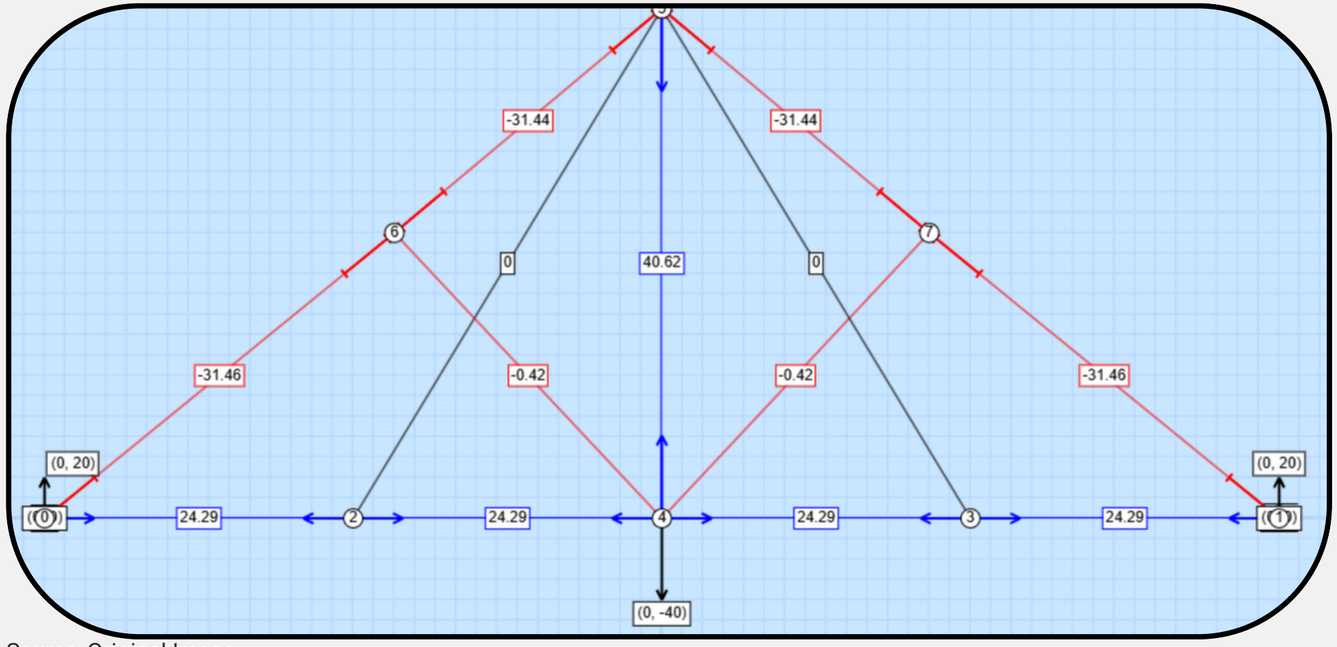
Aiden's Truss

Pros

- Straightforward design, mainly focusing on a triangle and with some support beams for it

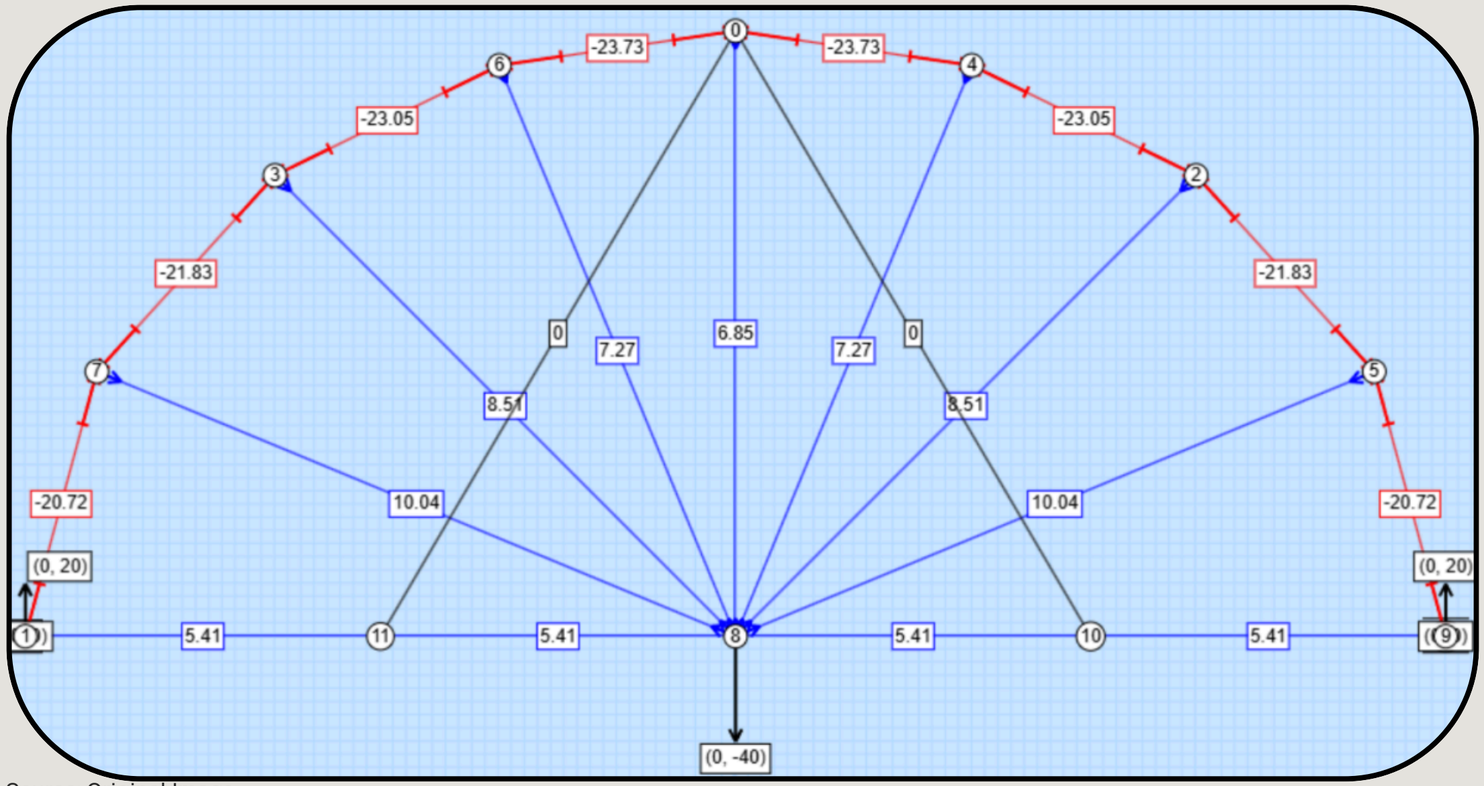
Cons:

- The center vertical length and sides of the triangle is under too much force
- Have to have multiple sections of spaghetti for one length
- The four support beams are almost useless as they are under very little force



Source: Original Image

Harry's Truss



Source: Original Image

Pros:

- Had similar thoughts to Jeffery's design but decided on a half-oval instead of a semi-circle
- The tension on the radial members is not that high

Cons:

- The rim lengths are under a decent amount of force
- Needs four sections to make the base

Andy's Truss

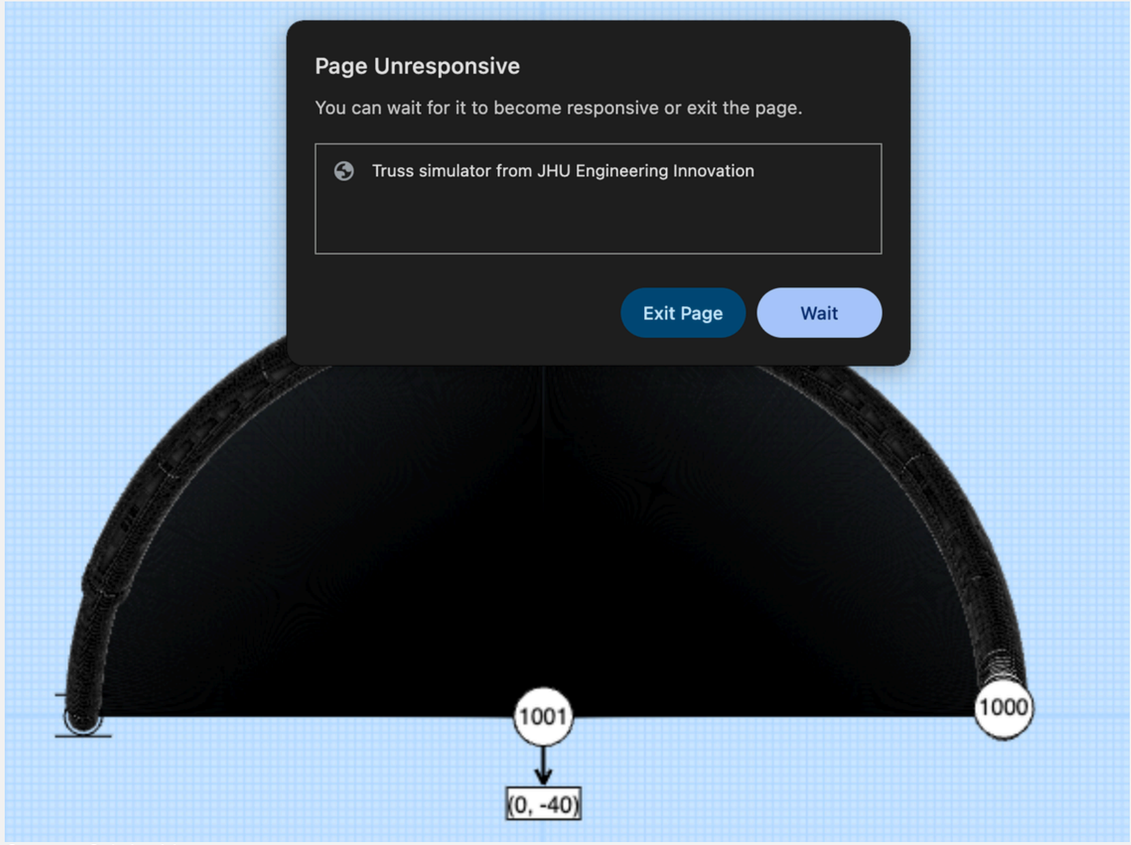
The idea was to minimize buckling length while maximizing tension distribution

Pros:

- Compressed members are very small so they will not buckle
- Tension force is spread evenly across 500 members

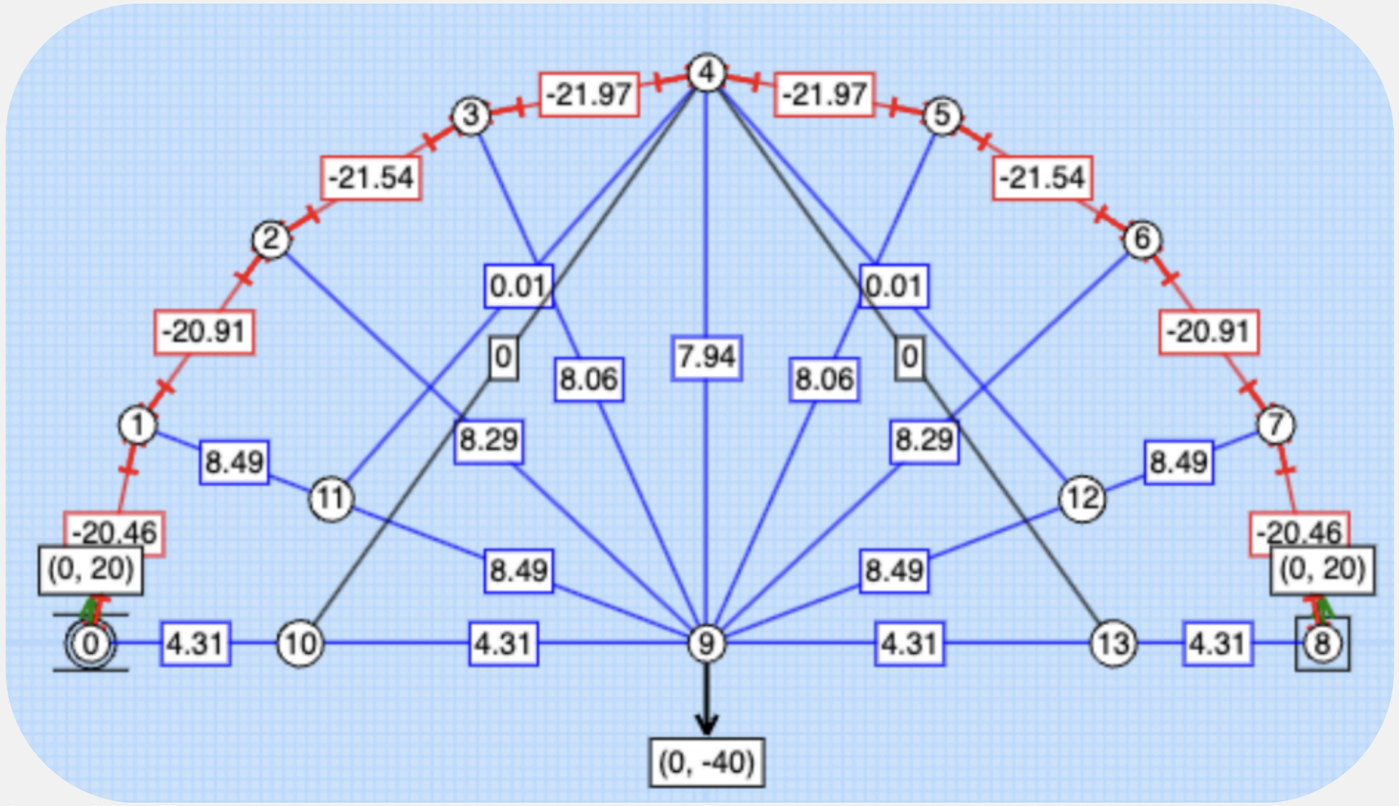
Cons:

- As you can see on the picture, it is so complex that it caused the page to crash
- Impossible to build and solve for the force on each node



Source: Original Image

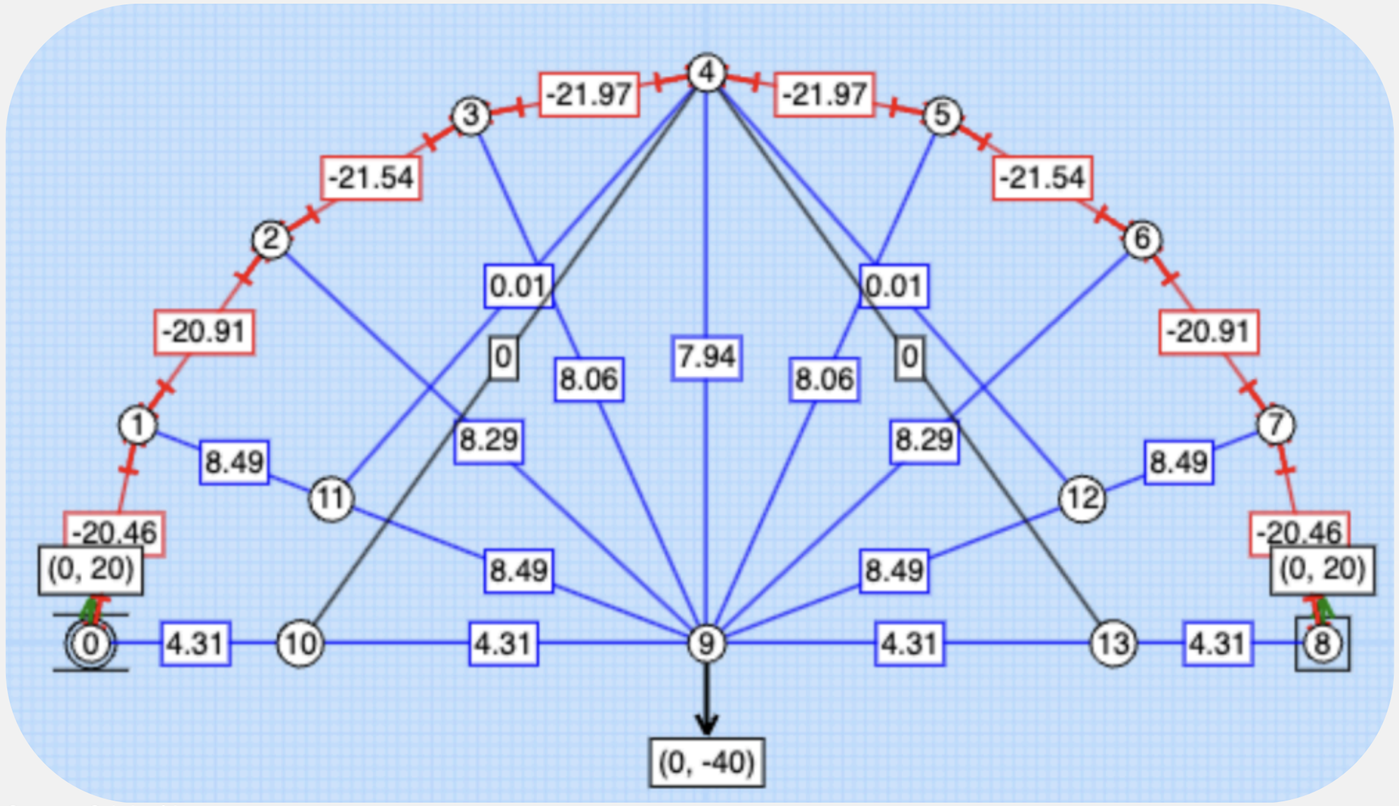
Final Design



Source: Original Image

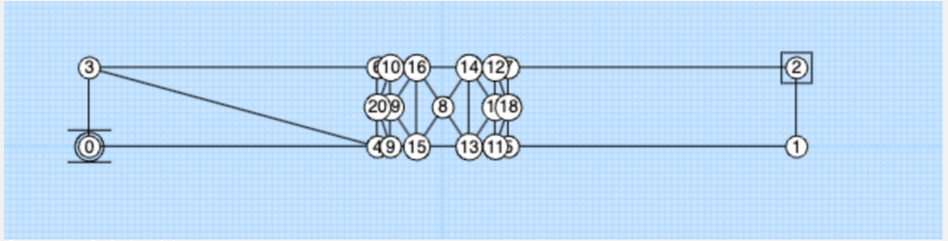
This final design incorporates Jeffrey's semi-circular concept, Harry and Aiden's elongated design, as well as Andy's increased-number-of-support-beams design. It is the perfect combination of all four members' proposals and balances out the issues present in each individual design.

Final Design



Source: Original Image

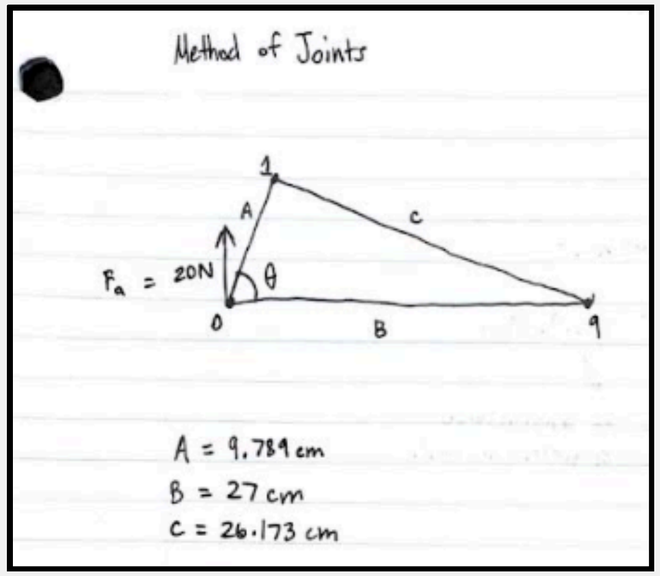
- Estimated Length: 54 cm
- Estimated Height: 25 cm



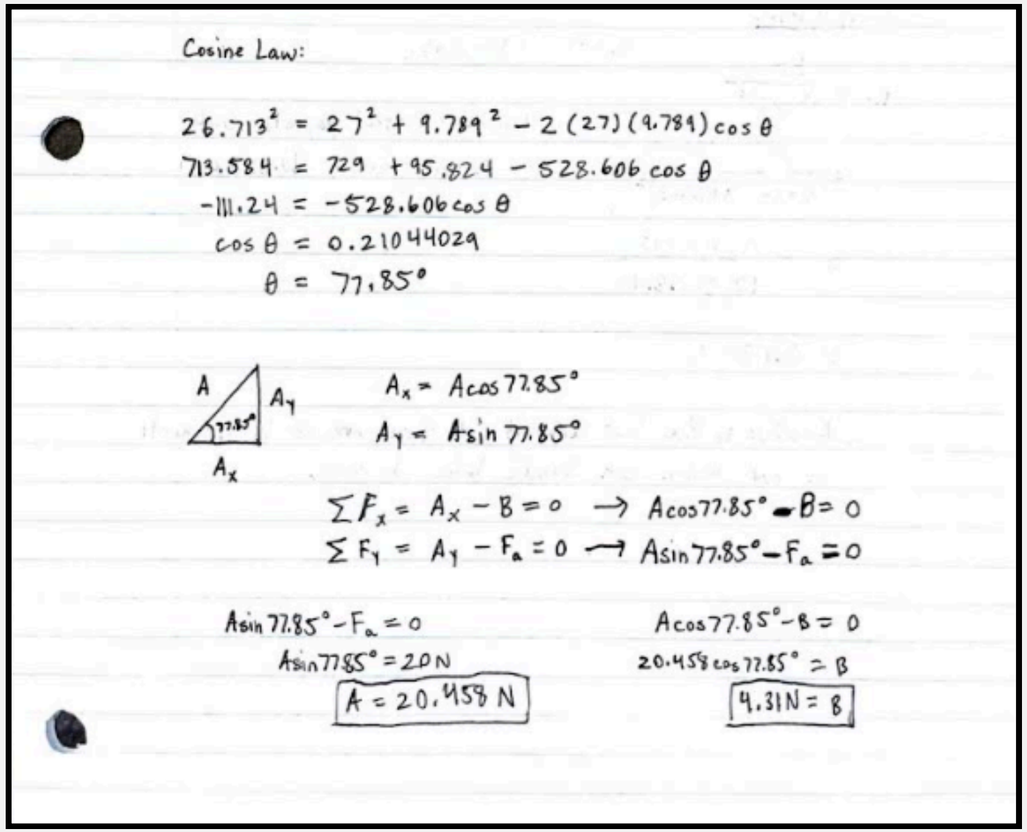
Source: Original Image

- Radial Design continued within the road of the bridge

Sample Truss Members in Tension & Compression



First, the side lengths of triangle ABC were determined from the truss simulator.



***Note that here, variables A, B, and C now represent forces.**

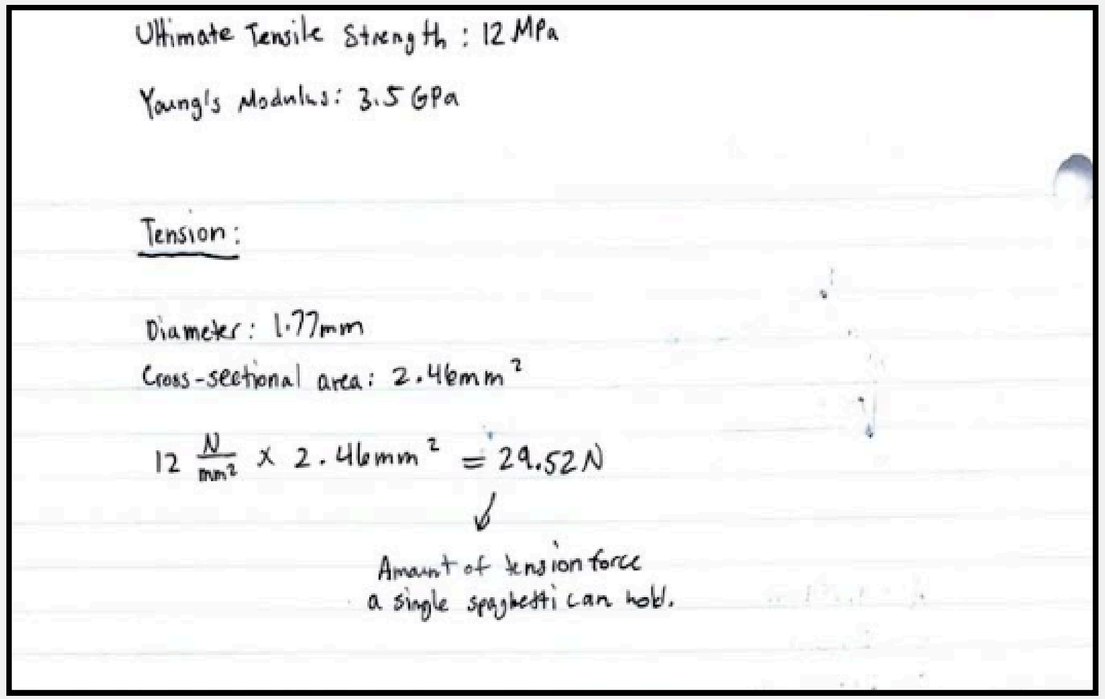
Since triangle ABC is not a right-angled triangle, the Law of Cosines was used to calculate the angle θ between sides A and B. By substituting the given side lengths into the formula, angle θ was found to be approximately 77.85°.

Next, force A was split into its x- and y-components using trigonometric ratios. Because the bridge is in static equilibrium, the sum of all x- and all y-components must each equal zero. This condition enables us to solve for the magnitudes of forces A and B, given that the vertical component of force F_a is 20N.

Thus, truss member A is experiencing compression of 20.458 N, and truss member B is facing 4.81 N of tension.

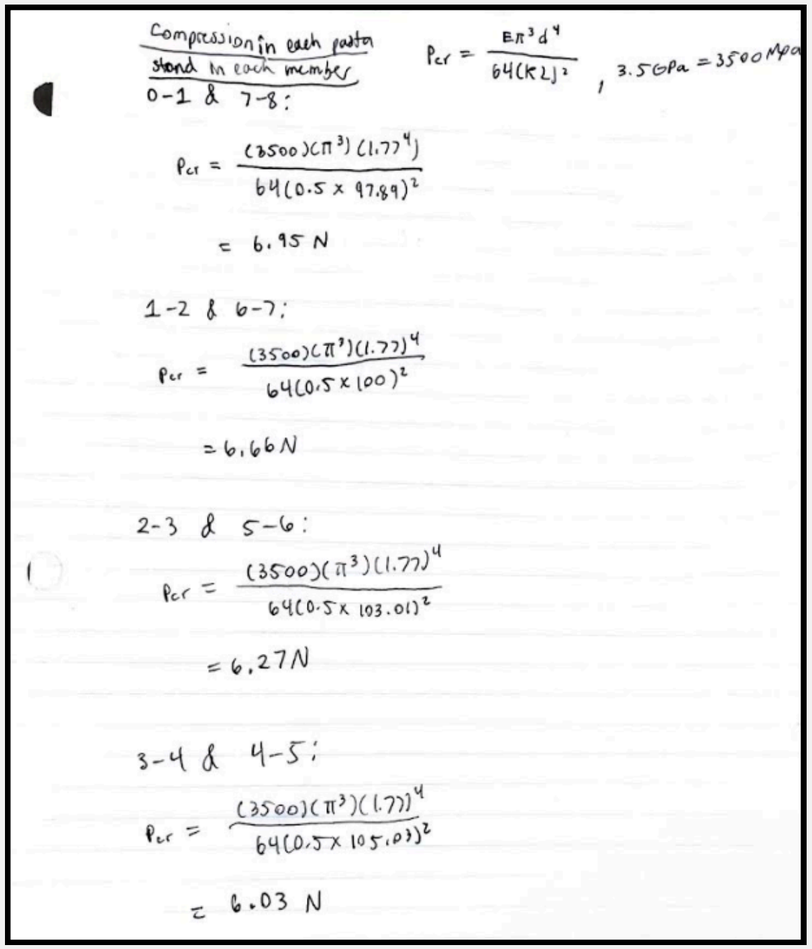
Image Sources: Original Image

Calculations for # of Spaghetti (Part 1)



Because the ultimate tensile strength (UTS) is independent of length, the tension force that one strand of spaghetti could withstand was determined by multiplying the UTS by the cross-sectional area of a spaghetti. Force = UTS * Cross-Sectional Area

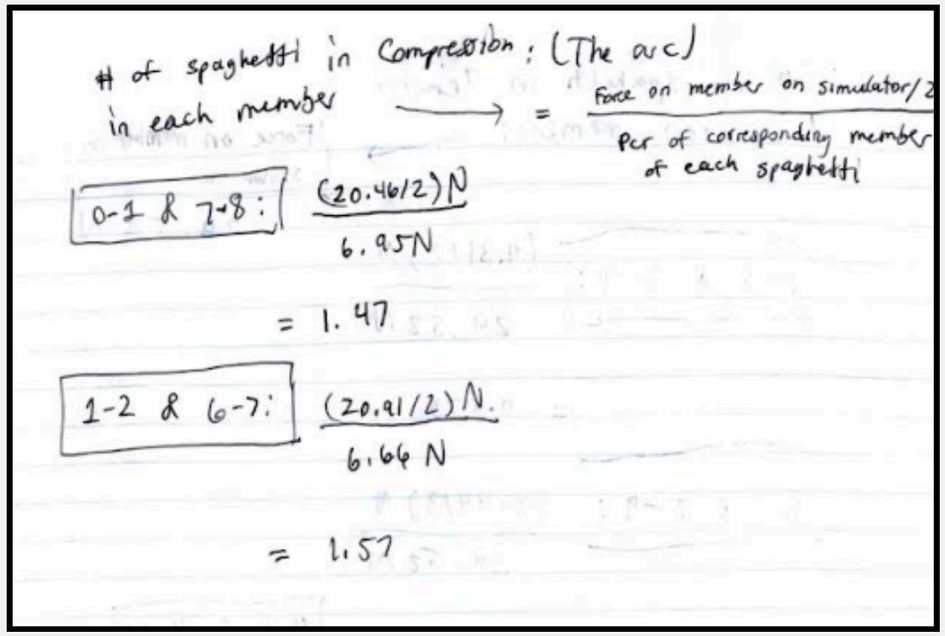
Image Sources: Original Image

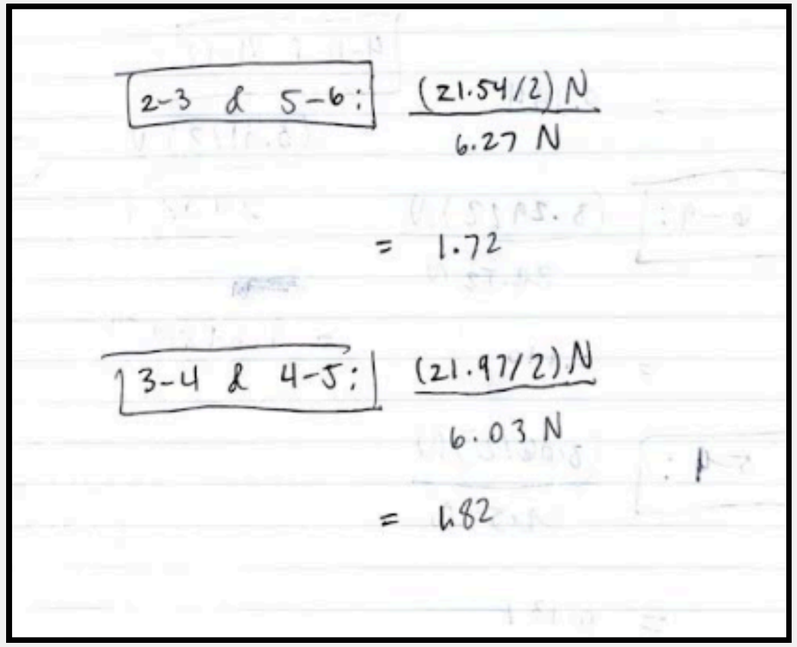


Because the critical buckling load is dependent on length, the length of every member in compression was used in the buckling equation to solve for the amount of force that would cause each one to buckle. Additionally, the value of 3.5 GPa was used for Young's Modulus, and converted into MPa to be consistent with mm as length.

An example of determining the P_{cr} is the member that connects node 0 to 1, which is 97.89 mm long, and buckles when a force of around 6.95 N is applied.

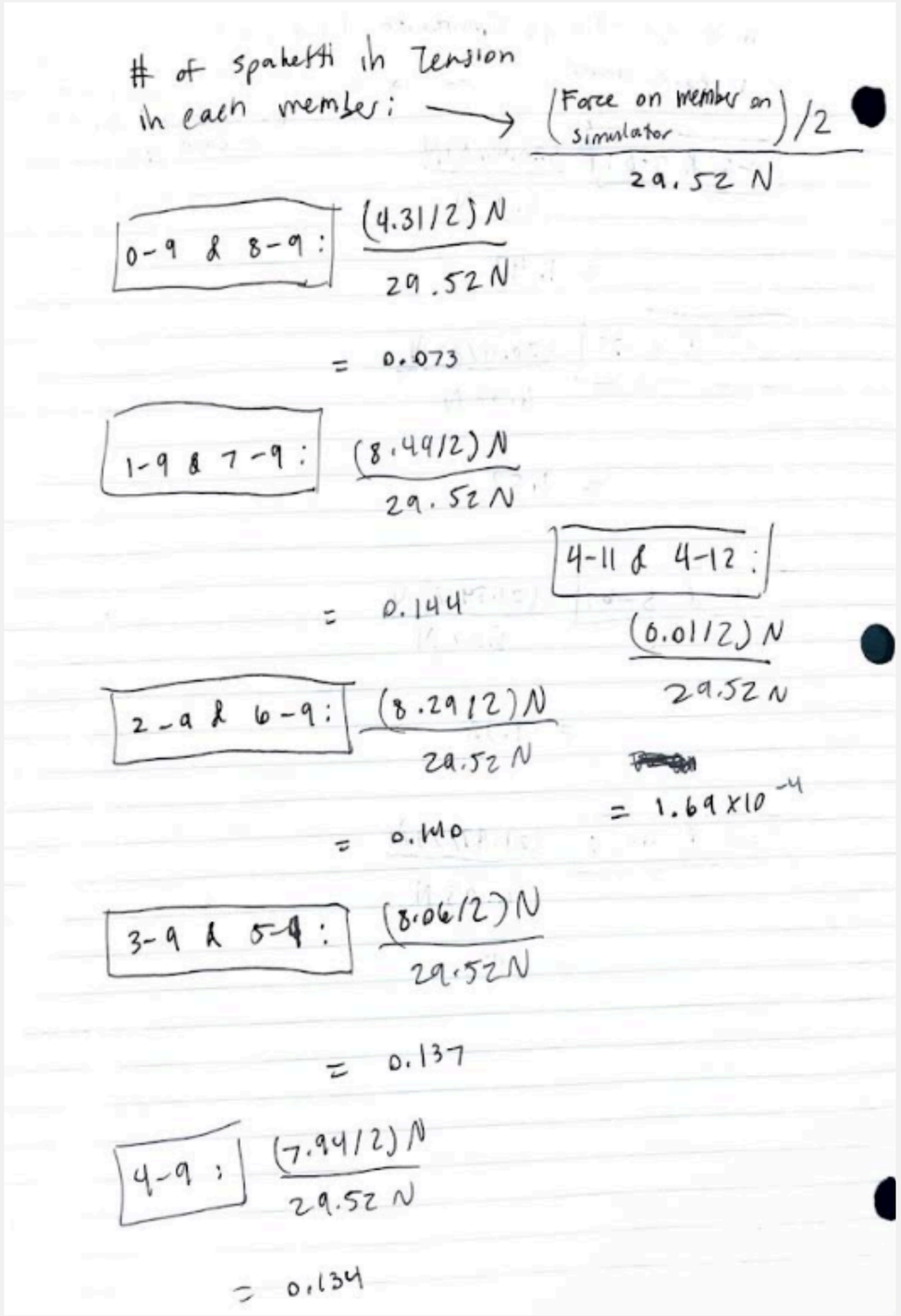
Calculations for # of Spaghetti in Compression (Part 2)





The number of spaghetti in compression was determined by dividing half of the force on each truss member facing compression by the critical buckling load of a pasta strand in that member. Half the force is used because the simulator, being 2D, only considers half of the entire bridge as the whole structure. Thus, in reality, the force applied to every member in the simulator would be distributed so that each half only experiences half the forces. Dividing these values provides how many spaghetti strands is needed to withstand the forces applied from the 40 N load. These values means that theoretically, 2 strands of spaghetti could resist the load of 40 N for members facing compression.

Image Sources: Original Image



Calculations for # of Spaghetti in Tension(Part 3)

The process for # of spaghetti in tension is similar to that of compression. However, because length does not impact the UTS, each strand of spaghetti can withstand the same tensile force: 29.52 N.

Dividing the tensile force applied to each truss member experiencing tension, it shows how many stands of spaghetti are needed to withstand each force applied. Note that the force on each member is halved for the same reason provided for calculations on compressed members.

These values mean that theoretically, 1 strand of spaghetti in members facing tension could resist the load of 40 N.

Design Clarifications

Since we wanted to make use of the mass we were provided, we decided to increase the # of spaghetti for every member in the design to allow the bridge to withstand a greater load.

We decided to use 4 spaghetti for every member in tension and 34 spaghetti for every member in compression.

Image Sources: Original Image

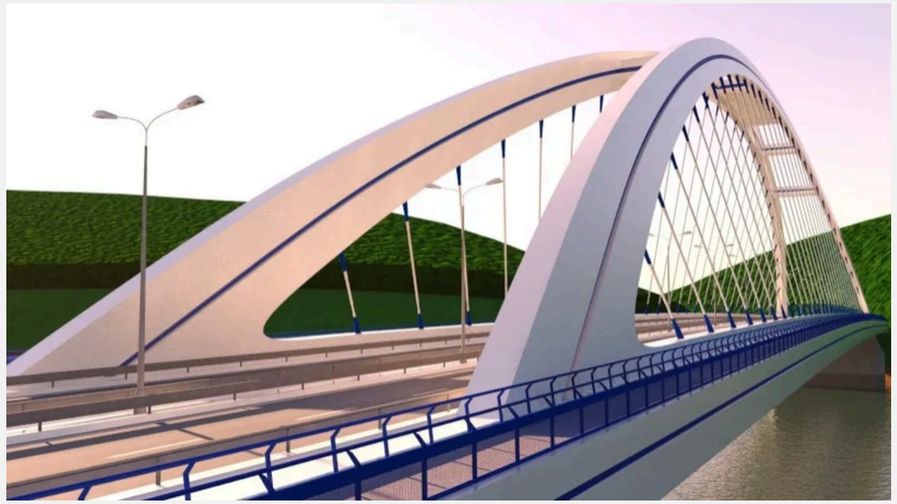


Image Source: Open Domain

Mass Analysis

Length of One Rim: 81.2 cm

Length of One Side’s Radial Members: 235.1 cm

Length of Middle Connectors: 54 cm

Thickness for Rim: 34 Strands

Thickness for Radial Members: 34 Strands

Thickness for Middle Connectors: 4 Strands

Mass of 25 cm Strand: 0.9g

Mass Per Centimeter of Spaghetti: 0.036 g/cm

$$0.036\frac{g}{cm} \times (81.2 + 235.1 + 54)cm = 200g$$

Total Mass For All of the Spaghetti

200 g + 20 g wood + ≈ 30 g epoxy = 250 g Total Mass

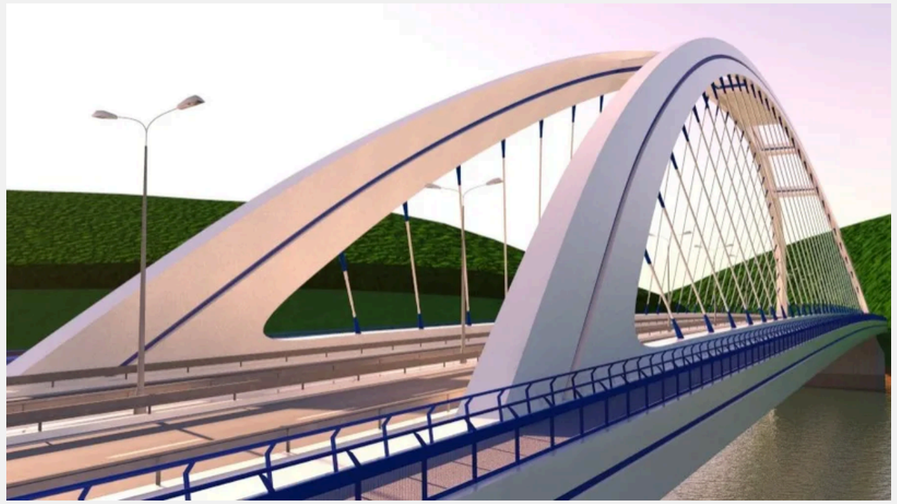


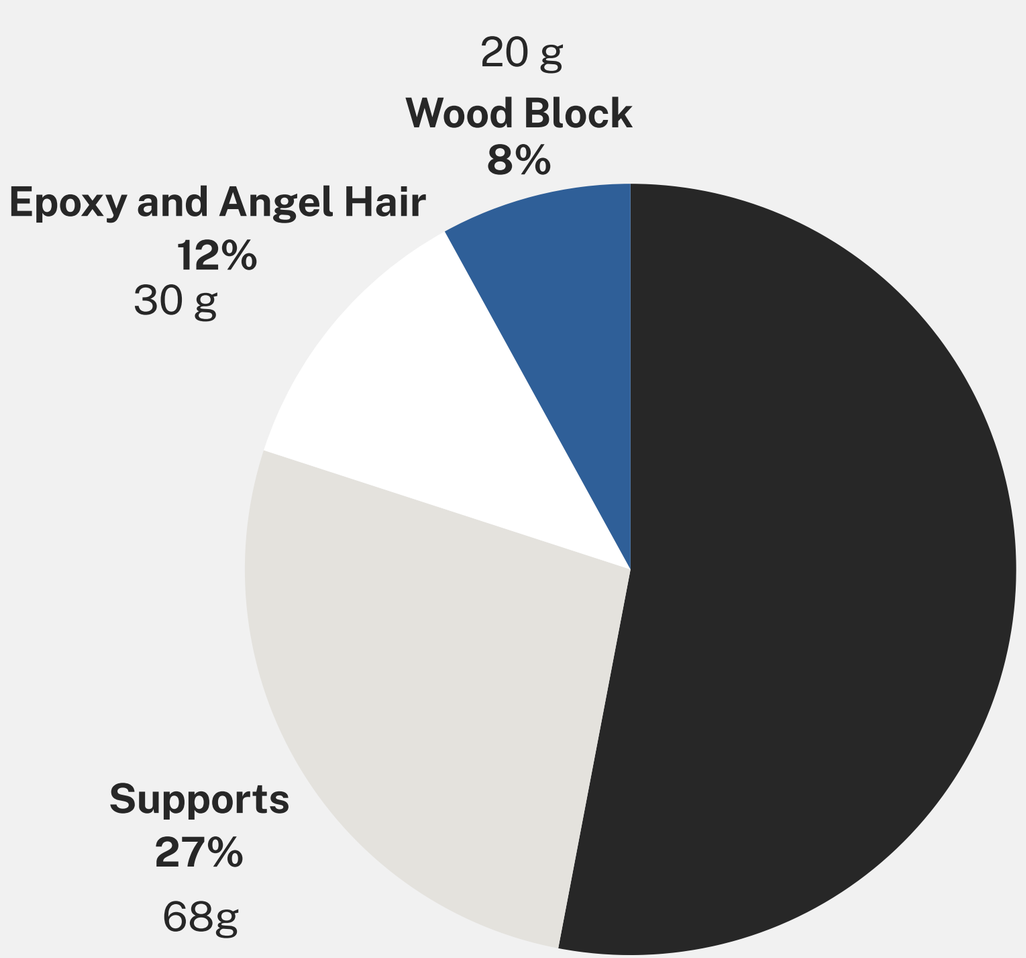
Image Source: Open Domain

Mass Analysis

Our bridge will be a round 250g, with the epoxy and middle of the bridge being the remaining 30g.

Total Mass

250 g



Max Load Analysis

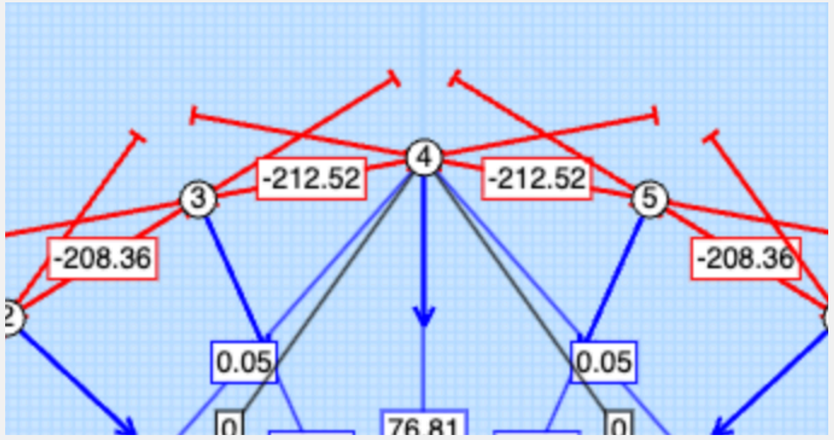
The compressed 34 spaghetti-thick radial members will buckle at **426 N.**

$$P_{CR} = \frac{\pi^2 EI}{(KL)^2}$$

$$\sigma_{UTS} = \frac{F_{max}}{A_0}$$

The tensioned 4 spaghetti thick radial members will reach their ultimate tensile strength at **236 N**

The max load this bridge can carry is confined by either the tensioned radial members or the compressed arc members. The value that is reached first defines the maximum load which is **388 N** or 40 kg on the simulator. But because the simulator does not consider another half, the maximum load is **776 N** or **80 kg**.



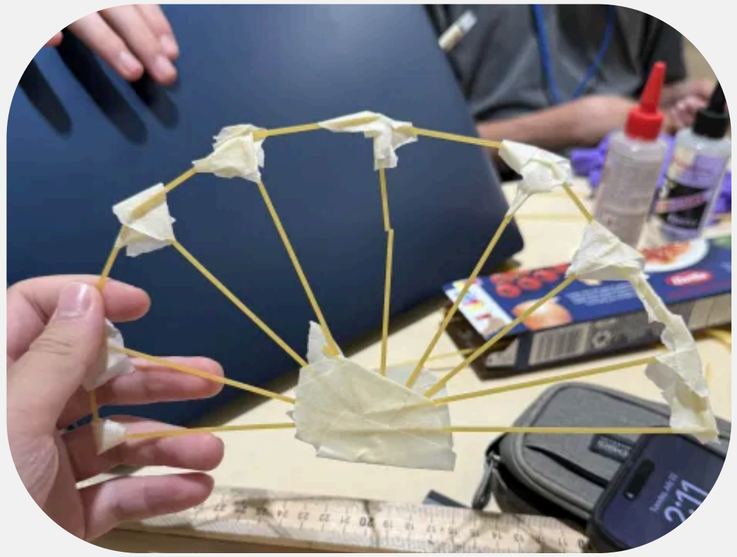
External Forces		
Node	Fx [N]	Fy [N]
9	0	-387
0*	0	193.5
8*	0	193.5
*Reaction forces at a support		

Image Sources: Original Image

Bridge Build & Test



Key Stages - Preperation



<- 1. First small prototype made by using one strand for each member





<- 3. Made the rims of various length 34 strand thick, left the middle empty to maximize the area moment of inertia

2. Made the radiuses of -> various length 4 strands thick



4. Drew the layout on → the table, began setting the radiuses in their proper place

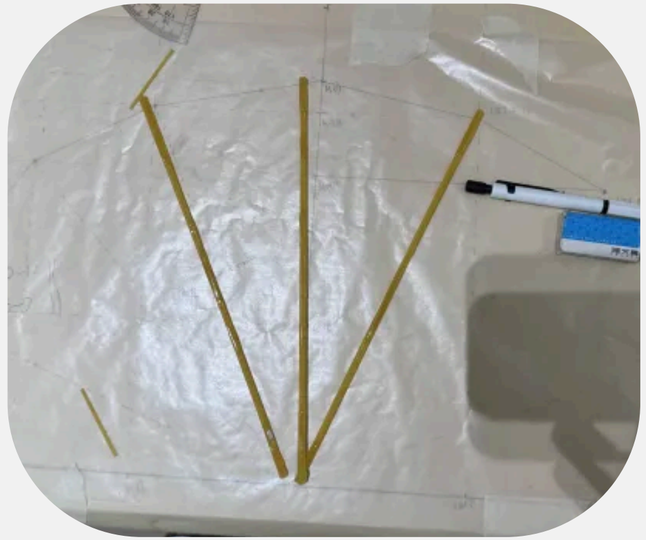
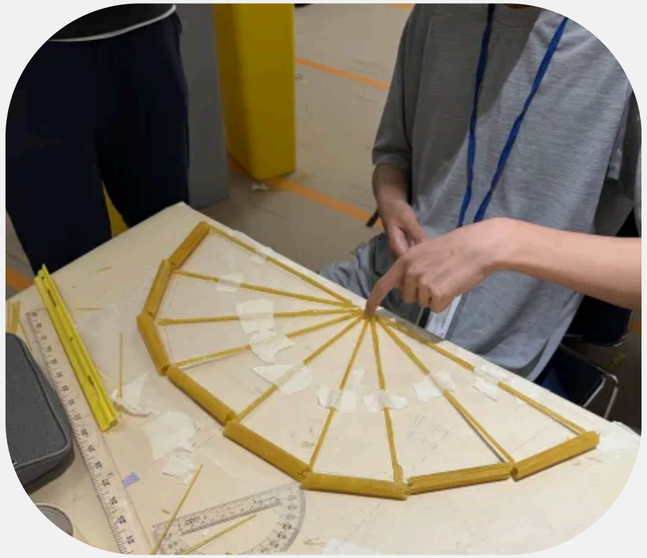


Image Sources: Original Image

Key Stages - Building



<- 5. First truss is done, the radiuses are epoxyed between the rim sections, put gusset plates on both sides to keep the radiuses in center



<- 7. After the trusses dried, we started to put the connectors on one side of the truss, then connected the other side to it

6. Second truss is made ->



4. **Final Product**!!! →

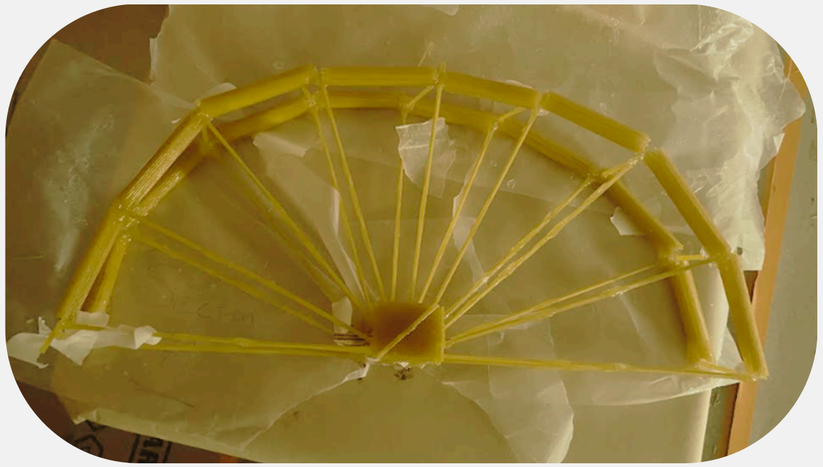
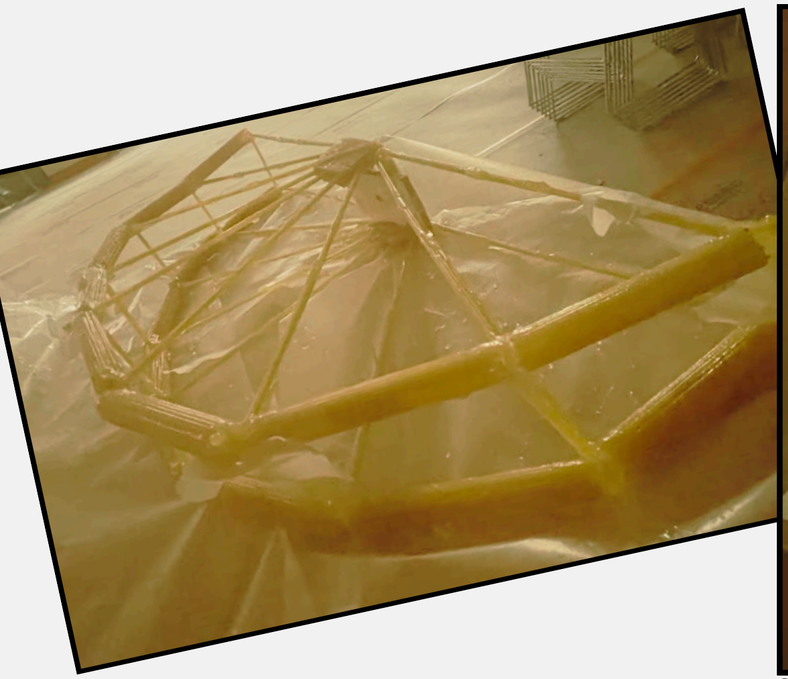
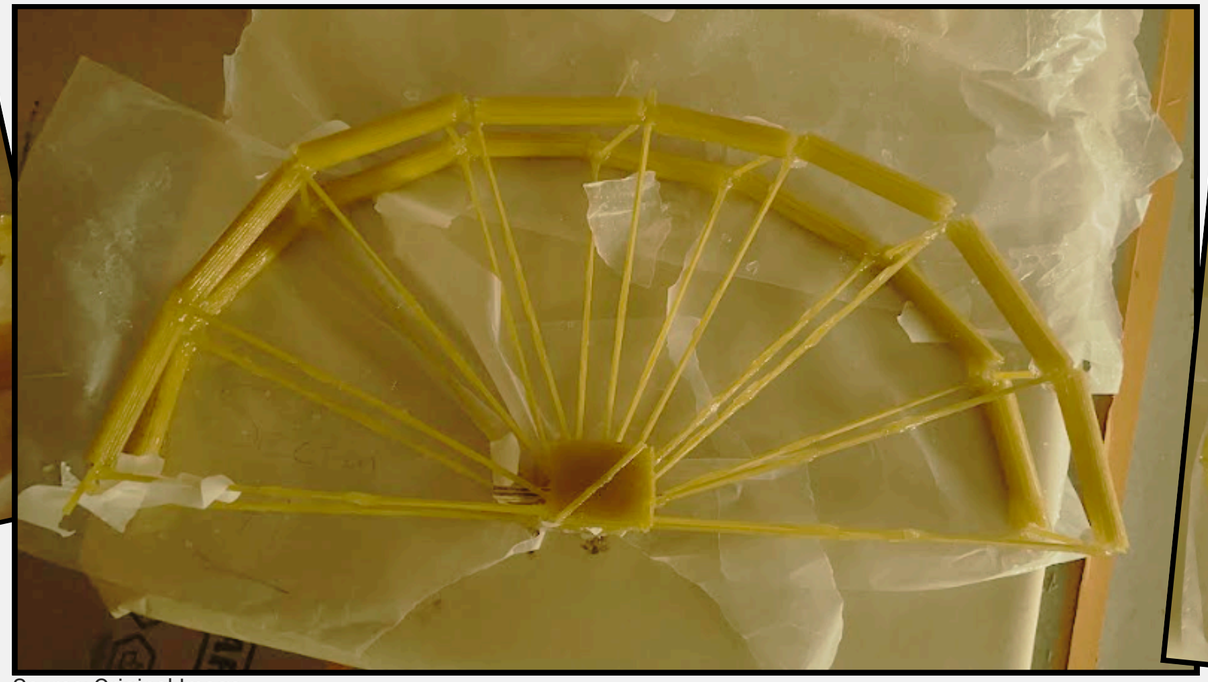
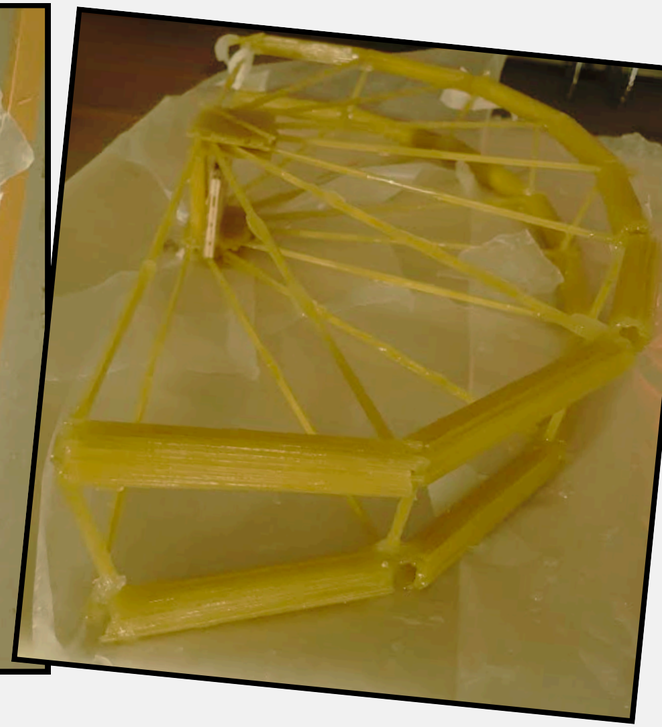


Image Sources: Original Image

Final Product

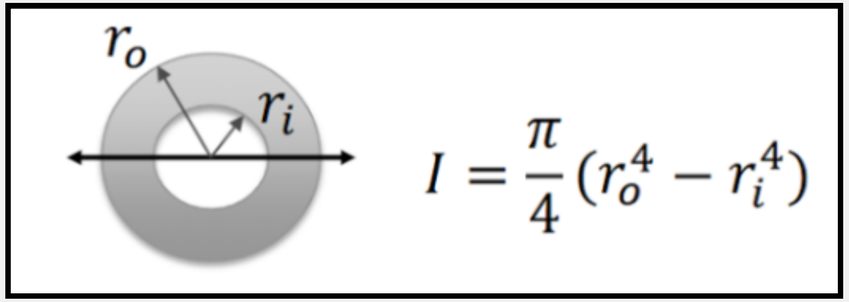






Source: Original Image

Challenges (Part 1)



Source: Open Domain

Our first challenge arose with the arch of the bridge. Our goal was to design a larger cross-section to achieve a longer radius, thereby increasing the load capacity without inducing buckling. Since the arch is constructed from hollow columns, increasing the external radius (r_o) enhances the area moment of inertia, which, when positioned in the numerator of the buckling equation, theoretically allows the structure to withstand greater loads. However, creating these hollow columns presented difficulties. Initially, we epoxied 34 spaghetti strands together and then wrapped them around a wooden stick covered with wax paper until the epoxy cooled. This process proved problematic: our gloves became covered with epoxy during wrapping, and once the column was in place, any attempt to hold it resulted in the gloves sticking. The effort required to detach the gloves sometimes dislodged the spaghetti, ruining many attempts and consuming both time and materials.

For the columns we successfully removed, another issue emerged: wax paper often remained stuck to the interior surface. Because the spaghetti strands were epoxied together, we removed the paper by scraping the inside using a single scissor blade. We then reinserted the wooden stick to push out the loosened fragments. However, removing the columns from the stick immediately after cooling meant the shape wasn't always well retained. In some cases, the cross-section had slightly collapsed or shrunk, and reinserting the stick caused it to crack the column walls. This led to further breakage and more resources lost.

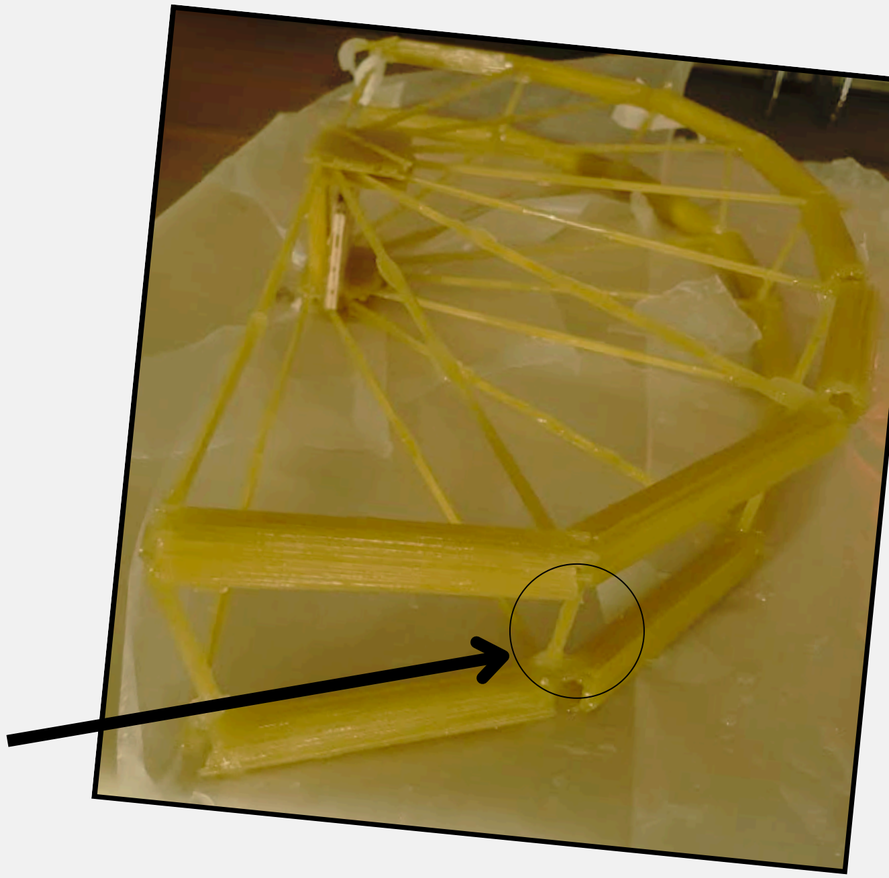


Source: Original Image

Challenges (Part 2)

Another challenge was the final assembly of all our components on each half of the bridge. Particularly, creating the arch with the spaghetti columns was extremely difficult. Since there is no flat surface on them to properly attach the internal members that face tension, attempting to epoxy them together was problematic. Creating a strong attachment would require a lot of epoxy, and even after, required holding for an extensive period, as the members would slide off due to the curvature of the column. Even with a lot of epoxy used, the connections were not as strong as we wanted them to be.

A third challenge was connecting both halves of the bridge. We created moderately thick sticks composed of multiple spaghettis to connect the arch and the base of each half. However, the edges of them all were not consistent. When we attempted to place one half on the other, some sticks were longer than others, making the shorter ones unable to create a connection. With timing running out, we had to move on and leave those members unconnected.



Future Improvement 1

Problem: Based on our calculations of how much force each member could stand, we chose to make the rim 34 strands thick and the radiuses only 4 strands long. This was a mistake as even though it looked fine on the simulator, this made the thin radiuses hard to hold the thick rim up. This design has caused many problems. First, it made our design almost go above the height requirement, which would've deducted points from our score and net load. Then, it also made our mass go way beyond the allowed mass, which significantly reduced our net load, and also affected our rubric score.

I**mprovement 1**: In future designs, we would reduce the number of strands used in the rim members to around 6-10 and switch from a hollow tube to a solid bundle. The hollow formation added complexity without providing the strength we wanted. A smaller, solid rim would dramatically reduce the mass - potentially by over 100 grams - and improve the bridge's strength-to-weight ratio, helping us avoid penalties and improve structural efficiency.

Improvement 2: We would also reinforce the diagonal members (blue supports) by increasing them from 4 strands to 6-8 strands each. These members are critical for transferring the load. Under-bulking them made them a weak part of the bridge, contributing to structural failure. Increasing their thickness would allow for better load distribution and significantly improve the overall performance and balance of our bridge structure.

Future Improvement 2

Problem: Another major challenge we faced was joining the web (diagonal) members to the hollow rim. Because the rim was made of bundled sphagetti tubes, it was impossible to always align the the edge on the two ends of the tube (see attached picture). Due to this, there was very little surface area for the expoxy to bond with, and it was extremely difficult to align the ends of the web members exactly with curved rim. This caused weak joints that easily cracked or came loose under small load.

Solution: To solve this in a future design, we would switch to a solid rim made of tightly bonded strands to provide a larger, flatter bonding surface. We would also pre-notch the rim or flatten the contact ponits slightly to help the web members seat securely. Another idea is to use temporary tape during assembly to hold joints at specific angles while the epoxy dries. With these changes, the joints would be much stronger, easier to construct, and less likely to fail under stress.



The edge of the ends of the rims are uneven, with some strands poking out.

Future Improvement 2 (continued)





The uneven edges on the ends of the hollow rim caused small contact surfaces with the epoxy, resulting in difficult connections with the diagonal web members.

Future Improvement 3

Problem: The last big problem that we faced was that we neglected effiency during the design process. During the planning phase, we made the dimensions and length of the members all different and very complex, which has led to us not finishing the design in time. Also, since we wanted to maximize our dimensions, we made the center radius 25 cm, neglecting that there will be a rim section above it.

Solution: When designing a prototype, it is important to take into consideration every aspect of assembling it. Each piece's fabrication should be already be designated to certain group members during the design phase so no one will ever be doing nothing. The design's dimensions should be simple enough to have minimal places for error because anywhere that can go wrong will go wrong. Overall, designing should not just be done away from the construction of the prototype, but worked in alongside. Testing should be incorporated thoroughly into the design process, ensuring the validity of the final build and possibility of assembly.

```
L1 = 27
L2 = 26.713
L3 = 26.019
L4 = 25.305
L5 = 25
```

```
ARCS:
0->1 & 7->8: 9.789
1->2 & 6->7: 10 (shortest)
2->3 & 5->6: 10.301
3->4 & 4->5: 10.503 (longest)
```

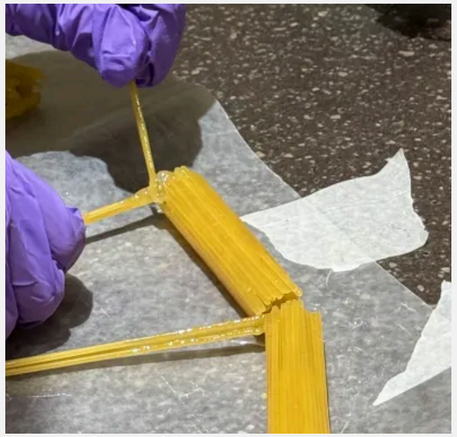


Source: Original Image

Two days into building with only basic parts complete.

Max Load Analysis Part Two

The theoretical max load is much greater than the expected actual max load after considering the building process. The main areas of stress that were not accounted for in the theoretical estimate was the strength of the joints. Because we assumed that the joints were perfectly transferring force, the only restriction of the max load was on the spaghetti members.



Source: Original Image

The rim members are extremely thick and sturdy, but their connections to each other and the other side of the bridge are extremely flimsy due to it being held together only by rushed epoxy as mentioned in the improvements. Due to this reason, the connections will likely collapse before the rims even reach a meaningful amount of compression.

Multiple connectors between the two trusses did not even connect both of them, leading to an imbalance of force and making it likely to cause the complete collapse of the bridge, with the two sides coming together. The gusset plates and connection of the rods are a weak spot theoretically, but in practice, were reinforced countlessly with epoxy and a strong gusset plate, ensuring it would not be the limiting factor in the design.

Max Load Analysis Part Two

The construction of the deck to support the weight was also rushed so the middle of the bridge will also support substantially less weight that the actual rims. To estimate the final max load, the hardened parts of the epoxy in the middle joints were tested along with the deck.



Source: Original Image

The test was to apply a small amount of pressure until the joints gave out a little. The amount of force applied was then estimated and because the force of the weight directly translates to force on the joints and decking, the exact amount of force required to break either part would be the max load. Through multiple trials, it was found that the middle connectors were significantly weaker, breaking apart at only **11 N** (2.47 lbf) while the decking would only snap at **39.2 N** (8.81 lbf).

In conclusion, the estimated max load in practice that the spaghetti bridge can withstand is **1.1 kg**, differing massively from the theoretical limit of over 80 kg because of the complexity of the design and failure to implement it into reality.

Thank You!

Presentation By: Harry, Aiden, Andy,Jeffery

