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# Spaghetti Bridge Design Analysis and Construction Report

EngrCEE 151A


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**Conceptual Design:**

When initially designing the bridge we thought of many different simple trusses that inspired our like Warren, Parker, Pennsylvania, and Camelback. When initially designing our base we started by creating a 50 cm long by 15 cm wide base. With 15 cm being our constraint for the width we designed 3 preliminary trusses that are shown in Figure 1. The first design was made up of 3 sections that were 5 cm tall, 5 cm wide, and had an X shaped connection in the center that had 2 7.07 cm long members crossing each other. The second design was shorter at 3 cm tall but was made up of 2 sections that were 7.5 cm wide with a vertical connection in the center with two diagonal members that made an upside down triangle. The third design was similar to the second but consists of two sections with a vertical member between them and two diagonal connections that make a triangle.

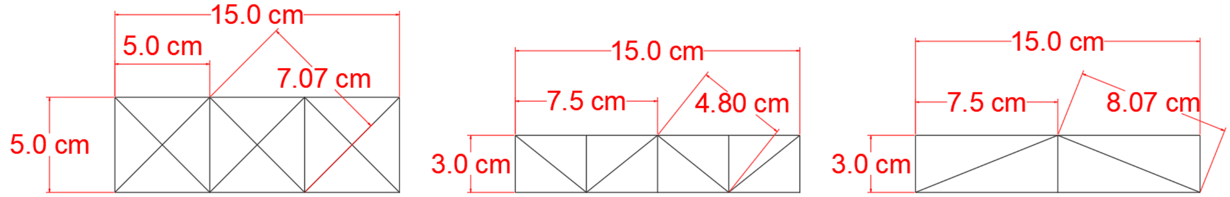


*Figure 1: Preliminary Designs of the Side of Base*

Out the three designs we built upon the second one by shortening the width to 12 cm. The side was then split into 4 sections that were 3 cm wide each. Using a 3, 4, and 5 triangle design we created our final design shown in Figure 2. We designed this using the second truss because it was based off of the Warren Truss with added vertical members for higher stability. The final design is slightly different from the second design because of the shortened width leading to shorter members overall. We also went from 13 members being connected to 17 members in the final design as shorter members would allow for greater support in compression. Warren also uses equilateral triangles for the truss to add stability, but does not have vertical members. The triangles in our design were closer to isosceles triangles while only having a 1 cm difference between the base and the sides of the triangles.

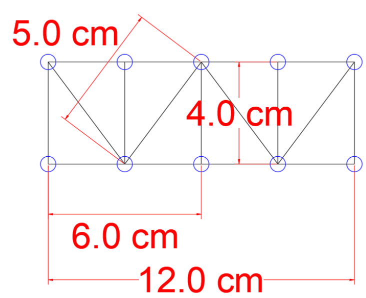


*Figure 2: Final Design of the Base's 12 cm Side*

After designing the 12 cm side of the base we constructed the 50 cm side of the base using the Figure 2 design as a base and adding sections to make it 50 cm wide. We changed the initial design of 3 cm wide bases to 7.286 cm wide sections that added up to 51 cm. We were lenient with the 50 cm design width and extended it by 1 cm to compensate for the design after a brief SAP test. This change made the diagonal section about 6.19 cm long and came out as shown in Figure 3. From the base we built the height upto to be 16 cm tall with the shortest side being at 12 cm. We had used the Camelback Truss as a base for the design as an arching or curved truss would not be easily plausible because of the spaghetti being very brittle. For this section of the bridge we had to make changes to fit our design parameters so we created the truss in Figure 3. The truss changes in the center compared to Camelback as we decided not to add an X intersection and kept the theme of triangle shaped sections. The dimensions that we chose were based off of Figure 2, but has 7 sections as it needs to be 50 cm with an increased length to the horizontal members.

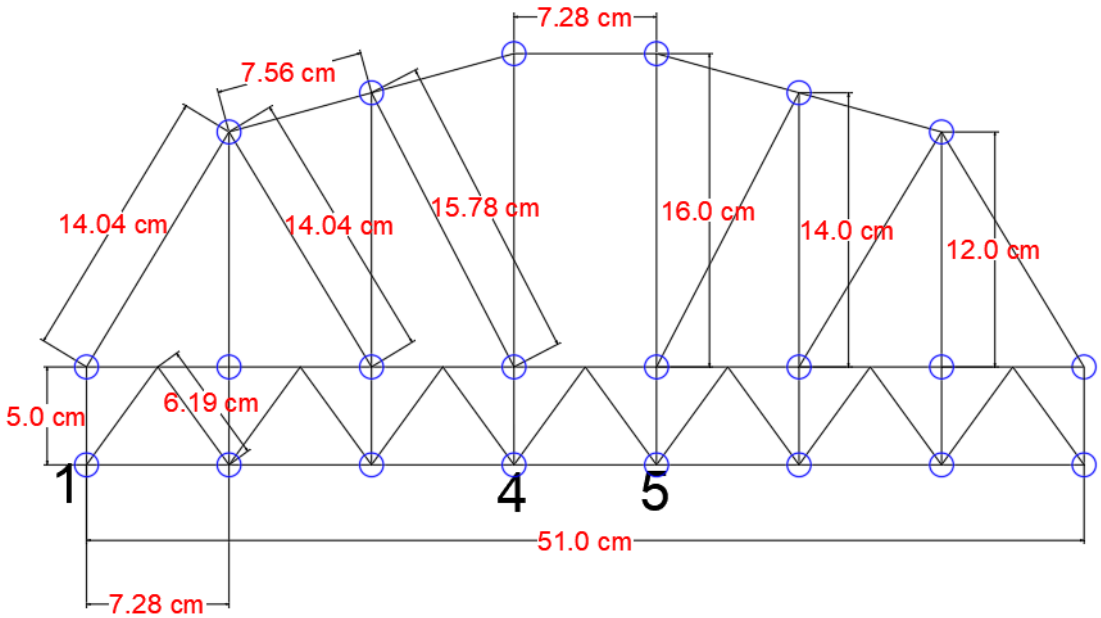


*Figure 3: Final Design of the Truss*

**Calculations of Internal Forces:**

The UCI-SAP program within MatLab was used to approximate the deformation of the bridge and the internal forces of the structure. The truss in Figure 3 was defined using 22 nodes and 49 members to make up the structure itself. The modulus of elasticity that was used was 1000 Mpa, a yielding tensile strength of 10 Mpa, and a radius of 0.6 mm per spaghetti straw. The lengths were also previously determined in the design phase. The internal forces that were calculated after applying a load of 100 onto node 5 are shown in Figure 4. The tensile and compressive forces are also mirrored across the structure almost identical due to the mirrored design. The slight differences come from the applied force being off center and in this case node 5 is to the right of the center of the structure. The highest compressive force from the applied load was 59.43 in the horizontal member above the applied force. The lowest compressive internal force was 1.908 on the horizontal member above node 4. The highest and lowest internal compressive forces are located on the same members mirrored across the structure. The highest tensile force was 53.03 on the diagonal member located next to the applied load. The lowest tensile force felt in the truss was 3.561 on the vertical member to the left of node 4.

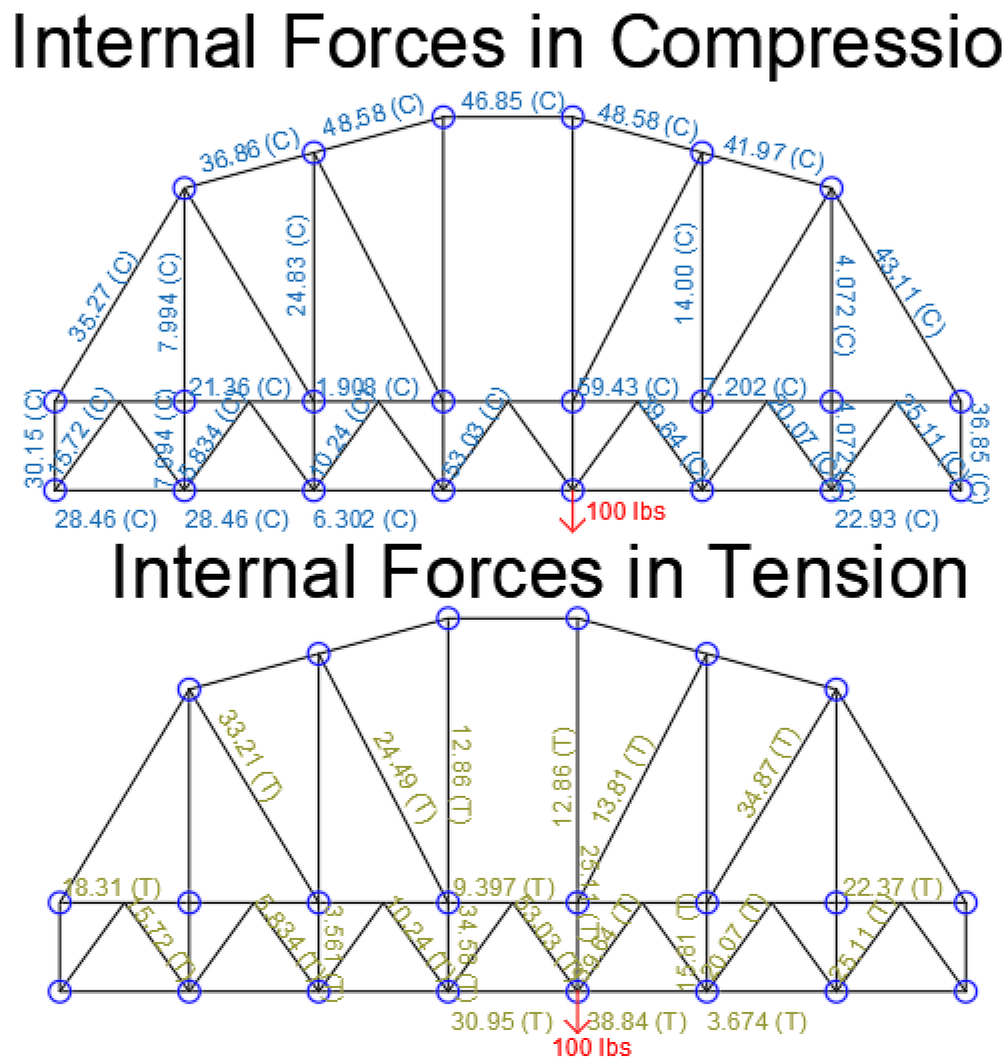


*Figure 4: Internal Forces when a Load is Applied at Node 5*

When a load of 100 lbs was applied onto the central nodes 4 and 5 located between 21.858 cm to 29.144 cm from the left or starting node 1. The maximum displacement was greatest at both nodes 4 and 5 at about 5.6. The displacement caused by the applied force is shown in Figure 5 in red. The greatest displacement happens along the applied force reducing as one moves further from node 5 and towards the pin supports. To help reduce the displacement caused by the load and strengthen members the number of straws per member would be increased.

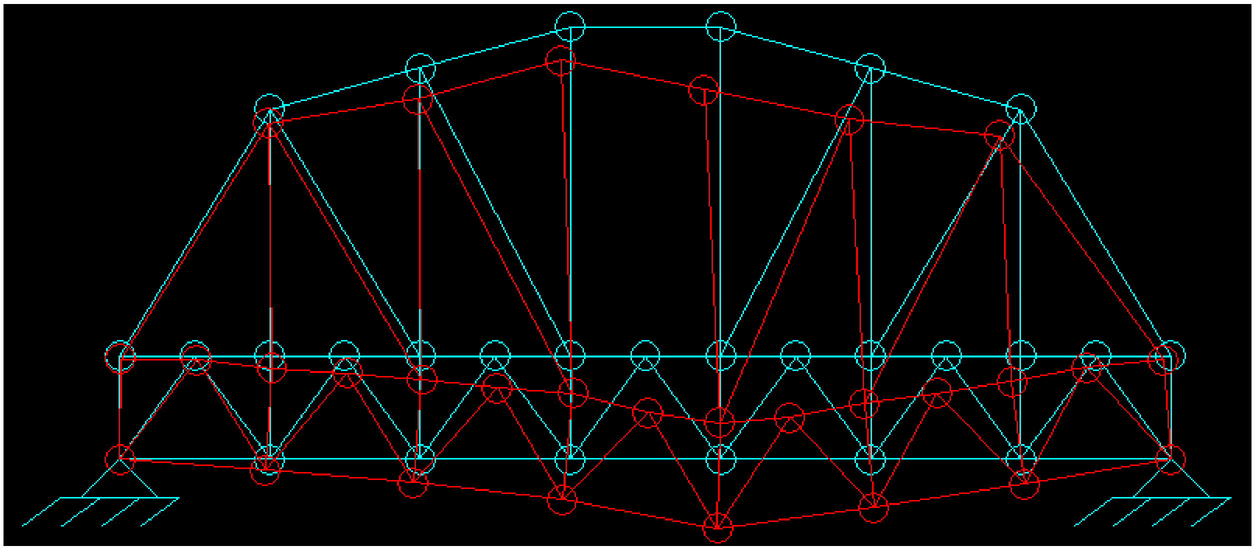

*Figure 5: Displacement Caused by a Load Applied at Node 5*

**Checking Strength and Stability of Members:**

When checking strength the resistance to buckling needs to be compared to the amount of load the member can take because spaghetti is brittle and would most likely buckle before reaching the maximum amount of load it can take. The longer members are shown to be affected the most by the applied force and would require a greater amount of spaghetti to help resist the displacement.

**Construction:**

Before construction we prepared by collecting information on what types of pasta are strongest in comparison to others and chose ___ as our main type of spaghetti. We then counted the amount of members that would be required in order to fully construct the truss on both sides; we needed 98 members. The side needed 17 members to be completed and 34 in total. The members were divided into groups depending on their length. Before cutting the members into their appropriate length bundles of 20 spaghetti straws were rubber banded together to help set a standard for all members. Every member that was cut had an extra 0.1 cm in length that would be shaved down with sandpaper to help keep measurements accurate. The cross-section formed from these bundles was circular, but the measured radius was not completely accurate as there are spaces between spaghetti straws that would cause a discrepancy.

After cutting all the members and shaving them to the appropriate length we weighed the members all together and realized the weight was too high. In order to lower the overall weight we removed certain members completely because we had to have room to add the epoxy as well. The side portion of the base suffered and needed to be removed to help reduce the weight. Then we started adding epoxy and we used ___ as our epoxy because it came in a syringe making application easier. Black epoxy was also tested but became too hard to apply after mixing, so the initial syringe epoxy was kept as the main tool to join members at joints. For added stability and accuracy we kept the bundles together with rubber bands so they would not move during the connecting process. After applying the epoxy we would wait at least 5 minutes in order for the joint to harden appropriately. To help the longer members and strengthen them the amount of straws per bundle were increased to 30 as they were most likely to buckle and break. We then connected the two sides with horizontal members at the top and the bottom that lined up with the joints.

Throughout construction there were errors where members had to be remade in order to fix any problems that arose when connecting the members. At joints there was also a problem where spaghetti straws at the center of the bundle would slide and move out of place while connecting the joints. This would lead to spaghetti straws sticking out of another end and that would lead to slight inaccuracies that would build upon each other. Another problem came from trying to adjust the members as they were being connected with the epoxy as little room was left to adjust any mistakes. Due to this members needed to be slightly shortened or slightly changed to fit the original truss design we specified.

**Results:**

When using UCI-SAP the truss could take a higher load then what was tested. The truss had taken more than 50 lbs when being tested. This was a conservative number considering the small cross-section used as an input. With a small cross-section there's a smaller area calculation leading to overall less strength. This may be true in the model but what isn't considered is the larger cross-section and the strength of the epoxy once added into the build. These aspects would help increase the ability of the bridge and increase the strength of the design. Before the actual moving load test was conducted the bridge was weighed and we realized that the weight was above 1.0 kg. We trimmed down some areas and decided to cut off spaghetti straws from the longer members as they had the most amount of straws at 30. This weakened our members overall, but it then met the requirements as needed.

When it came to the testing phase the first 20 lbs were supported without any sort of cracking or breaking. When the load was increased to 40 lbs the bridge started cracking and finally broke under the force. This stemmed from the horizontal connections at the base of the bridge which weren't tested as thoroughly as the rest of the bridge's design. They cracked and broke while the truss design didn't have any cracks or damage even after the members were trimmed down. The strength of those weaker horizontal sections was also weakened after the first test which also affected it during the second test. In a real world situation this would be devastating as the horizontal area where vehicles travel is one if not the most important part of the bridge's design. To remedy these faults in a future design thorough tests would be run on all sections and the construction of the bridge would be taken on differently as problems arise from cutting exact sizes because it leaves no room for joints. The connections at the joints would be done differently in order to compensate for any straws pushed out or moved out of place as well.