TAYLOR'S UNIVERSITY

Wisdom • Integrity • Excellence

SCHOOL OF ARCHITECTURE, BUILDING & DESIGN

BACHELOR OF SCIENCE (HONOURS) (ARCHITECTURE)

BUILDING STRUCTURES (ARC 2523)

PROJECT 1

FETTUCCINI TRUSS BRIDGE

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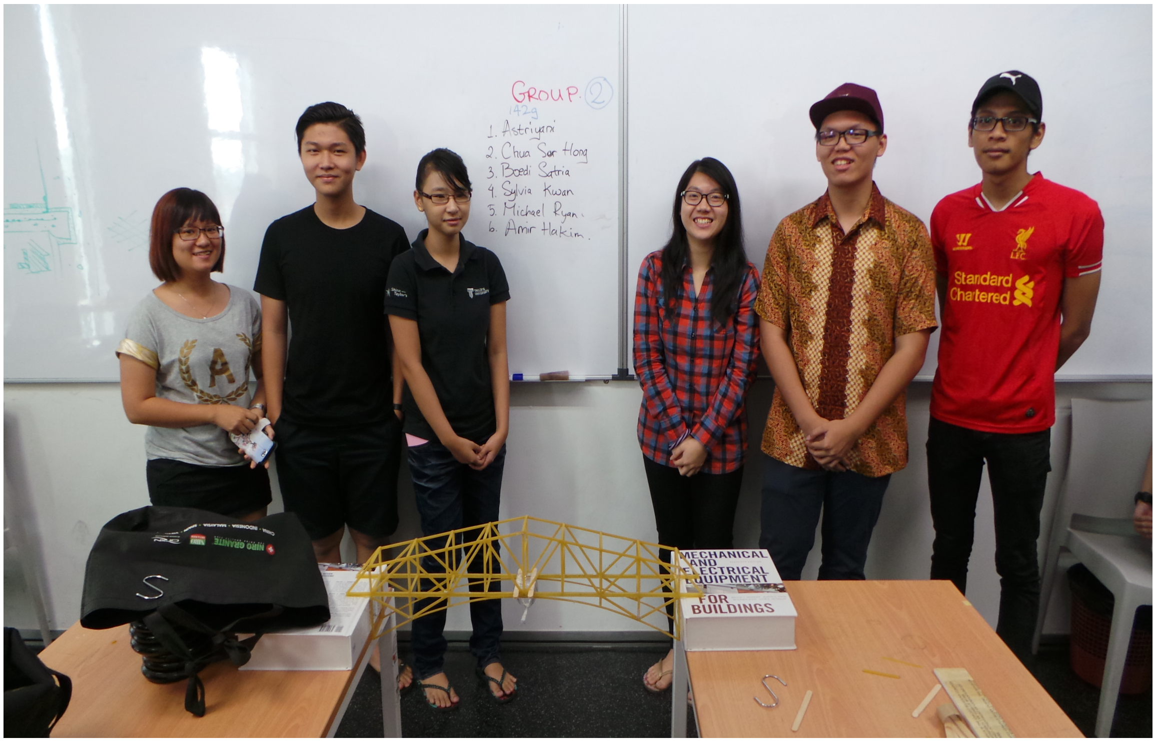
PREFACE



This report is the in-depth documentation behind the final outcome of Fettuccini Truss Bridge. This project aims to develop the understanding of tension and compressive strength of construction materials, in this case, the fettuccine. It also develops a student's understanding of force distribution in a truss system in order to design a perfect truss bridge, which not only have high aesthetic value but also material efficient. The designed bridge would then have to be translated into a form of a Fettuccini Bridge model. The model will then be tested for its efficiency in carrying point loads by hanging weights on to the bridge model. By applying the theory into the bridge model, we will be able to evaluate, explore and improve the attributes of fettuccini along the process of model making.

CONTENTS

1.0 INTRODUCTION

This project is sub-divided into two tasks which are Task 1 : Truss Analysis Exercise and Task 2 : Design a Fettuccini Truss Bridge .

In Task 1, we are to choose from the given different truss systems to be analyze. By doing this, we should be able to determine the most effective truss arrangement then provide explanation for it.

As for Task 2, we are in a group of 5 members need to carry out precedent study of a truss bridge selected. Then, from the information obtained from the selected case study, we are required to design and construct a physical fettuccini bridge model of 600mm clear span and maximum weight of 150g. The bridge should have the ability to carry or support a load of 5kg for at least 10 seconds.

In order to complete both task, it is essential for us to study the truss system beforehand. Truss is a structure built up of three or more members, which are normally considered being pinned and hinged at the joints. There are different types of trusses as shown in figure below. Load applied to the truss is transmitted to joint so that each individual member is in either pure tension or compression.

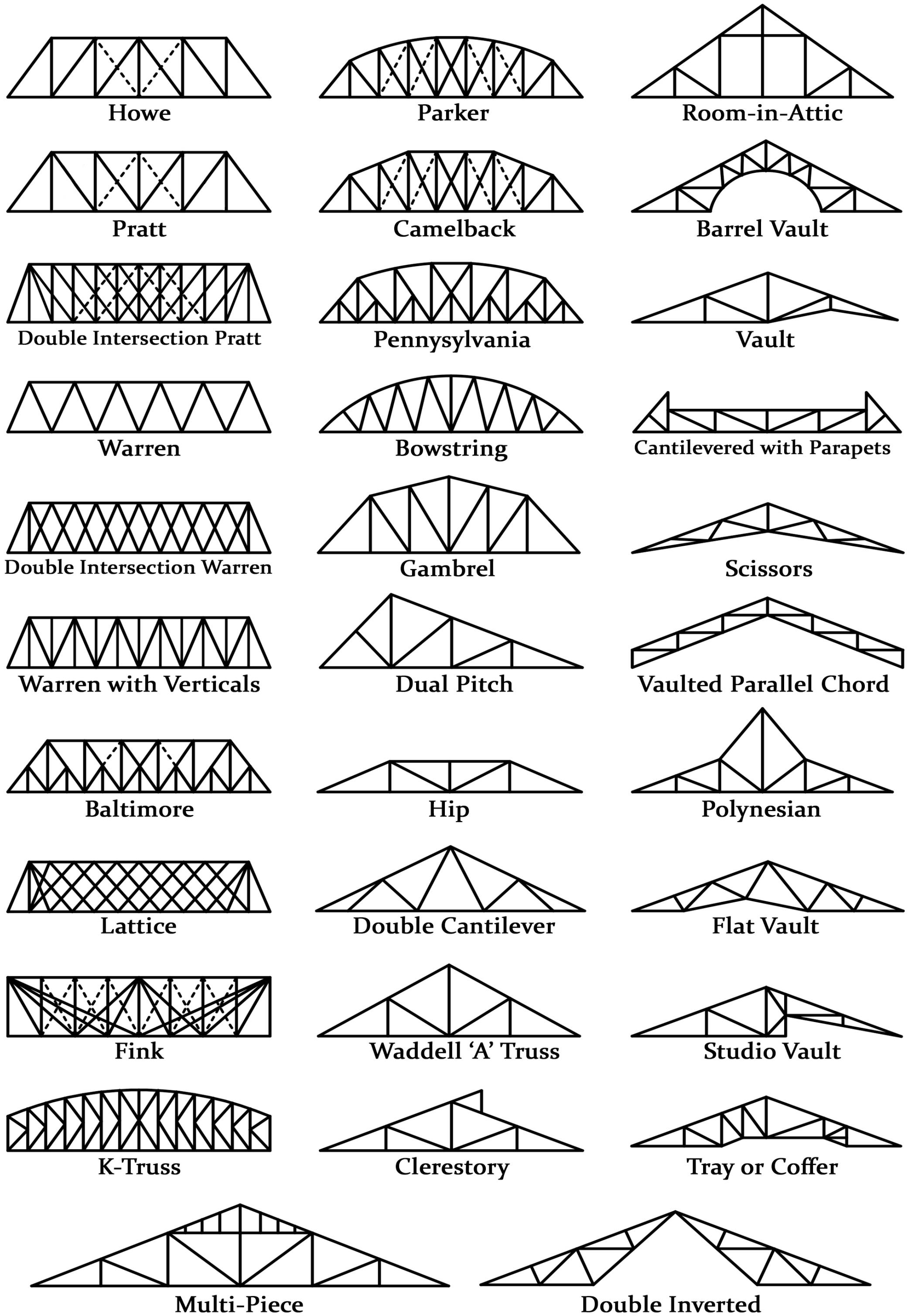


Figure 1 Types of truss bridge

2.0 PRECEDENT STUDY

Before designing our truss bridge, we are required to choose a precedent study to learn how the forces, tension and compression, work on the bridge members when the load were put on the bridge. The chosen bridge also become the initial idea how we designing our fettuccini bridge.

2.1 Cantilevered bridge (Double Warren Bracing)

Any rigid construction extending horizontally well beyond its vertical support, used as a structural element of a bridge is classified as cantilevered bridge**.** This cantilever bridge is easily identify especially one in which the projection is great in relation to the depth, so that the upper part is in tension and the lower part in compression.

A cantilever is a structural member which projects beyond its support and is supported at only one end. Cantilever bridges are constructed using trusses, beams, or girders. By employing the cantilever principles, it allows structures to achieve spans longer than simple spans of the same superstructure type. They may also include a suspended span that hangs between the ends of opposing cantilever arms.

Some bridges that appear to be arch type are, in fact is a cantilever truss. This types of truss may be identified by the diagonal braces which are used in the open spandrel. A true arch bridge relies on vertical members to transfer the load to the arch. Pratt and Warren bracing are among the most commonly used truss types. The classic cantilever design is through the truss which extends above the deck.

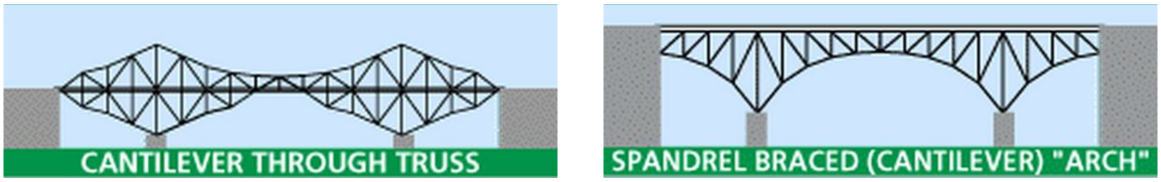


Figure 2.0.1 Type of bridge arrangement in the cantilever design.
Source : Bruce S. Cridlebaugh , 1999-2008 , Bridge Basics , http://pghbridges.com/

2.1.1 Forth of Fifth Bridge

Figure 2.1.1 Forth of fith bridge

History and Significance

Forth Bridge was the most prominent steel structure when it became operational in 1890. The cantilever railway bridge was built across the Firth of Forth at Queensferry, 14km west of Edinburgh. It still continues to remain a significant and admirable engineering structure of the Victorian era.

Claim to Fame : For 27 years the Firth of Forth Railway Bridge held the world's record for span (521 meters). The overall length of the bridge is 2,529 meters.

The 2,529 meters long railway bridge acts as a significant thoroughfare connecting the north-east and south-east of Scotland. The bridge primarily connects the cities of Edinburgh and Fife and further leads to Dundee and Aberdeen. It is located adjacent to the newly constructed Forth Road Bridge.

The bridge was first tested and used in January 1890, where two units of 304.8 meters long trains consisting of a locomotive with 50 wagons each passed across the bridge side-by-side through the south entrance. Forth Rail Bridge was finally commissioned in March 1890.

The bridge was designed by Sir John Fowler and Sir Benjamin Baker and built by Sir William Arrol & Co, a Glasgow-based company. Much credit, however, has been given to Sir Benjamin Baker and his co-worker Allan Stewart for designing and supervising the construction work.

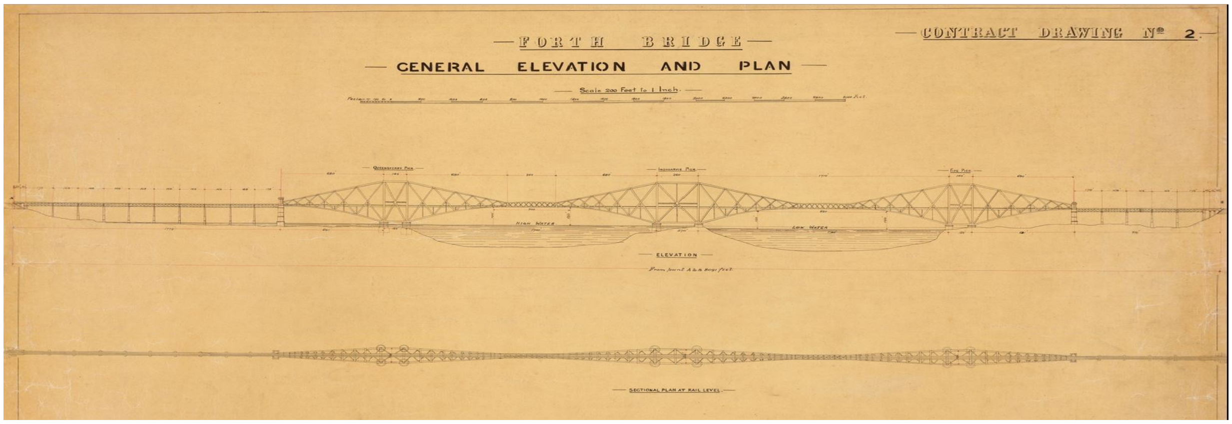


Figure 2.1.2 General Elevation and Plan of Firth of Forth Bridge
Source : http://www.networkrail.co.uk/virtualarchive/forth-bridge/

Design and Construction

Forth Bridge is 2,529 meters long, with trains passing through the double track at a height of 48.16 meters and the towers, which reach a height of 110 meters. The two main spans of the bridge are 521 meters, the two side spans are 207 meters and the 15 approach spans are 51.2 meters each.

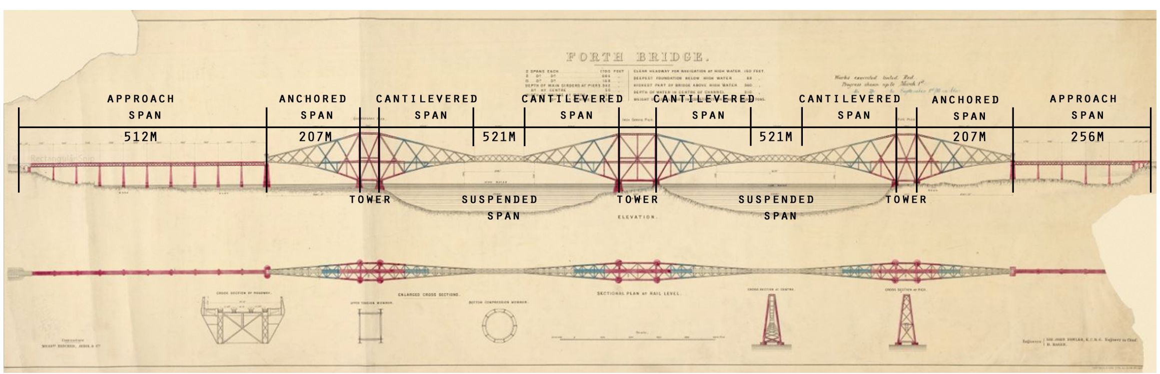
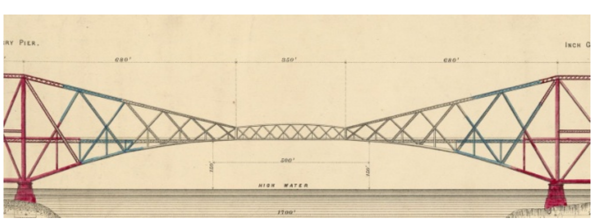
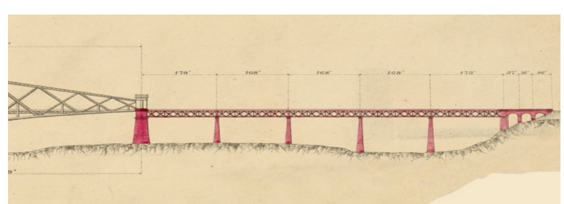


Figure 2.1.3 Detailed Elevation and Plan of Firth of Forth Bridge





Source : http://www.networkrail.co.uk/virtualarchive/forth-bridge/
Figure 2.1.4 Main span between Queensferry Pier and Inch Gravie Pier.
Figure 2.1.5 segments of approach span

The bridge consists of three separate four-tower high, double-cantilevers which are joined by 107 meters long girders and connected to the main structure of the bridge by huge rivets. The cantilevers are supported by granite piers.

The river bed at the south cantilever, which is 28 meters below the high-water level, made use of compressed air to stop water pouring into the working chamber at the base, while the other cantilevers were constructed using caissons measuring 21 meters in diameter.

Foundations were constructed using cylinders which were lowered using sandbags. Working chambers were created to pump compressed air, whereas airlocks and airshafts provided access for men and materials.

Bridge construction was carried in two phases. The first phase which was carried out from 1882 to 1885 involved works on the substructure, including sinking the caissons and constructing the foundations and piers to support the superstructure. The superstructure, which weighs about 51,324t, was built from 1886 to 1890.

Altogether, the construction of the bridge made use of 54,000t of steel, 20,950 cubic meters of granite, 6,780 cubic meters of stone, 49,200 cubic meters of concrete, 50t of cement and seven million rivets.

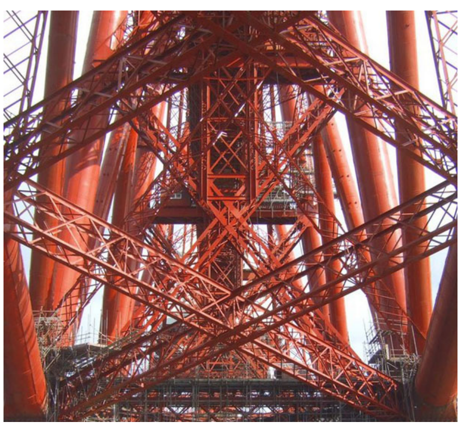


Figure 2.1.7. The use of 54000 tons of steel in the construction of Forth Bridge.

Steel used for the construction was manufactured by Frederick Siemens (England) and Pierre and Emile Martin (France). Construction work was carried out by approximately 5,000 workers.

2.1.2 Load Distribution Analysis

Introduction of Double Warren Bracing

Warren truss, patented by James Warren and Willoughby Monzoni of Great Britain in 1848, can be identified by the presence of many equilateral or isosceles triangles formed by the web members which connect the top and bottom chords. These triangles may also be further subdivided. Warren truss may also be found in covered bridge designs. The subcategories of Warren truss are as followed:

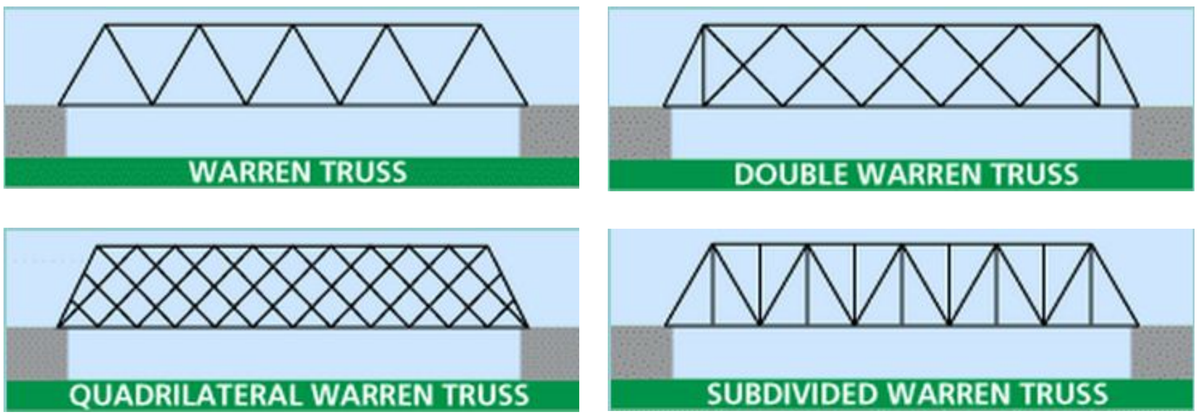


Figure 2.1.8 Subcategories of Warren truss system.

Generally in Warren truss, diagonal members are alternatively in tension and in compression. The Warren truss has equal length compression and tension web members, and fewer members than a Pratt truss. For larger spans the modified Warren truss may be adopted where additional restraint to the internal members is required (this also reduces secondary stresses).

Warren trusses are commonly used in long span buildings ranging from 20 to 100 m in length. These types of truss are also used for the horizontal truss of gantry/crane girders.

Tension and Compression Members

It is important to study the tension and compression members of the system in order to do the structural analysis of Forth Bridge. Each of three cantilevers is clearly and deliberately tapered outwards the base to increase its resistance to overturning. Members experience tension or compression forces in the lattice structure of the cantilevers. The joining spans were identified and designed differently: compression members are solid and stocky: to resist buckling effect while tension members are open and light to reduce wind resistance where possible. The compression members were intricately braced together, again to help resist buckling.

The overall structural behavior of the cantilevers is clearly expressed in their form. The cantilevers taper longitudinally from a huge depth at their foundations to a much reduced depth at the tips, exactly following the reduction in bending intensity from the root of a cantilever to its tip. Reinforcing this idea, the size of the members making up the compression and tension arms of the cantilevers increases towards the supports. Even the joining spans between the tips of the cantilevers are designed to reflect the distribution of bending forces, with a larger depth at the centre than at their support points on the tips of the cantilevers.

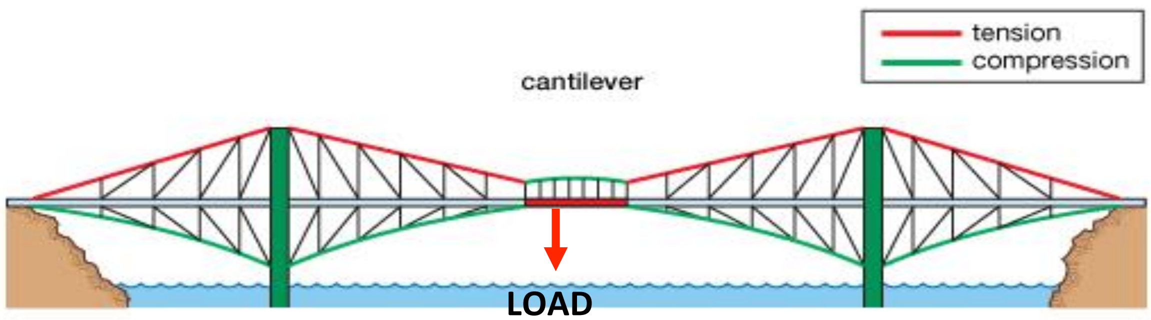


Figure 2.1.9 Forth Bridge – There is a clear distinction between tension and compression members.

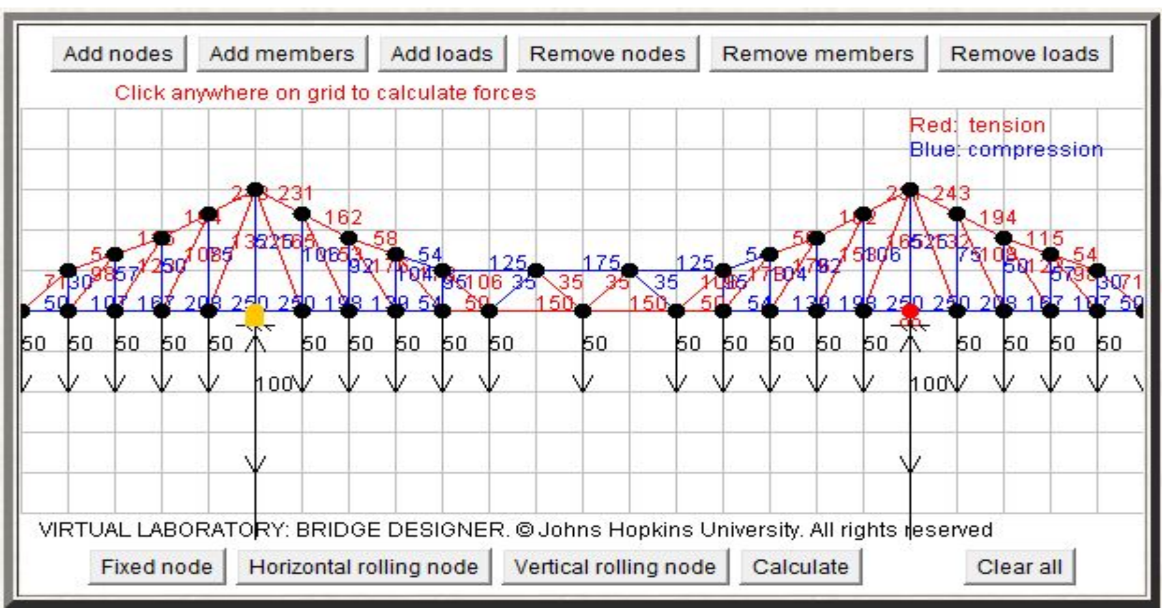


Figure 2.1.10 Truss simulation illustrating tension and compression of each member of the upper structure.

2.2 Arch Bridge (Pratt Bracing)

The basic principle of arch bridge is its curved design, which does not push load forces straight down, but instead they are conveyed along the curve of the arch to the supports on each end. These supports (called abutments) carry the load of entire bridge and are responsible for holding the arch in the precise position unmoving position.

Arch bridges are always under compression. The force of compression is pushed outward along the curve of the arch toward the abutments where the tension in an arch is negligible. The natural curve of the arch and its ability to dissipate the force outward greatly reduces the effects of tension on the underside of the arch.

There are several classifications of arch bridges. The placement of the deck in relation to the superstructure provides the descriptive terms used in all bridges: deck, pony, and through. Also, the type of connections used at the supports and the midpoint of the arch may be used. Another method of classification is found in the configuration of the arch. Examples are solid-ribbed, brace-ribbed (trussed arch) and spandrel-braced arches.

This type of bridge comprises an arch where the deck is completely above the arch. The area between the arch and the deck is known as the spandrel. If the spandrel is solid, usually the case in a masonry or stone arch bridge, the bridge is called a closed-spandrel arch bridge. If the deck is supported by a number of vertical columns rising from the arch, the bridge is known as an open-spandrel arch bridge.

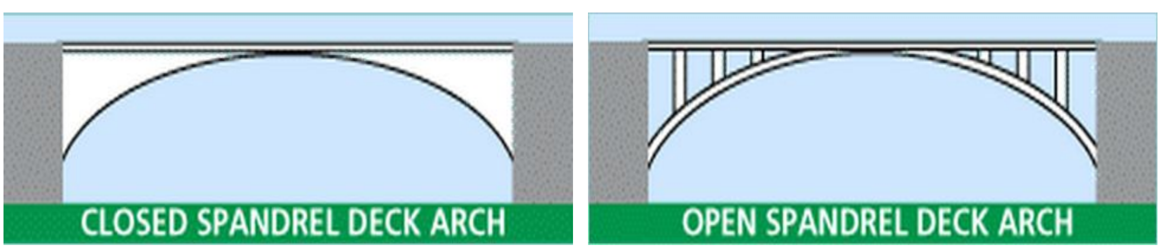


Figure 2.1.11 Type of bridge arrangement in the arch design.
Source : Bruce S. Cridlebaugh , 1999-2008 , Bridge Basics , http://pghbridges.com/

2.2.1 Navajo Bridge

History and Significance

Figure 2.2.1 These two Navajo Bridges, one historic and one new, both stretching 750 feet in length, this graceful bridge rises 470 feet above the Colorado River

The Historic Bridge

In the 1870s, pioneers from Utah began to expand their settlements into northern Arizona. Nearly 600 miles (965 km) of deep canyons along the Colorado River stood in their way. A ferry was established there in 1873. Named after the first ferry operator, John D. Lee, Lees Ferry became an important route for pioneers, settlers and local traffic. In the 1920s, automobiles began using the ferry as a means to cross the Colorado River. A bridge site was selected 5 miles (8km) downriver at Marble Canyon. Construction of the bridge began in June of 1927. This was rugged and remote country and it was difficult to get men, materials and equipment from one rim to the other, a distance of only 800 feet (244m). During construction, a ferry was essential for transporting men, tools, construction materials and heavy building equipment. However, on June 7, 1928, high waters, a weakened ferryboat, and worn cables resulted in disaster. The ferry capsized with three men and a Model T Ford on board. Coconino County refused to replace the ferry, causing extensive construction delays. For the next seven months, construction equipment and materials were brought in by truck, requiring an 800-mile journey around the canyon.

It was an historic day when, on January 12, 1929, the bridge was opened to traffic. At the time, it was the highest steel arch bridge in the world and made traveling between Utah and Arizona much easier. The bridge was known as the Grand Canyon Bridge for five years following the dedication. In 1934, after great debate in the Arizona legislature, the official name was changed to Navajo Bridge.

Claim to Fame: At the time of its construction, the Navajo Bridge was the highest steel arch bridge in the United States, and for the next 66 years it served as the only crossing of the Colorado River for 600 miles.

The New Bridge

Navajo Bridge served the area well for 66 years. However, as automobiles and trucks became larger, wider, and heavier, the need for a stronger, wider bridge became evident. The historic bridge was only 18 feet (5.5m) wide and had a 40 ton (36 metric tons) limit. Approaches to the bridge on each side were dangerous with limited sight of oncoming traffic. Pedestrian safety was also a factor. Although pedestrians were not allowed on the bridge, the temptation was too great for many. Over a 13 year period, 72 accidents occurred on or while approaching the bridge; eight were fatal.

The time had come to replace the historic bridge. It was decided a new bridge would be built just downstream from the existing bridge, with new approaches on each side. The historic bridge would remain and serve as a pedestrian bridge and provide visitors with a breathtaking view of the Colorado River 467 feet (142m) below.

Construction on the new bridge began in May of 1993. During construction, it was necessary to make sure no rocks fell into the river. All rock for the footings was cut and hauled up to the rim. The rock was cut using a technique that made it appear natural and in places it was stained to give it a weathered look. On May 2, 1995, two years after construction began traffic was diverted onto the new Navajo Bridge.

The dedication took place on September 14, 1995. Once again, the ceremony attracted a large number of people.

Design and Construction

	Historic Bridge	New Bridge
Construction	2 years	7 months
Length	254 m	277 m
Steel Arc Length	188 m	221 m

Arch Rise	27.4 m	27.4 m
Height Above River	142 m	143 m
Width of Roadway	5.5 m	13.4 m
Amount of Steel	1,100,000 kg	1,800,000 kg
Amount of Concrete	380 m^3	1,370 m^3
Amount of Steel Reinforcement	37,000 kg	197,000 kg
Cost	$ 390,000	$ 14,700,000

Table 2.2 Comparison between the historic and new Navajo Bridges

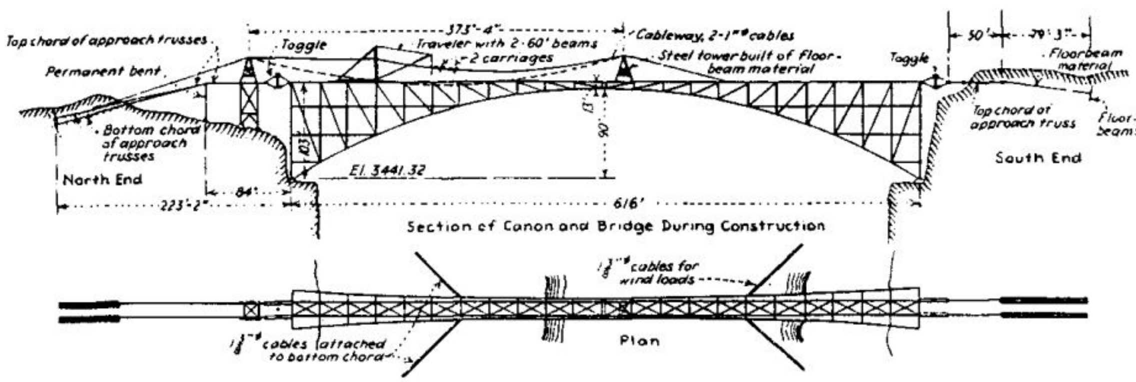


Figure 2.2.2 Plan and Construction Profile of Bridge, from Engineering News-Record. 5 January. 1928

2.2.2 Load Distribution Analysis

Introduction of Pratt Bracing

The Pratt truss is a very common type, but has many variations. Originally designed by Thomas and Caleb Pratt in 1844, the Pratt truss successfully made the transition from wood designs to metal. The basic identifying features are the diagonal web members that form a V-shape. The center section commonly has crossing diagonal members. Additional counter braces may be used and can make identification more difficult; however the Pratt and its variations are the most common type of all trusses.

The Pratt diagonal web members are inclined outwards from the center of the span to form V-shapes. The vertical members are in compression while the diagonal members are in tension. The subcategories of Pratt Truss are as followed:

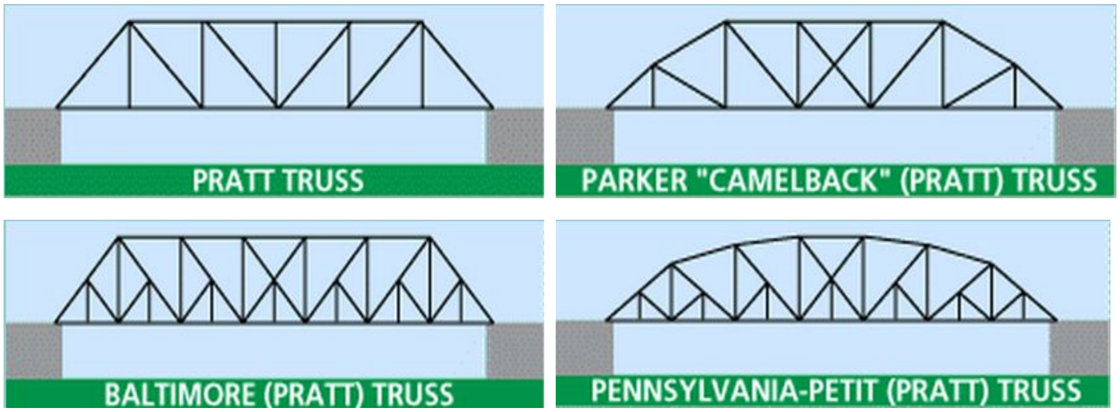


Figure 2.2.3 Subcategories of Pratt truss system.

Tension and Compression Members

Basically the tension and compression forces that work on Navajo bridge is the same with Arch Bridge. The arch act as compression members instead of tension because of negative bending effect while the pratts bracing members help in distributes the load to the arch.

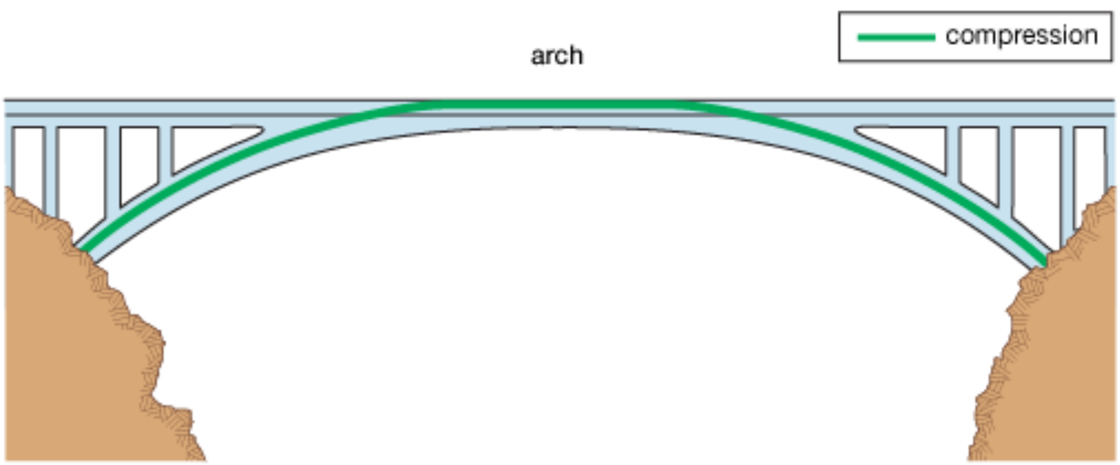


Figure 2.2.4 Navajo Bridge – There is a clear compression member in the arch truss.

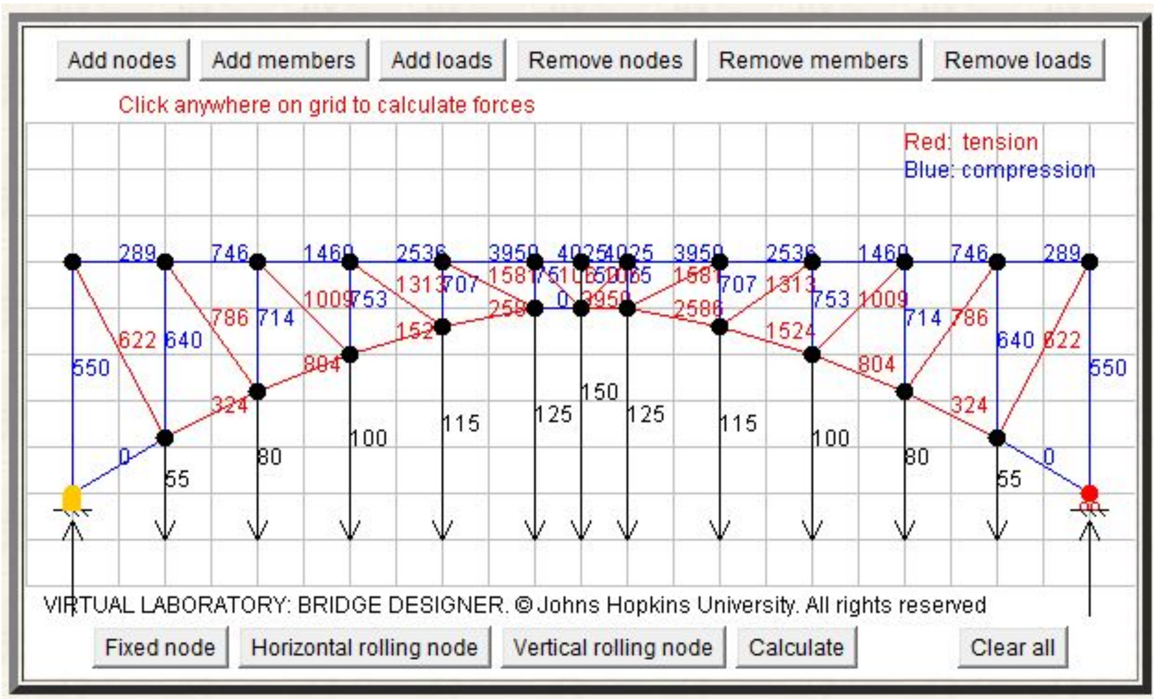


Figure 2.2.5 Truss simulation illustrating tension and compression of each member.

3.0 ANALYSIS AND DISCUSSION

3.1 Strength of Material

In materials science, the strength of a material is its ability to withstand an applied load without failure. The field of strength of materials deals with forces and deformations that result from their acting on a material. A load applied to a mechanical member will induce internal forces within the member called stresses when those forces are expressed on a unit basis. The stresses acting on the material cause deformation of the material. Deformation of the material is called strain when those deformations too are placed on a unit basis. The applied loads may be axial (tensile or compressive), or shear. The stresses and strains that develop within a mechanical member must be calculated in order to assess the load capacity of that member. This requires a complete description of the geometry of the member, its constraints the loads applied to the member and the properties of the material of which the member is composed. The calculated stresses may then be compared to some measure of the strength of the member such as its material yield or ultimate strength. Material strength refers to the point on the engineering stress-strain curve (yield stress) beyond which the material experiences deformations that will not be completely reversed upon removal of the loading and as a result the member will have a permanent deflection.

3.1.1 Tensile Strength

Tensile strength measures the force required to pull something such as rope, wire, steel, any metal or a structural beam to the point where it breaks. It is the strength of material expressed as the greatest longitudinal stress it can bear without tearing apart.

Tensile strengths have dimensions of force per unit area and in the English system of measurement are commonly expressed in units of pounds per square inch, often abbreviated to psi. When stresses less than the tensile strength are removed, a material returns either completely or partially to its original shape and size. As the stress reaches the value of the tensile strength especially when the material is ductile, it has already begun to flow plastically rapidly forms a constricted region called a neck, where it then fractures.

3.1.2 Compressive Strength

In the study of strength of materials, the **compressive strength** is the capacity of a material or structure to **withstand loads tending to reduce size**. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Maximum stress a material can sustain under crush loading.

The compressive strength of a material that fails by shattering fracture can be defined within fairly narrow limits as an independent property. However, the compressive strength of materials that do not shatter in compression must be defined as the amount of stress required to distort the material an arbitrary amount. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test. Compressive strength is a key value for design of structures.

3.1.3 Strength of Fettuccine

Generally, fettuccini is a brittle material which breaks easily when stresses are implied on it. However, for this project fettuccini is the key material in our truss bridge design. Hence, it is important for us to study and analyse its strength before proceeding as understanding of the material will contribute to the end result.

Some properties of fettuccini (dry state)

- Ultimate tensile strength ~2000 psi
- Stiffness (Young's modulus) E~10,000,000 psi (E=stress/strain)

In order to apply the understanding of fettuccini's strength, we are required to carry out few simple experiments based on the description of a standard tensile test and compressive test due to unavailability of a universal testing machine. Therefore, the result is not suitable for the use of other purposes. It is only for us to enhance on the bridge structure.

Tensile Test

1. A water bottle was hung from one end of a fettuccini stick and the other end was held up to allow the load to act on the fettuccini stick.
2. Water bottle was added by stages, allowing the weight to gradually increase.
3. The fettuccini stick was loaded with forces until it breaks.
4. The steps are repeated to all the other fettuccini brand.

Figure 3.1.1 Load of 600g applied to fettuccini stick.

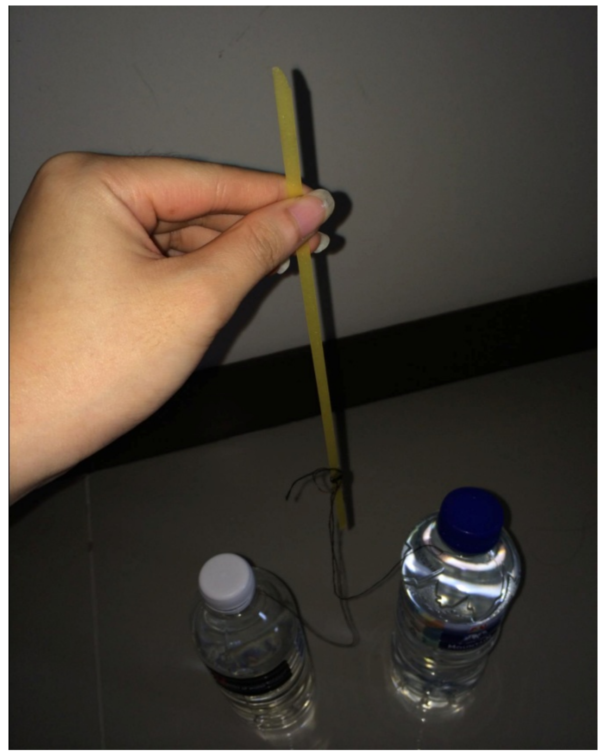


Figure 3.1.2 Load of 1100g applied to fettuccini stick.

Brand	Load Sustained
San Remo	1100 g
Butoini	1000 g
San Remo (Spinach)	750 g
Kimball	600 g

Table 3.1.1 Tensile strength of fettuccini from different brand. San Remo has the highest tensile strength.

Bending Test

Fettuccine is a brittle material. Therefore it is understood that it has low compressive strength compared to its tensile strength. However, we understand that when a fettuccine stick is laid horizontally and a point load is placed on the middle of the stick, the fettuccine stick is subjected to both tension and compression, causing it to bend. Thus bridge member under compression has to be strengthened.

1. The fettuccini stick is laid horizontally between two tables of same height.
2. S-hook is placed at the center acting as the point load.
3. The load is added gradually until it breaks.

4. The steps are repeated to all the other fettuccini brand.

Brand	Load Sustained
San Remo	230 g
Butoini	200 g
San Remo (Spinach)	140 g
Kimball	135 g

Figure 3.1.3 Load is placed in the bag carried by S-Hook   *Figure 3.1.4 Load is added until it breaks.*

Table 3.1.2 Compressive strength of fettuccini from different brand. San Remo has the highest compressive strength.

3.1.3 Strength of Adhesive

Type of Glue (Brand)	Features	Effective Level
3-Sec Glue (V-tech)	• Fastest solidify time • Strongest grip between connection • More intense texture	**1**
3-Sec Glue (502)	• Fast solidify time • Strong grip between connection • Watery texture	2
Elephant Glue	• Longer solidify time • Strong grip between connection • Watery texture	3
Hot Glue	• Longest solidify time. • Bad workmanship-create bulky finishing • Solid texture	4

Material Selection

Based on the tensile and compressive tests carried out, it is shown that fettuccini from the San Remo brand has the best strength compare to the others. The type of adhesive is also selected after a thorough comparison.

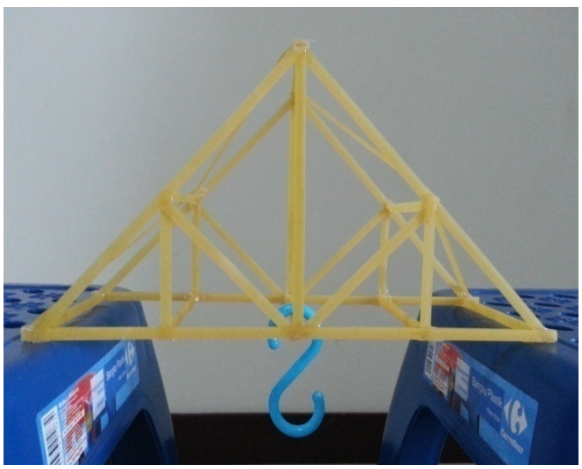
Both San Remo's brand have a good quality but we chose San Remo fettuccine rather than the spinach fettuccine because the spinach fettuccine can easily oxidized, this can reduce the strength and rigidity of the fettuccine itself.

Super glue is the best choice in this project even though it has some weakness which is the after effect, it's characteristic creates some kind of crystallization after being used.

3.2 Truss Analysis

FROM SMALL PROTOTYPE TO INITIAL DESIGN

At the initial stage of our idea development stage, we were not sure about the strength of each truss system. Therefore, we decided to start off with few prototypes as the kick-start to our final design.



PROTOTYPE ONE

Truss System : Waddell "A"

Dimension : 24cm x 11cm x 8.5cm

Weight : 20 g

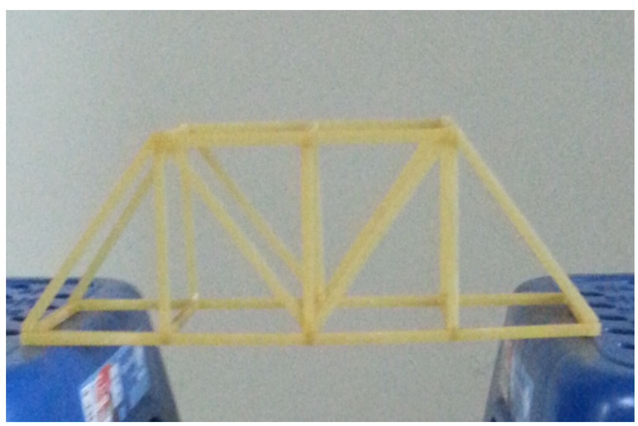
Load Sustained : 1.4 kg

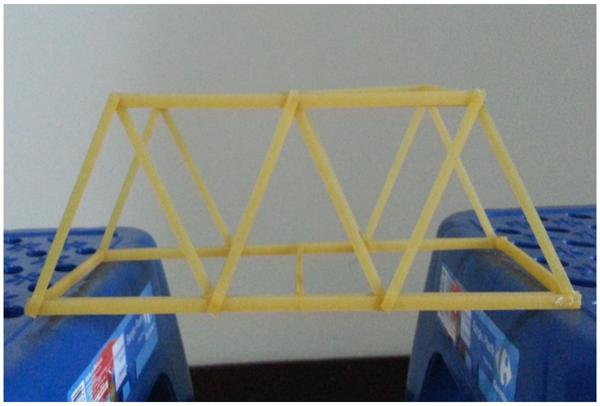
PROTOTYPE TWO

Truss System : Pratt

Dimension : 24cm x 8cm x 8cm

Weight : 25 g





PROTOTYPE THREE

Truss System : Warren

Dimension : 24cm x 7cm x 9cm

Weight : 20 g

Load Sustained : 0.9 kg

3.2.1 Strength of Chosen Truss

From the prototypes studied above, it is shown that although Waddell "A" truss system has the same low weight as Warren truss system but it has the highest load sustained. Therefore, we proceed using the Waddell "A" truss system for our initial final bridge design.

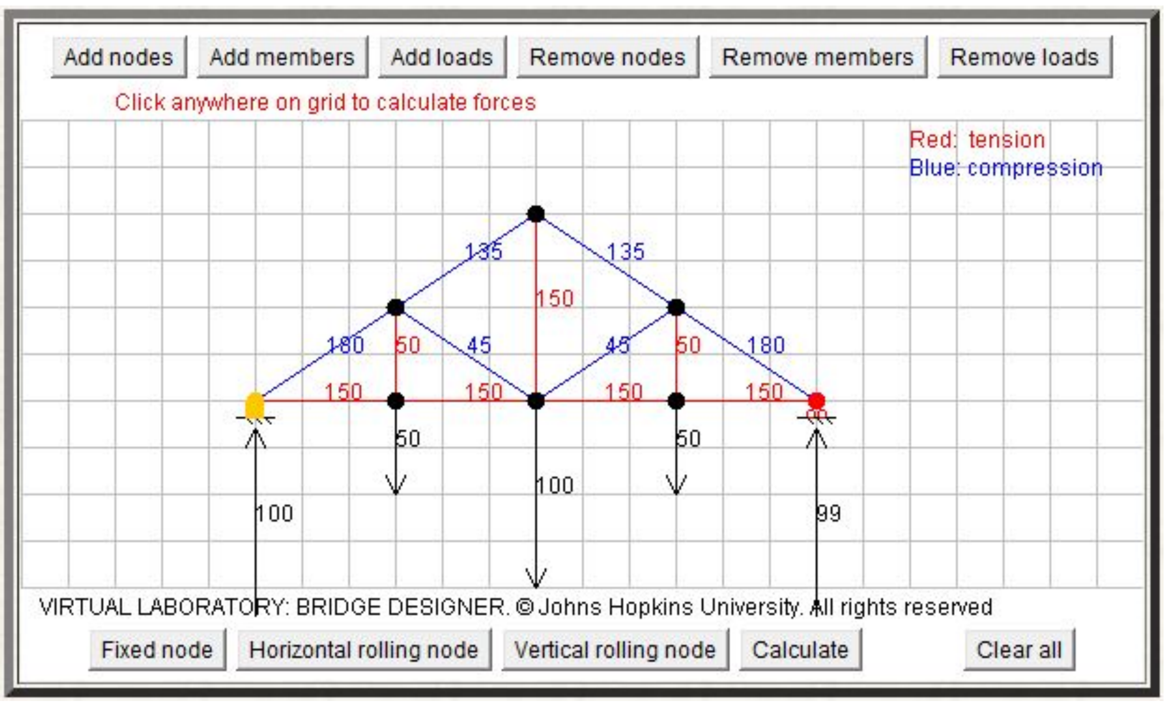
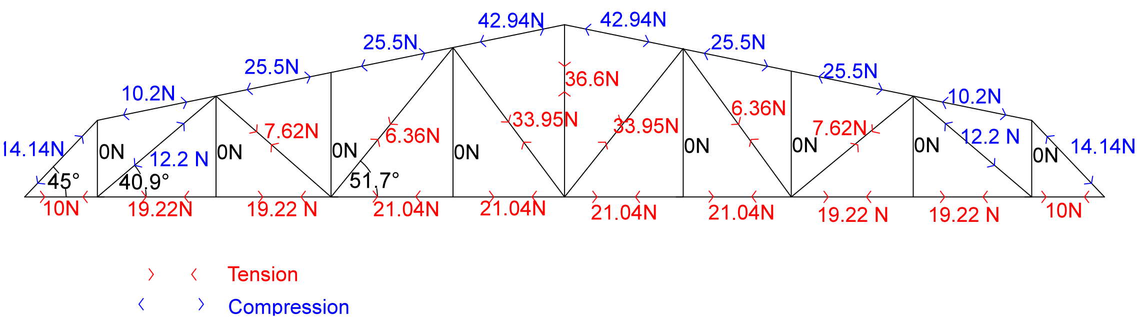


Figure 3.2.1 Tension and compression components within Waddell "A" truss system.

Based on the truss analysis we made using the bridge design software, we found out that all the upper structures were under compression and the lower structures were under tension. The inner structures which are the bracings underwent both compression and tension as shown in the figure. Different ways of constructing the members were used to strengthen the different parts of the structure which underwent different internal forces.

As we tested earlier, the fettuccini has stronger tensile strength than compressive strength. Therefore, reinforcement had to be enhanced at the upper part of this truss system which underwent compression force. Hence, we decided to increase the thickness of the upper chords by layering the chords with more fettuccini sticks. However, the more layers added the higher the weight of the overall bridge. Meaning that, it will decrease the efficiency of the bridge performance. Thus, we have to do trial and error method to identify the most suitable method to enhance the bridge

3.2.3 TRUSS BRIDGE ANALYSIS

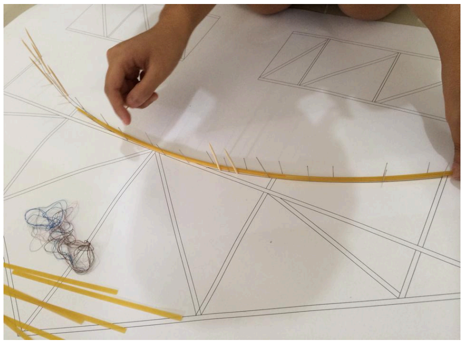


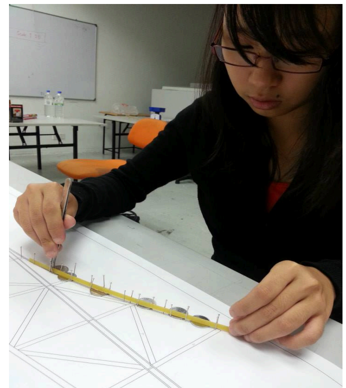
Final Analysis of the truss bridge, ignoring the arch that makes the bridge imperfect.

The vertical members are carrying 0 load. Hence, efficiency can be improved by decreasing or eliminating the vertical members. The members in the center receive the highest critical force and have the highest tendency to collapse. It should be strengthen by more bracing.

4.0 CONSTRUCTION PROCESS

4.1 Work in Progress

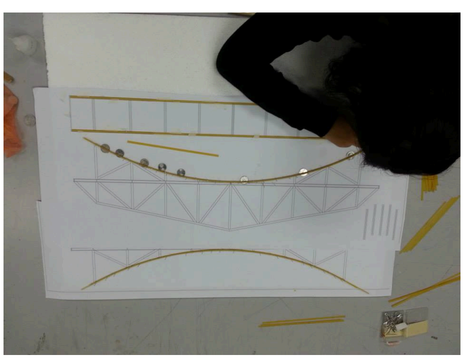


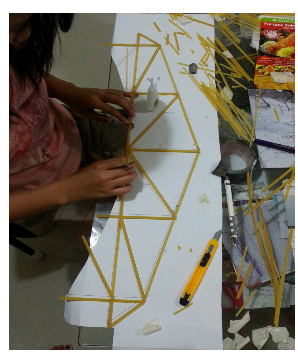


Creating the arch by help of needles pinned to the cad drawing mounted on polystyrene board.

Cutting the fettuccine according to the shape in the CAD drawing

Making the cut ends smooth and even so it can be joined nicely. This aids in transferring the force nicely.





Arranging the parts on the CAD drawing neatly before gluing them together.

4.2 Types of Joining Used

The type of joint used in our bridge can drastically change its strength. There are three basic types of joints, the Lap Joint, End Joint (Butt Joint), and Notched Joint.

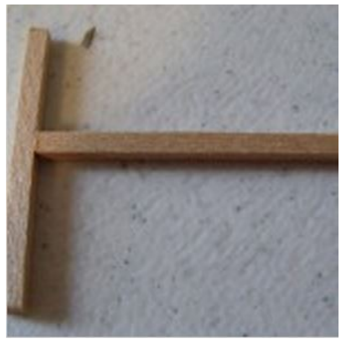




Figure 4.1.1 The arrangement of members for Lap Joint, End Joint and Notched Joint respectively.

The lap joint is one of the strongest. It helps members in compression to resist bending. The lap joint has a potential weakness; it will also experience snapping between the vertical and the horizontal members. Therefore, we did modification to the lap joint by adding on T-beam into this joint to reinforce it.

The end joint is not a very strong joint, especially for tension members. In tension, the two pieces of fettuccini will just pull right away from each other. In compression, this joint will allow the piece to bend in a perfect arc. The lap joint holds the piece stiff, which does help it to hold more.

The notched joint gives more strength than the end joint, but less than the lap joint. And if the notch is a little too big, it creates a weakness in the notched member. However, it is also more difficult to build with the brittle fettuccini, which makes it not applicable to our bridge design.

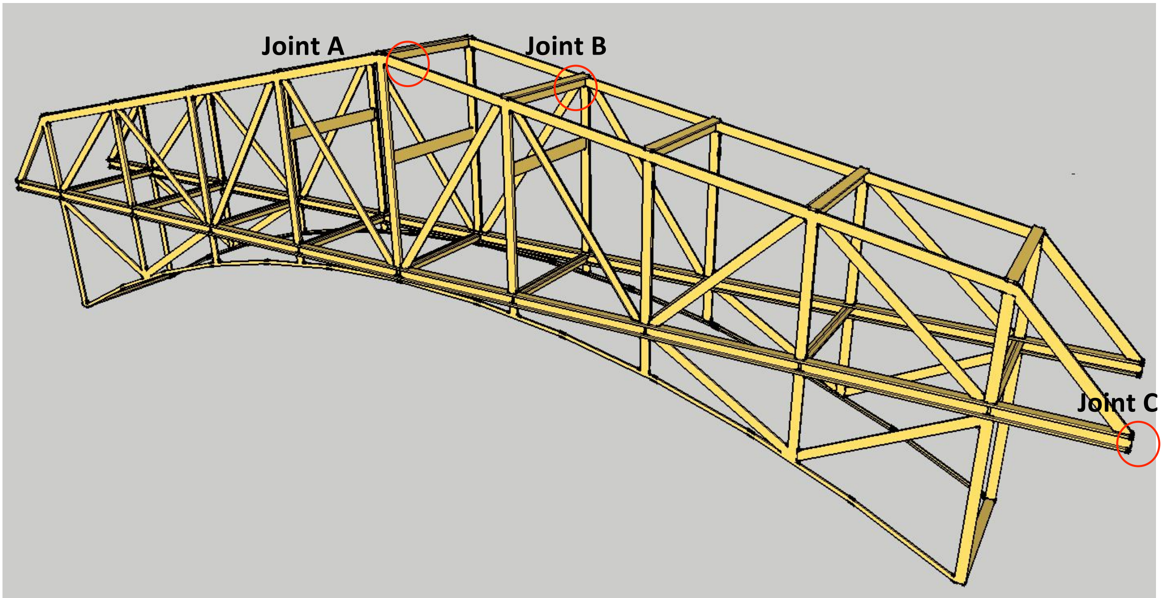


Figure 4.2.2 The 3D simulation to provide clearer joint system used.

Joint A

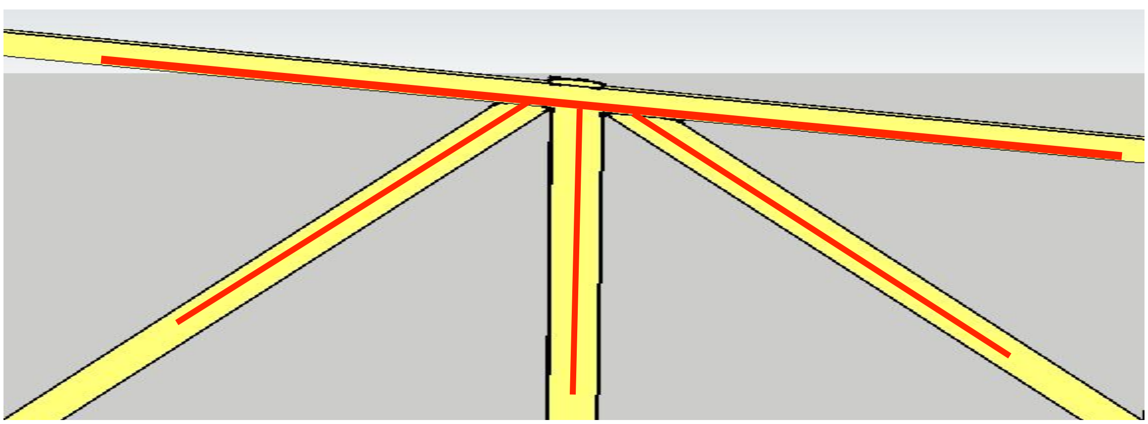
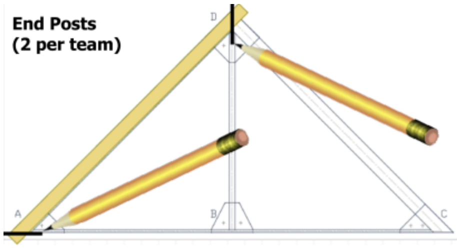


Figure 4.2.3 The 3D simulation to show joint used in Joint A.

In Joint A, we used the common joining method which is the end joint that is also known as butt joint. In this joining method, the glue need to be very strong and the face of connection need to be very precise in order to achieve firm joining. Therefore, we used sand paper in our construction process to make sure that the faces are flat and connectable to each other.

Step 1:



Step 2:

Joint B

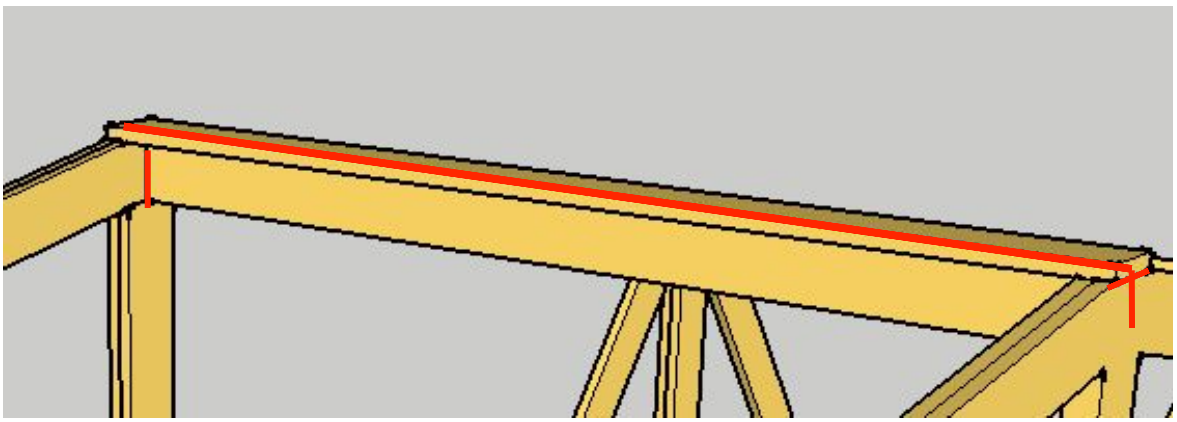


Figure 4.2.4 The 3D simulation to show joint used in Joint B.

In Joint B, we used the typical joining method which is the lap joint. However, we experienced failure in the first and second bridge testing. The lap joints used experienced snapping when the point load stresses too much on it. Therefore, we reinforced it by adding the T-beam into its cross-sectional profile.

Joint C

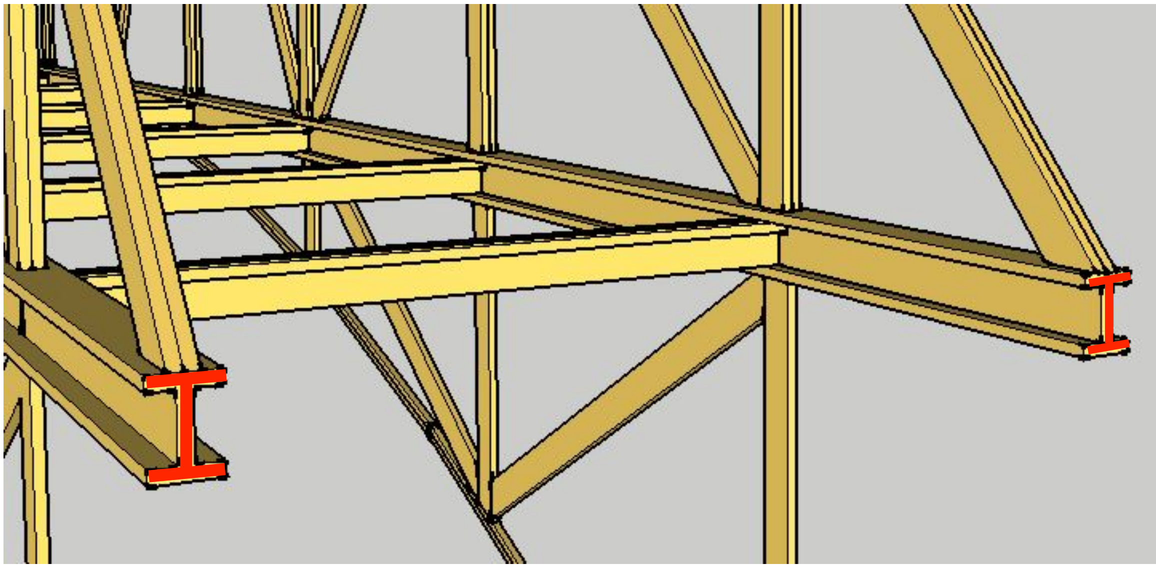


Figure 4.2.5 The 3D simulation to show joint used in Joint C.

In Joint C, we used the reinforced joining method which is the end joint but reinforced with I-beam. The usage of I-beam is believed to add on the strength as the fettuccini has stronger resistance when it is vertically placed on horizontal surface.

5. DESIGN PROCESS

5.1 Initial Design

A typical Waddell “A” truss was selected for our bridge design. However, we understand that the efficiency that we have from initial bridge will decrease by the longer span of bridge. Thus, we decided to improve the structure by adopting information from the precedent studies we carried out – Navajo Bridge. The open-spandrel arch which not only improve the bridge aesthetically but also the load distribution.

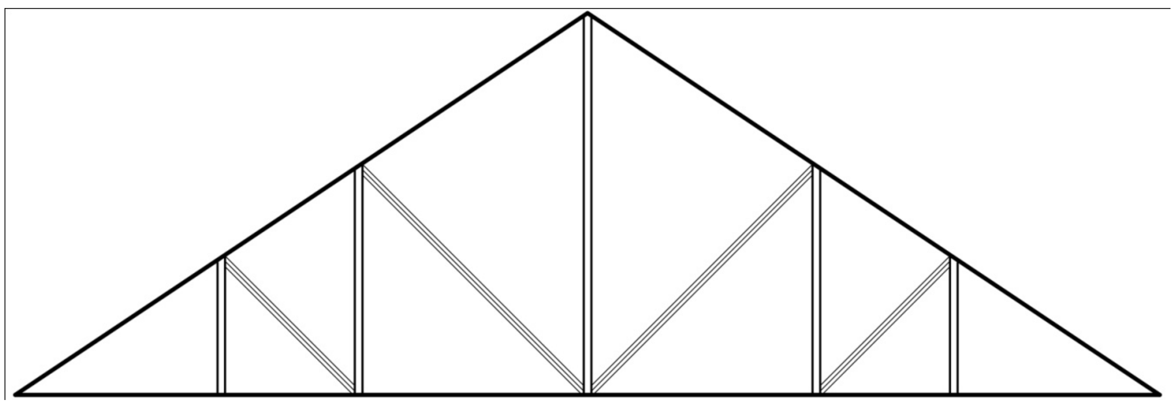


Figure 3.2.2 The arrangement of members for original Waddell “A” truss.

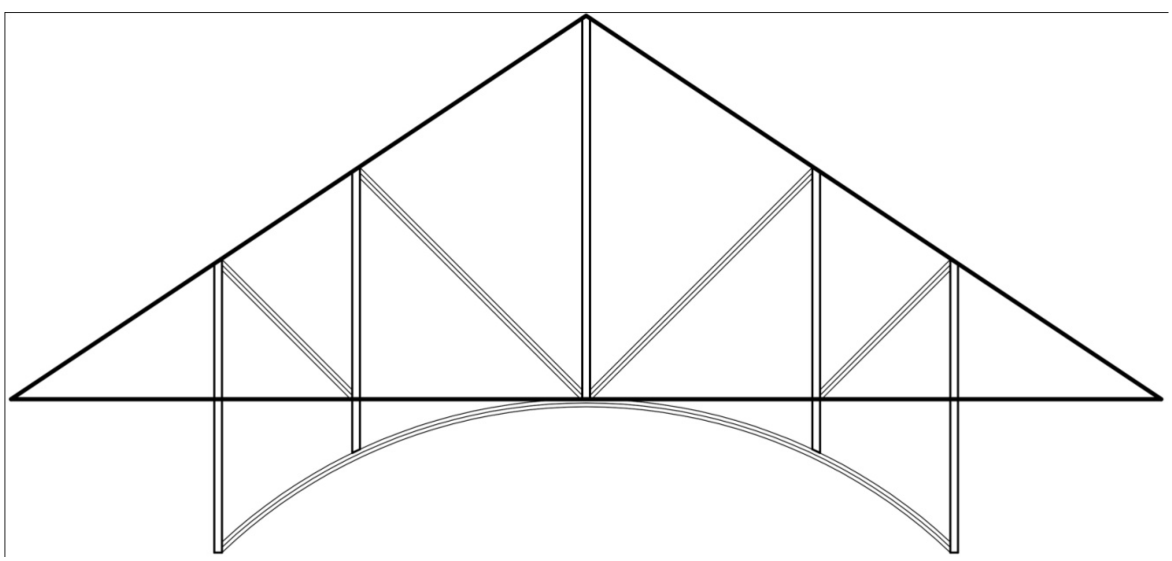
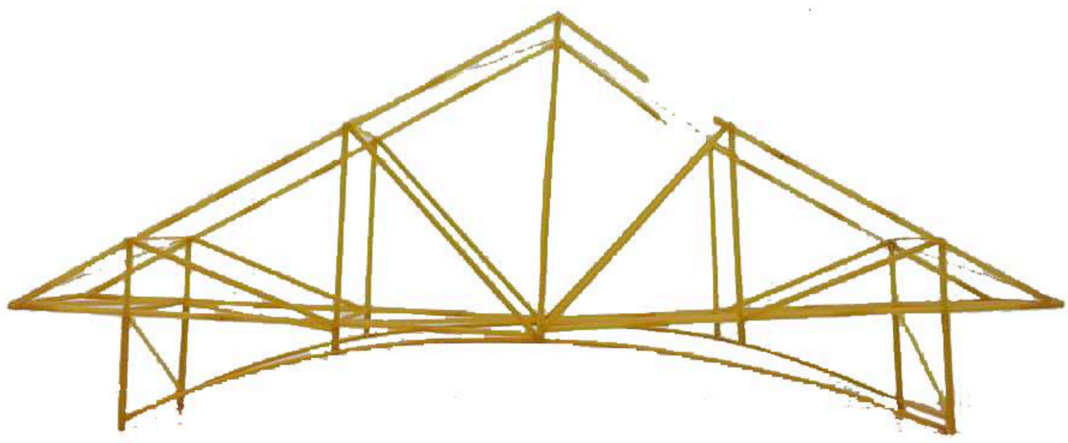


Figure 3.2.3 The arrangement of members for modified Waddell “A” truss.

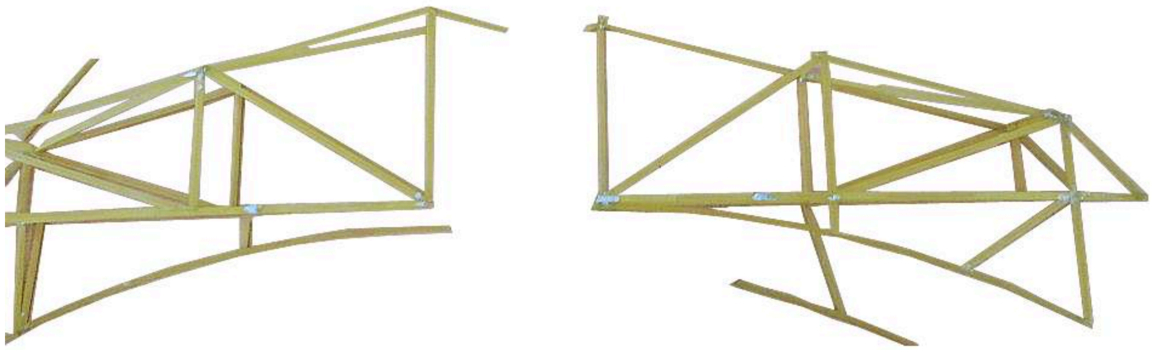
The bottom truss was designed to curve upwards to withstand the tension members, in addition to prevent the bridge from failing due to deflections when point load is applied. Furthermore, the vertical members were extended to a higher height in order to be strengthened to withstand vertical forces.

5.2 1ST Bridge



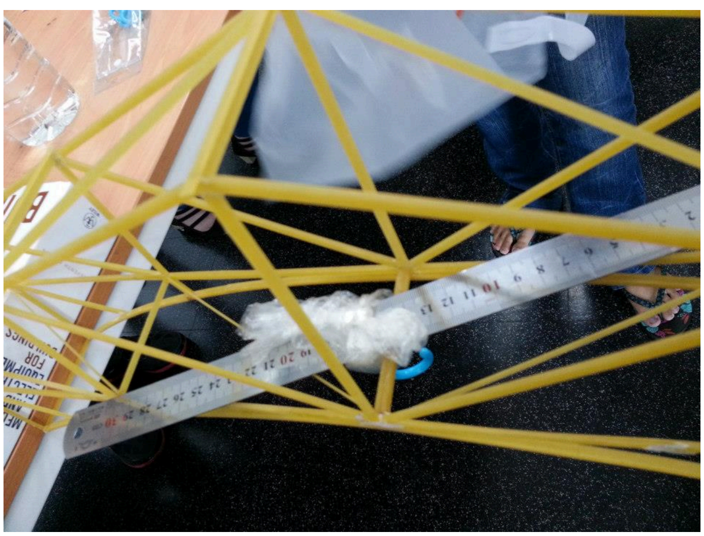
The first bridge has a weight of 155 g and able to withstand a load of 800 grams. It fails in the upper member, which is too long and poorly supported. The triple layers of arch remains unaffected after the testing. As the bridge exceeded the 150 gr weight requirement, some modifications are made to bring down the weight. This includes: lowering the height of the bridge, decrease a layer of arch, and decrease the length in both ends of the bridge which rests on the table during test. reducing the length of the ends of the bridge which rest on the table

5.3 2ND BRIDGE



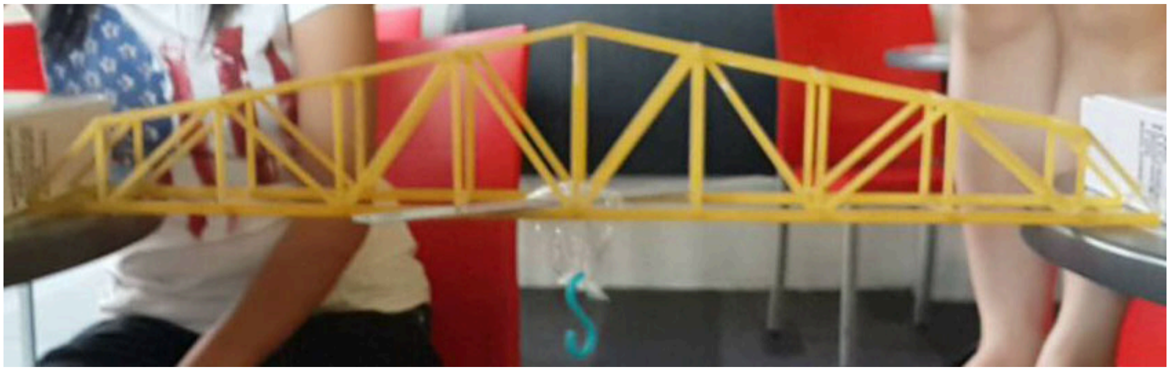
The second bridge is not much different than the first bridge beside the height of vertical members, but it still failed after stand the load of 2 kg in the center parts of bridge. The weight is succesfully reduced become 145gr that improved the efficiency. We realized for this second bridge the workmanship also influence the strength of the bridge, thus we not only need to improve the design by adding the truss member and reduce the span, but also our workmanship.

5.4 3RD Bridge



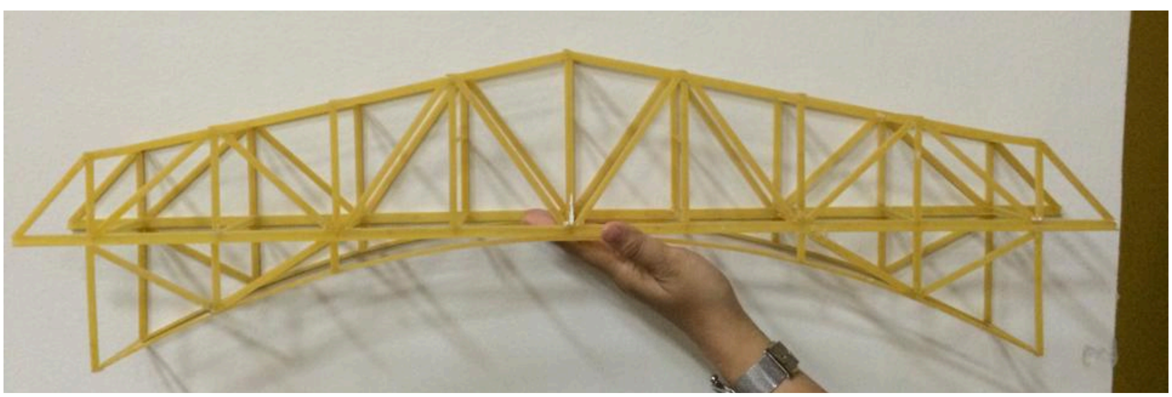
The third bridge is much more stronger than the previous bridges. The t-beam and i-beam strengthen the structures. The weight which is 147gr To improve this bridges, the center part of bridge need to be strengthen by adding horizontal member. The top part also need to be strengthen rather than bracing the base since from the testing the bracing on the base bend frantically when stand the load but still in the perfect condition after the bridge failed.

5.5 4TH Bridge



The fourth bridge is made for the sake of achieving better efficiency with doubleing the vertical member of the base i-beam without adding arch element to the truss. We assume the bridge can stand better efficiency with stronger base and reduce the weight with take off the arches, but after the the testing the bridge can only stand 2,5 kg which much more weaker than the previous bridges. So we decided to proceed with the previous design with the improvement.

5.6 Final Bridge



The final Bridge can only withstand 4 kg which is improve 0.25kg load with 3 short additional horizontal member in the center part of truss bridge. It even can stand it heaviest load longer than previous bridges that fall directly after it heaviest load loaded to the bridge. This design still can be improve by strengthen the midddle part of bridge since the bridge still below 150gr. The I beam also need to be stregthen by layering the vertical member of i-beam to let load transfer effectively distribute.

6.0 CONCLUSION

	Mass (g)	Load (kg)	Efficiency
1	155	0.8	4.12
2	145	2	27.59
3	147	3.85	100.83
4	133	2.5	47.00
5	145	4	110.34

Our last bridge is the most efficient among our test models. So we would say that it was a success for us in improving the bridge. Even though our final bridge cannot withstand the load more than 5 kg as the requirement of this task, we still achieved knowledge and deep understanding of the material behaviour of our bridge. We also understand how to determine the shape and force that works in the member and utilize it to design an effective truss bridge, which can be seen through the improvement that we achieved through each bridge.

From this task we can conclude that to improve our design bridge, we need to maintain our workmanship that wouldn’t be achived without understanding of material that we used. Not only the understanding of materials, the efficiency of the bridge is also one of the most important thing to be considered in this project. As an architect, we should always be seeking for ways to improve efficiency, and hence use less materials and move towards a sustainability.

7.7 Case Study Truss Analysis:

From the case study we considered two factor to determine the most effective truss bridge arrangement, the number of member with zero force and the highest critical forces. The zero force member means that the member can be take-off from the truss arrangement since it didn't carry or distribute the load to the others member and critical force member determine the most critical and chance of the member that collapse or fail when the load transfer. The higher critical force the higher chance of that member to collapse.

	Case 1/2	Case 3	Case 4/5	Case 6
Number of Member with 0 forces.	2	1	0	3
Highest critical force	252kN	228,05kN	227.05kN	277.86kN

7.8 Case Study Conclusion:

From the data we can conclude that the case 3 is the most effective. Compared to the case study 4/5 with case study 3 that only have 1kN differences, the case study 3 have 1 zero force members which means the case 3 can have lighter material than case 4/5 that result on better efficiency.

From these case study we achieved better understanding of how the force (tension and compression) work in each member of truss based on Newton Law's. Therefore, when we want to improve the efficiency of truss bridge, the arrangement and shape of our truss not only based on our assumption, but also from strong basic understanding that can be proven scientifically. We realized that sometimes the theory is not work 100% in reality, but the basic understanding can help us to predict the cause of failure and decide the most important part of the bridge that need to be strengthen or take off since it's not needed to achieve better efficiency.

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