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Balsa Wood Bridge

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By

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Abstract

The project requires the individual to design and construct a truss bridge made from balsa wood and wood glue to perform several objectives. The main objectives are to articulate the bridge by raising it, to conform to dimensional requirements, to allow a vehicle to travel along the road deck, and to hold a minimum load. The bridge must be able to articulate in two different ways. First, the articulation system can lift the road deck vertically while on top of the bridge. Second, raise the bridge with a pivot when the articulation system is placed at the specified end of the bridge. The bridge was able to raise the road deck to the required 280 mm height and allowed a sheet of paper to slide between the abutment and bridge using the pivot, holding it for ten seconds. The bridge without the articulation system weighed less than 85 grams when measured with a digital scale. The vehicle represented by a block pulled with a string can travel across the road deck without obstructions. The bridge was then tested for loading by adding weights to the inserted rod; however, the bridge couldn't reach the 20 kg load before it began to fail.

Contents

1. INTRODUCTION

a. Description

The problem of the project is for one to design and construct a bridge that's able to articulate with an articulation system, have a vehicle travel across the road deck, weigh less than 85 grams, and able to take a certain amount of load through the center hole of the road deck. Through engineering, an articulation system can be designed and attached to the bridge using components strings, spools, etc. as well as being able to meet design requirements and handling the required load. Since the bridge is required to be made from balsa wood and glue, understanding the materials and how to effectively use them would be insightful to design a bridge that won't collapse under a heavy load.

b. Motivation

The project was motivated primarily due to safety concerns regarding COVID-19, therefore a project that can be done in the safety of home was needed, and with sufficient engineering merit to demonstrate engineering proficiency.

c. Function Statement

The function of the balsa wood bridge is for it to be able to span a divide while supporting a load, the bridge must allow passage to moving structures moving perpendicular to the span of the bridge, passing above the original height of the bridge.

d. Requirements

In this project, the design of the bridge has several requirements that need to be filled for it to be able to accomplish its tasks. Fundamentally, the bridge must be made from balsa wood and only glue can be used (exception being the articulation components like pulleys and string), but the other requirements include but not limited to:

- The weight of the bridge should not exceed 85 grams without the articulation components.
- The dimensions of the bridge must have a span of 400 mm, resting on 60 mm wide steel abutments.
- The 38 mm wide solid balsa wood road deck must extend to the length of the bridge.
- On the road deck, there must be an 8 mm diameter hole at the center.
- The road deck must be within 12 mm of the abutment level at the outside edge of each abutment or bridge end.
- The road deck must be centered on the bridge, either horizontal or a smooth curve from both ends.
- If the road deck is curved, the grade is limited to a maximum difference between two points is 25mm.
- The road deck should be free from obstructions that a 32 mm wide and 25 mm tall block can travel the length of the road deck.
- The articulation system on the bridge must be able to raise at least 50% the road deck 280 mm above the original resting position.
- The articulation system should be able to allow a 20 lb. paper to be slipped between the bridge and the abutment at one end.

- The bridge must be able to handle a load between 18.9 kg to 20 kg.

e. Engineering Merit

The engineering merit of this project is to present all the learning that culminated through the program, to demonstrate the process of conceptualization, calculation, design, prototyping, testing, and presentation of information. This can be done through the applications of physics, statics, and dynamics.

f. Scope of Effort

The scope of the project will cover the entire design of the bridge, including the articulating components needed to raise it.

g. Success Criteria

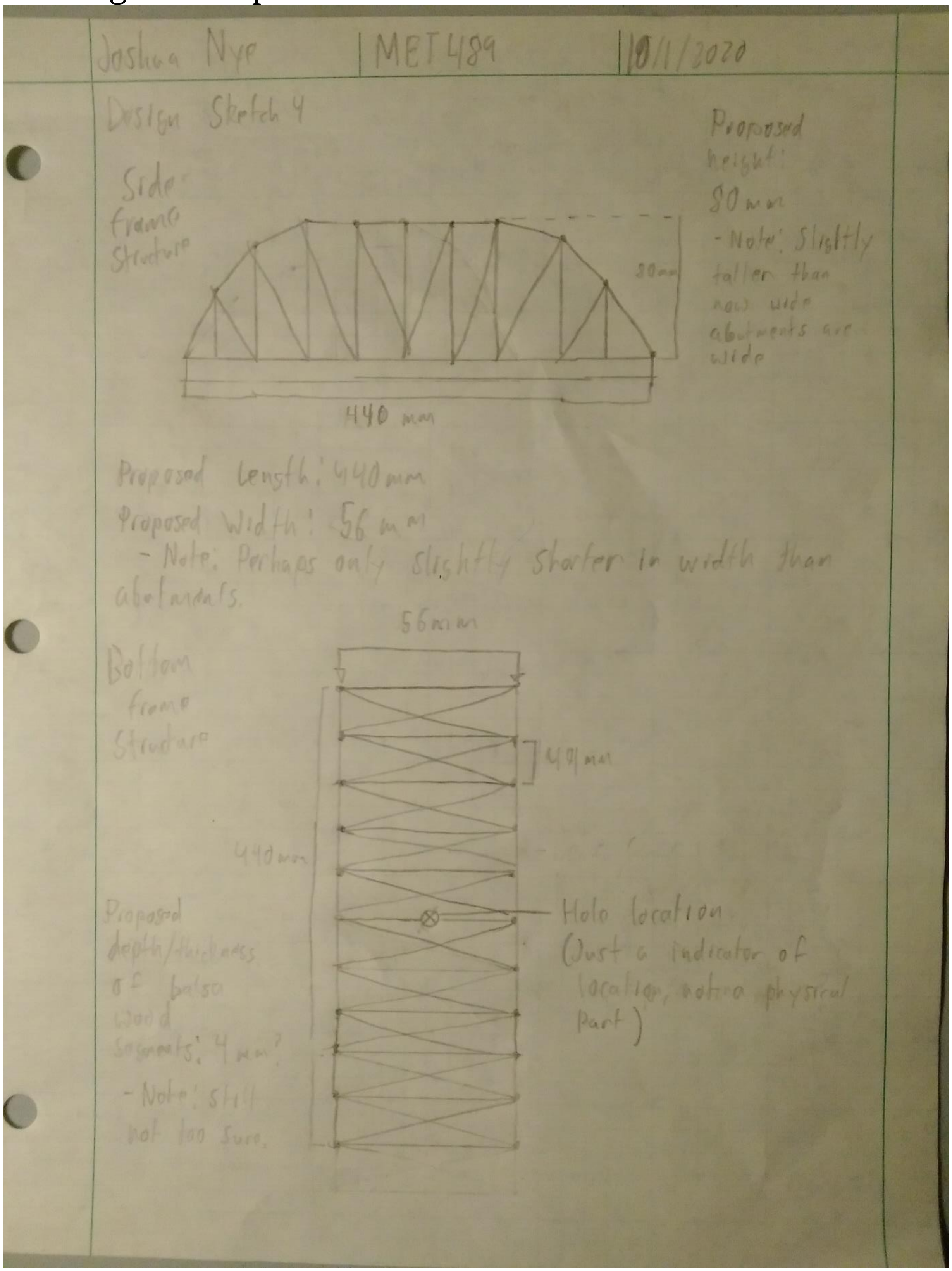
The success criteria of the balsa wood bridge are to span a distance, to support load, and to articulate.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The design was conceived with the idea of a truss bridge with plenty of supports to help distribute the load. Based on the requirements, much of the decisions revolved around the length of the bridge, the number of supports on a bridge (within reason), simple vs. complex, etc. The overall idea is to make a simple, but effective bridge design without too many unnecessary complexities.

b. Design Description



c. Benchmark

Comparing the following benchmark to the problem of the project, the benchmark chosen is a YouTube video of a similar balsa wood bridge project for a 2015 AP Physics class shown. The video shown the testing/competition of the various students' bridges undergoing a load. The interesting this is that for the bridge that placed first, it managed to hold onto 12.25 kg of load before collapsing (3). The noticeable features were that the bridge looked traditional for truss bridges, the bridge was also large and tall with a decent number of supports for the balsa wood trusses.

d. Performance Predictions

The predictions regarding the performance of the balsa wood bridge are that it wouldn't be able to take on a load of 20 kg placed at its center without collapsing. The articulation system should be able to raise the bridge, as well as lift the road deck above 280 mm. In addition, a vehicle should be able to traverse across the road deck without problems, and that the bridge will weigh less than 85 grams.

e. Description of Analysis

For the analyses of the balsa wood bridge project, the topics that will find the most application are mechanics of materials, and statics. This includes drawing free body diagrams, finding forces and stresses, which include bending and shear stresses since the bridge is likely going to bend a bit before it collapses. A bit of dynamics may also be used for the articulation system for the bridge since the articulation system is going to be lifting the road deck.

f. Scope of Testing and Evaluation

The scope of the testing and evaluation covered in the project will be what's stated in the criteria, which includes having a "vehicle" traversing the bridge, the articulation being able to raise the road deck, the bridge resting on the abutments, 10 grams allowing a gap for 20 lb. paper, supporting a load between 18.9 kg to 20 kg, and the weight of the bridge being below 85 grams.

g. Analysis

The requirement that was investigated for the first analysis were the forces of the load on a bridge, using a basic bridge free body diagram in order to locate forces and reactions. As shown in Appendix A-1, the 20 kg load in the center was measured, and the reactions at the ends of the FBD representing where the bridge meets the abutments, Ay and By both had 10 kg upwards. Since the abutments cannot withstand lateral forces, forces in the x-axis weren't considered. The loads were then multiplied by the acceleration of gravity (9.81 m/s^2) to convert them into force values. Once the force values were obtained, the next step was to use MDSolids' Truss Analysis feature to sketch a bridge with members. The general sketch of the bridge truss design on the program is shown on Analysis 1A. The bridge truss design was then computed on the MDSolids' program to display the forces acting in tension and compression on Analysis 1B. It was then roughly copied into a greensheet on Appendix A1-2, rounded to 1 decimal place and the forces listed out.

The requirement that was investigated in the second analysis was the weight of the balsa wood bridge design. In this analysis, the bridge design had to have some proposed measurements such as the lengths and widths of the bridge and some of its sections. A few assumptions were also made for the analysis to work, such as the balsa wood segments being rectangular prisms, and that the proposed thickness of the wood segments was 4mm. Through calculating the volumes of the sections of the bridge, the total volume came out to be 106901.2 mm^3. The density of the balsa wood came from two different sources, a website called Engineering Toolbox which offered a range of 110 to 140 kg/m^3 (1), and the other source was Marks' Standard Handbook for Mechanical Engineers which stated the densities of balsa wood were 117 kg/m^3 (2), 141 kg/m^3, and 320 kg/m^3 (although these densities were found in the chapter 11.2 regarding cryogenics). It was decided that the density of balsa wood for this analysis was 140 kg/m^3, which was then converted to 0.00014 g/mm^3. Multiplying the density and the volume, the weight turned out to be 15 grams.

The requirement that was investigated for the third analysis was the articulation system. What was kept in mind for the articulation system was that it was to be attached or rested on top of the center of the bridge, spanning both length and width. Shown on Appendix A-7, a few assumptions that had to be made was that the pulleys, spools, and string/rope were weightless, as much of the focus would be on the articulation system's frame, tension from the road deck, and tension from the weight-handle on the pulley. Another assumption was that the rods on the articulation system are cold rolled plain steel, as it was based on a steel rod found on Home Depot's website (4). Last assumption was that the road deck was a rectangular prism to simplify calculations. The first step shown on Appendix A-7 was to create a free body diagram of the system to be able to determine the forces of tension on the articulation system from the road deck and the weight-handle on the pulley. The density was already given from a previous analysis, and the dimensions would be 38 mm, 440 mm (based on the length of the bridge), and 4 mm (based on the previous analysis' assumption on thickness). Calculating both resulted in a weight of about 10 grams. Since there are four spools that are connected to the road deck, the tension from the road deck would be divided into four, and so each of the handle-weights would have to weigh about 5 grams. The idea for this was that the handle-weights to be in equilibrium with the road deck so that the said road deck can be suspended while trying to measure the height during testing. Once that was completed, the next step was to figure out the weight of the entire articulation system in order to acknowledge and understand how it would affect the overall frame of the bridge. In both Appendix A-7 and Appendix A-8, the individual volumes of the balsa wood blocks making up the frame of the articulation system were calculated, as well as the steel rods (density as well) (6) in addition to the handle-weights resulted in a weight of 19.72 g. During the construction phase of the project there were some changes to the design of the road deck and the operation of the articulation system that this analysis is no longer relevant to the working device, and is kept here to archive the work and thought process during the design phase.

The requirement that was investigated in the fourth analysis was to determine the friction that would affect the road deck of the bridge from the block. The few core assumptions in this analysis was that the block traversing the road deck was also made from balsa wood, and that the block was not wheeled. At this analysis, the road deck would share the same thickness assumption as previous analyses. Firstly, the friction values had to be obtained for the calculations to occur. Unfortunately, there were no specific values of friction for balsa wood, so the next step was to use friction for wood-on-wood. The static friction was between 0.25 and 0.5, and kinetic friction was 0.2. Next, a free body diagram of the block was to be made, determining the forces of friction, normal, gravity, and applied. The dimensions of the block were 38 mm for the width, and 25 mm for the height, so it will be assumed the length is also 38 mm. Calculating the weight based on the dimensions and the density of balsa wood resulted in about 5.054 g. The force from gravity was calculated to be -49.57 g*m/s^2, which in reaction the normal force would be 49.57 g*m/s^2. For friction calculations, there would be two different forces for friction based on what was given for the values of 0.25 and 0.5. Minimum static friction was 12.39 g*m/s^2, and maximum static friction was 24.78 g*m/s^2. Kinetic friction was calculated to be 9.914 g*m/s^2. The applied force would have to exceed these values to cause the block to move.

In the fifth analysis, the requirement that was investigated was the bridge articulation to raise the bridge with a 10-gram weight to allow a sheet of paper to slide between the bridge and the abutment. The initial concern was that the articulation system's design was supposedly to attach on top of the center side frames of the bridge, and while it would be good to lift the road deck, it wouldn't be as good to lift a bridge. The suggested idea would be to reposition string/rope from the furthest set of spools, tie them around the areas of the bridge that will be lifted, and try to tilt it enough for the paper to slide between the abutment and bridge. Also, in the articulation design, the handles attached to the strings of the pulleys would weigh 5 grams each initially since the focus was for the road deck. Adding a 10-gram weight would total to 15 grams, which is about the same weight as the balsa wood bridge design as stated in second analysis. The assumptions in this analysis are that the articulation system is secure on top of the bridge, and there aren't any other external forces acting on the bridge. A free body diagram was drawn for the area of interest, and it would be under tension due to the string lifting it, shown in Appendix A5-1. Note that there would be two strings tied to the same area for their side of the bridge, so the forces for both should be about the same values. The angle appeared to be around 37.5 degrees from the point of interest to the second set of spools. The tension would be calculated from the weight of the handle plus the 10-gram weight (converted to kilograms), and the force of gravity 9.81 m/s^2 and 0.147 N was calculated. The force acting in the y-direction of the point of interest came out to be 0.117 N and the force acting in the x-direction was 0.089 N, as shown in Appendix A5-2. It was determined that it would likely be able to lift that area of the bridge enough for the sheet to slide between the bridge and the abutment.

In the sixth analysis, the amount of torque acting on the articulation mechanism were analyzed. Considering that there are two sets of the same mechanism in total, it is assumed that the calculations will be the same for the other articulation mechanism. Taking some of the calculations from the third analysis, the mass of the road deck acting on the spools is 5 g. and the mass of the handle/weight on the pulley also being 5 g. were already found. All that is needed is to calculate the force with the acceleration of gravity. Because of the second set of the articulation mechanism exists, the calculation would only consider half of the mass of the road deck considering that it is shouldering half of its actual weight. Since there are also two spools on the mechanism taking on the force of the road deck, the total force from the road deck will be divided between those two spools. The forces acting on each spool should equal 0.025 N, and the forces acting on the pulley should equal 0.05 N and should be acting in equilibrium in the entire mechanism. With the forces, the torque can be calculated. The pivot point that was chosen for the torque calculations was the midpoint of the entire steel rod. Both the spools would be the same distance from the midpoint, so the value of torque for both Spool 2 and Spool 1 should be 0.316 N*mm CCW, and the torque for the pulley would be 2.15 N*mm CW.

In the seventh analysis, the amount of max shear stress from torsion acting on the pulley and spools on the steel rod as well as the angle of torsional deformation were analyzed. With the torque calculated from the sixth analysis, the other components that needed to be found were the radius from the center of the steel rod to the point of interest and the polar moment of inertia. The diameter of the steel rod was 3.125 mm, and the radius to the point of interest would be 1.56

mm. The polar moment of inertia that was calculated was 9.36 mm^4. Having all those components, the max shear stress from torsion can be calculated. The max shear on spool 1 (A in calculations) is 0.0526 N/mm^2, the max shear on spool 2 (B in calculations) is 0.0526 N/mm^2, and the max shear for the pulley (C in calculations) is 0.360 N/mm^2. The other aspect of torsion to be calculated is the angle of torsional deformation. The shear modulus for the steel rod is 8*10^10 Pa. Taking all the values of torque, the length of the steel rod being 96 mm, and the polar moment of inertia, the torsional deformation of the entire steel rod calculates to be 0.0205 degrees. During the construction phase of the project there were some changes to the design of the road deck and the operation of the articulation system that this analysis is no longer relevant to the working device, and is kept here to archive the work and thought process during the design phase.

In the eighth analysis, the tension acting on all the cables for the entire articulation system was to be determined. There is a total of four cables that will be lifting the road deck (and eventually the bridge), and there are two pulleys each having a handle/weight on them. From the third analysis, the actual total mass of the road deck was 9.36 g, but was rounded up to 10 g for simplification of calculations, and each handle/weight is 5 g. Calculating with the acceleration of gravity, the total tension from the road deck is 0.0981 N. Because of the fact that there are the four cables holding up the road deck, dividing the road deck by four should give the value of about 0.025 N acting on each cable. On the pulleys, the value of tension acting on each one should be about 0.05 N. During the construction phase of the project there were some changes to the design of the road deck and the operation of the articulation system that this analysis is no longer relevant to the working device, and is kept here to archive the work and thought process during the design phase.

For the ninth analysis, the forces and torque acting on the pivot pin for the bridge lifting articulation was determined. The pivot pin is to be located at the end of the bridge and attached to the articulation mechanism which was modified to hold the said pivot pin. Another modification to the bridge design was the bridge extended by 30 mm on each side, totaling to 500 mm. Assuming that the pivot pin is properly secured, the only forces that are acting on the pivot when at rest is the force of gravity/weight and the normal force, which both equal 0.0355 N. Another calculation done was the torque acting on the pivot pin, now the bridge will begin to raise. With the length of 500 mm, and the force being 0.14715 N, the torque equals 73.57 N*mm.

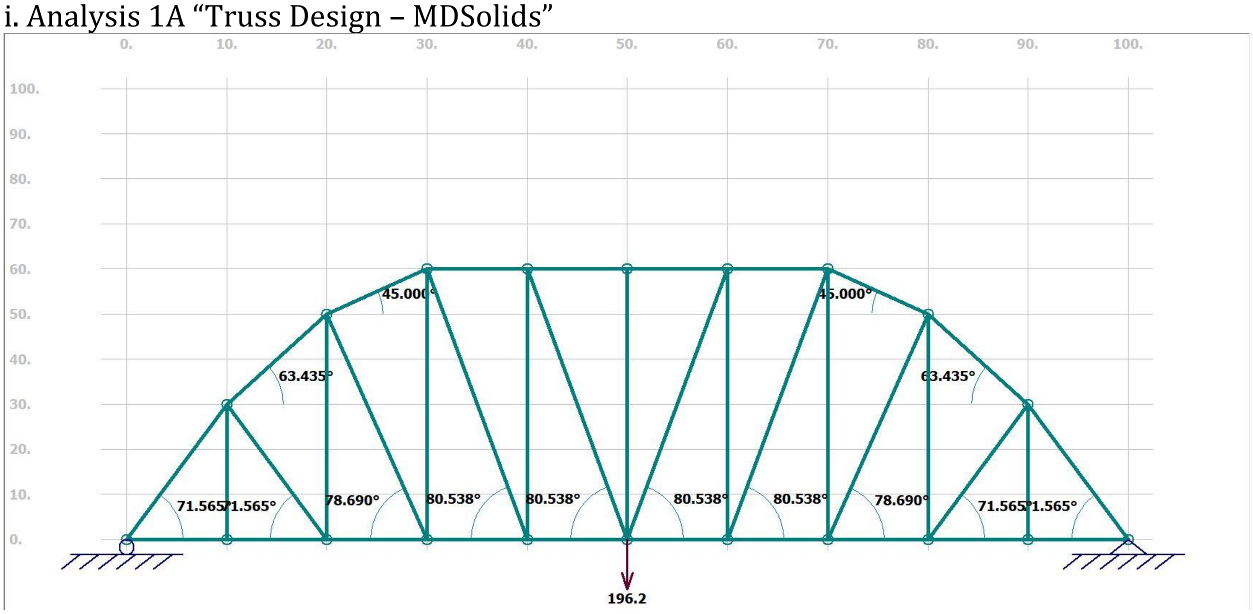
On the tenth analysis, the forces on the crank/pulley and the forces needed to lift the bridge were determined. The assumptions are that the cable for the articulation system are properly tied/connected to the width segment on the opposite end of the bridge, and that the pivot pin is properly secured. To be able to find the forces acting on the pulley, the forces around the connected cable at the end of the bridge must be determined. Considering both the pivot and cable connections are at opposite ends of the bridge, the articulation mechanism will have to bear the full weight of the bridge to be able to lift it. The angle of the cable connecting the articulation system to the end of the bridge was calculated by the inverse tangent of the length from the connected end to the articulation system being 503.175 mm, and to the height being 132 mm, which they equal to 14.69 degrees. The force of the weight of the bridge was calculated by converting the 15 grams to kilograms, and multiplying that value by the acceleration of gravity to get 0.14715 N. The neutral force would equal the same value of 0.14715 N. From there, the tension from the weight of the bridge can be determined by dividing 0.14715 N to the cosine angle of 14.69 degrees, which equals 0.15212 N. That tension value will affect the pulley, and so the other force that needs to be considered is the tension from the weight of the handles. Initially, the weight of 5 grams is part of the design and acts as a handle, and the addition of the 10 grams to the lifting mechanism per the bridge criteria will total to 15 grams. The tension from the weight of the handles should equal to 0.14715 N. For the pulley to be able to lift the bridge, the force must exceed 0.15212 N, and likely will require an additional weight in the design or human input. In the construction phase, there was a slight change that was made in the manner of how the bridge would be lifted. On the sides of the bridge structure are the Bridge Structure Flat Supports that have a 10mm by 10mm square hole at the ends in which the string would loop on the outside of the bridge and raise it through those square holes. Other than that, it's close to the same principle.

For the eleventh analysis, the forces acting on the weight/handle from the pulley as well as the normal tensile stress affecting it. It was decided that the weights/handles would be iron fishing weights, since it was reasoned that they're light enough weights to be used for the balsa wood bridge in addition to having a loop to connect with a cable or wire. The assumptions that were made for the analysis was that the weight/handle was cylindrical since only the length and diameter were provided, and that the handle is in tension. An adjustment from the original design was that the handles would now weigh seven grams from five grams due to information from the tenth analysis. The free body diagram of the handle displays that the only forces acting on it were the force from tension and the force from weight. The 7 g handle was multiplied by the acceleration of gravity (9.81 m/s^2) which resulted in a value of 0.06867 N. Since the handle is in tension, the value 0.06867 N would be the force from tension too, therefore the handle should be in equilibrium. To calculate the normal tensile stress, the area of the cross-sectional area had to be calculated. With the assumption that the handle is a cylinder, the area was calculated to be 95.03 mm^2. Taking the force and dividing it by the area, the normal tensile stress of the handle came out to be 723 Pa. In the construction phase of the project, the fishing weights are no longer used as the handle/weight for the articulation system and a simple crank is used instead. This analysis is no longer relevant to the working device and therefore the analysis is kept here to archive the work and thought process during the design phase.

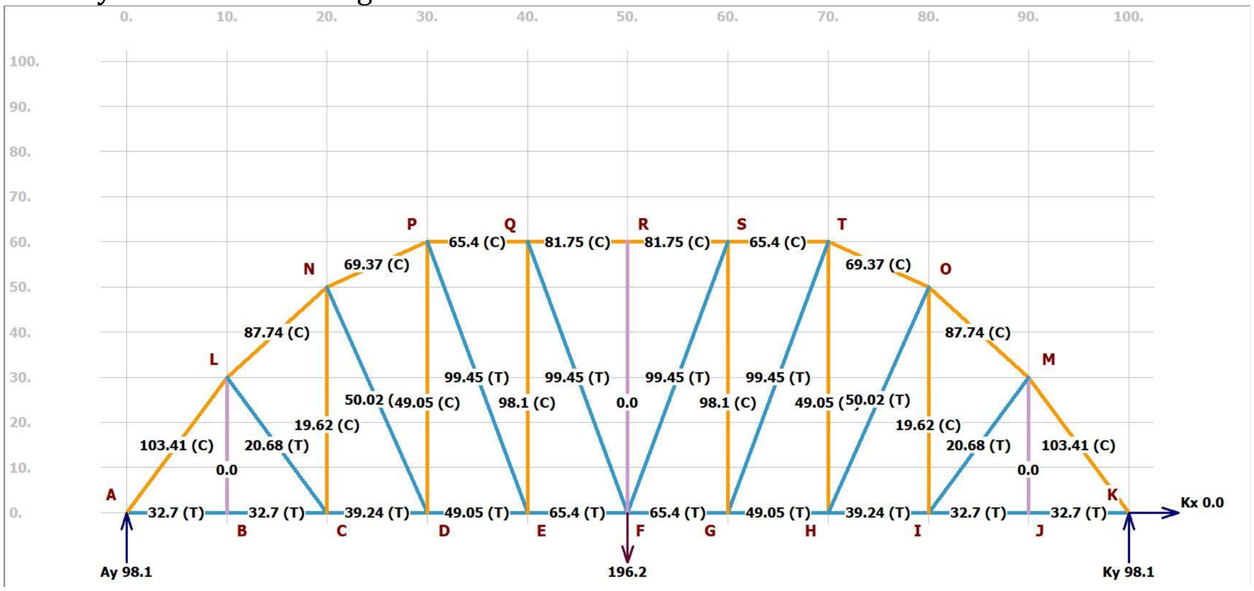
For the twelfth analysis, the position of the holes on the road deck for the articulation system's road deck lifting, as well as the size of the holes and the washers/disks were determined. This analysis relied on a couple of previous analyses in order to find the locations for the holes. The location of the holes are relative to three different assets of the bridge: the center hole on the road deck, the side frames on the balsa wood bridge, and the articulation mechanisms on the articulation. The center hole was 220 mm from the length side of the road deck, and 19 mm from the width side of the road deck. The center hole relative to the side frame's length (176 mm) is 88 mm. The spools of the articulation system are about 35.35 mm from the ends of the steel rod, and 12.175 mm from the side frame, and 44 mm from the center of the side frame. In that case, the holes should be at least 3.175mm from the width, and about 44 mm from the center hole. Since the holes are a bit close to the length side of the road deck, its considered that an additional 2 mm to 4 mm closer to the center of the road deck would be sufficient Once the locations were determined, the hole sizes needed to be determined. Since the hole sizes need to be slightly smaller than the center hole of the road deck while being conscious of the location of the vertical lifting holes, it's going to be at most 5 mm in diameter. Finally, the washers/disks that the articulation system will lift (which the washers/disks will lift the road deck) have to be bigger in diameter than the holes, so it would likely have to be around 7 mm to 8 mm in diameter. However, during the construction phase of the project, the holes were eventually removed on the road deck since the bridge is lifted by a loop in the strings, so this analysis isn't relevant for the working device. Therefore, this analysis is simply to archive the work and thought process during the design phase.

While in the construction phase of the project, there wasn't much in the way of additional analyses done for the design. For the most part, the construction of the bridge remained faithful to the bridge design. However, there were some changes that were made in the construction of the bridge that weren't part of the design or were no longer needed, some were relatively small changes while others were relatively major changes. For example, the original design had a pulley/spool that had a fishing weight attached to a string and would control the lifting of the road deck or the bridge, which was removed for a simple hand crank because it was much simpler to work with and the drilled holes on the articulation system's lengths tightly held the steel rods that a crank would have been more effective at turning the rods than a weight on a spool/pulley even with added lubrication from oil. Another change in the design was that the road deck was originally going to be lifted using disks via holes in the road deck. This was later changed because the additional holes on the road deck would have caused issues with required design parameters, and the strings would literally be in the way when testing an object moving through the road deck (and thus also requiring changes to the design of the road deck), therefore the road deck would then be lifted with a simple string looped around it. Related to this change is how the entire bridge then as a result of the previous changes, in which the quick solution was to adjust the design of the recently-added Bridge Structure Flat Supports to include a 10mm by 10mm square cut at the opposite end so that the loop of the string can be placed there to lift the bridge, although this would require the string to be much longer. Any other changes that were made to the design are relatively small such as changes in length or positioning, or were just additional parts either supporting the bridge structure or were a response to changes in other areas in the bridge like the cranks on the articulation system.

i. Analysis 1A "Truss Design – MDSolids"



ii. Analysis 1B “Truss Design with Forces on Members – MDSolids”



h. Device: Parts, Shapes, and Conformation

The parts and shapes that came up based on the analyses was a constantly evolving process as the resulting design came into being. Given that the bridge will be comprised of balsa wood, the main frame of the bridge will have to be made from thin segments. The articulation system will be made from balsa wood blocks, with through holes on their length to insert the steel rods with spools. The hand cranks will be made from regular wood dowels.

i. Device Assembly

The assembly of the bridge will be 500 mm in length, which will span between two steel abutments, having an opening of 400 mm. It consists thin segments glued together with wood glue to make the main frame of the bridge, a road deck that will span the entire bridge, and an articulation system that has a dual purpose of raising the road deck about 280 mm, and raising the entire bridge for a brief period to allow tall objects to pass where normally they won’t be able to when resting horizontally on the abutments. Because of these different forms of articulation, the system must be an external component so that it can fulfill both tasks.

j. Technical Risk Analysis

The technical risks regarding the balsa wood bridge include the weight. As stated in the criteria, the weight of the bridge cannot exceed 85 grams (without the articulation system). While the frame itself is well under the weight limit, the adhesive glue may add additional unnecessary weight during the construction process, so careful usage of the glue is needed to optimize strength of the frame while at the same time minimize the added weight.

For the articulation system, there is little to no doubt that when placed on top of the bridge that it will be able to lift the road deck. However, because the articulation system is external, it may have a bit of trouble of raising the entire bridge considering that the pivot is also external and must be secured at one of the ends of the bridge’s length. It is makeshift solution, but it’s the only viable option that doesn’t affect the strength of the bridge frame but can perform both articulation tasks.

k. Failure Mode Analysis

The primary loading that the bridge will experience during testing will be from the 18.9 to 20 kg load that will be inserted at the center of the bridge, which will affect the entire bridge as it tries to support the load. Its assumed that the balsa material (at least the balsa wood segments making up the frame) will be considered ductile, and would fall under the maximum shear stress theory, since it would slightly bend at failure before eventually fracturing.

l. Operation Limits and Safety

The operational limits for the bridge regarding safety are that the bridge shouldn't be loaded for more than 20 kg and should only be loaded at the center of the bridge. Objects should not move across the bridge when the road deck is raised. The articulation system must be properly set up at its positions before either lifting the road deck, or lifting the bridge, no other operations should be conducted during each kind of lifting.

3. METHODS & CONSTRUCTION

a. Methods

The methods that were used to address the engineering problem regarding a balsa wood bridge utilized elements from statics, which included force diagrams and equilibrium equations. Another element used was solids, which included analyzing for normal and shear stresses, torsion, and angle of stress from torsion, etc. Other relevant elements include calculations of weight from volume and density, torque, etc. To be able to make the solution to the engineering problem happen, the individual has to be able to utilize the analyses to refer to so that the construction of the balsa wood bridge can be done properly with resources on-hand, and whatever can be supplied to create the bridge from the constraints at home. Some of these resources include raw balsa wood segments, blocks, and sheets, which can be cut into proper sizes and shapes to conform with what was analyzed. These raw resources will be supplied through purchases from an online store. Other resources will include pulleys, spools, and cable/wire/string which will be acquired from an online store as well. A steel rod would be acquired from a local hardware store.

With these parts, certain tools will also be used to be able to cut and shape the parts into their design specifications to be able to construct the bridge. Some of these tools include a metric ruler, a pencil for marking measurements, a miter box for accurate angular cuts, a razor saw to cut through the balsa wood smoothly, a hacksaw to cut through the steel rod, wood glue to eventually etc. For the most part, the tools should be sufficient to create the parts manually, only a few of them would require a machine to do so.

i. Process Decisions

During the process of sketching the bridge design, there were about four different designs in total for the project. On the fourth design, it was determined to be the one that will be used for the project for a few reasons. Referring to Appendix F1 Decision Matrix, the primary reason it was the design that appeared the most simple and straightforward that can be done. Another was that it was the most conforming to the bridge criteria standards, while the other designs were not close due to factors such as articulation design and that the bridge itself would be comprised of different pieces as opposed to a cohesive whole. The other reasons were that Design #4 was conforming to the weight requirements and referencing Analysis 2 the weight turned out to be 15 grams. The criteria of the bridge had the weight being less than 85 grams, so Design #4 still has plenty of room to work with should there be any changes to the design in the future, which is very likely. Another criterion was that the load being able to distribute across the truss beams, which Design #4 will fit just fine considering that it has both vertical and diagonal beams to distribute the load across the bridge. Referring to the first analysis and the pictures associated with it, when a load of 20 kg (196.2 N in the picture) is applied to the center of the bridge, the force across each beam and section can be seen. Lastly, the length of the bridge was also considered. While the span of the bridge must be at least 400 mm, the length of the bridge for Design #4 totals to 500 mm, so about 50 mm on each side can rest comfortably on the abutments, and still be able to fulfill that requirement.

During the construction phase of the project, much of the original decisions in Design #4 were kept. However, there were a few adjustments and additions that were made to improve the design. Firstly, was a removal of a single bottom frame in the middle and replacing it with just longer support segments. The decision behind this was that the support segment was in the way of the center hole of the road deck and wouldn’t be able to test for loading unless that was out of the way. The next decision that was made was the adjustment of the smaller hole positions on the road deck. These ones were also on top of the shorter support segments on the bridge frame and had to be adjusted closer to the center line of the road deck. Another decision related to the road deck that was made from necessity was using Imperial drill bits for holes. These were the closest ones to the design specifications. For the smaller holes, it was within tolerance, but for the larger hole, its well out of tolerance. However, it should still be able to insert the 8 mm diameter rod through it when testing happens.

There was some thought into making additional redundant supports for the bridge design to reinforce it. Perhaps an additional design to support the side frame and rising arc verticals. Another was to potentially use some of the raw balsa wood sheets since there's still a lot of those materials for supporting the bridge design, maybe cutting them to proper size and gluing them to the side for added support. These ideas were later incorporated into the working device, since there's still a lot of weight that can be added to the bridge that would still be within project parameters, and there isn't really much of an issue into adding additional supports to help the bridge. More details are in the construction sub-section.

b. Construction

i. Description

The construction of the bridge will utilize raw balsa wood, which would be ordered from online suppliers in bulk to allow for plenty of materials to work with to create the necessary parts. Should there be complications in the construction process, there's plenty of material to make replacement parts. Other parts which include the steel rod, spools, and pulleys will be ordered through both local and online suppliers. Construction will occur in an orderly fashion, firstly starting with the actual design of the bridge itself. Any of the raw balsa wood materials will be measured and cut to their proper sizes to fit into the designs of the bridge and articulation system. Generally, the balsa wood segments would go together to create the entire bridge itself, the balsa wood blocks would form the frame of the articulation system, and combined with the sets steel rods, pulleys, and spools to complete the said system, and the balsa wood sheets would make up the road deck. The project is comprised of about 20 parts (including manufactured and ordered parts), and will have about three sub-assemblies, which all three will be combined to make an entire assembly. The first sub-assembly is the bridge itself, which will comprise of all the segments to make the frame. The second sub-assembly is the articulation mechanism, which are the pulley, spools, and the steel rod. There will be two sets of this assembly, for which they will go into the third sub assembly, which is the frame of the articulation system. Then, all these assemblies will go together on one bigger assembly that comprises the bridge frame, the road deck part, and the complete articulation system.

ii. Drawing Tree, Drawing ID's

For the assembly 10-002, it comprises of the drawings of the segments such as drawings 20-001 and 20-003 in Appendix B for which will create the bridge frame that will hold everything together. In assembly 10-004, this comprises of the part 20-002, and two units of 20-025.. Assembly 10-003 will be made up of steel rods with spools and dowels, drawing 20-013 to act as the makeshift pivot point for bridge lifting, and the balsa wood blocks shaped into their proper length (20-011) and width (20-012) parts to make the articulation system. Finally, the 10-001 assembly will be made up of the 10-002 bridge frame assembly, the 10-004 road deck assembly, and the articulation system assembly 10-003.

iii. Parts

Most, if not all the parts and raw resources will be purchased from various suppliers for both local and online. Most the parts like drawing 20-001 and drawing 20-003 in Appendix B will be cut into proper sizes from the purchased raw balsa wood materials. The process for the creation of these parts are relatively simple, requiring only a pencil, metric ruler, a miter box, and a razor saw to create. Drawing 20-002 will be cut and sized from raw balsa wood sheets, also purchased. Although it would be too wide and long for placement in a miter box, a table saw would probably be sufficient for cutting it to proper length, and a drill to create the through holes. Drawings 20-011 and 20-012 will be shaped from raw balsa wood blocks, which were also purchased. These would be cut from a table saw initially, before using a drill to create the holes and radius. For the articulation mechanism, the drawings 20-008, 20-009, and 20-010 will be straight up purchased parts that will be put together. The drawing 20-013 will be a steel rod that's cut into the size with a hacksaw, which will then be inserted into the articulation system's frame.

There would likely be a few more parts that will be created in the construction phase of the project, much of these would most likely be redundant supports that would help the frame. Part 20-023 is a new and confirmed part, and this would be a horizontal support that simply connects the side frame verticals to the second rising arc vertical. Either four or eight units of this part would be created. Part 20-024 is the dowel hand crank, which will replace the pulley and handle system from the original design, due to the steel rods having a tight fit into the drilled holes onto the balsa wood block lengths. Two of these will be created. Part 20-025 is the road deck holder which will be glued onto the ends of the road deck so that it stays on the bottom frame of the bridge while in operation. Two of these parts are to be created. Part 20-026 is the side frame holder, which this part simply holds the articulation system in place while it's in operation on top of the bridge frame. Two units of these parts will be created. Part 20-027 is the bridge structure flat support, which is glued onto the side of the bridge frame to hold it together and includes a square hole for the string loop of the articulation system to latch onto for raising the bridge. Two of these parts will be created.

iv. Manufacturing Issues

There are a few potential manufacturing issues that can come up during the construction phase, especially since the construction will utilize tools and materials from home. For instance, the saw that will be used to cut the steel rod into appropriate sizes can break or become damaged, requiring one to purchase a replacement saw. The next issue can be that some parts such as the steel rod wouldn't be available at a local store, and it may result in having to go to another store or placing an order online. This wasn't an issue, as the local store had the steel rods in stock. It was even checked on their online store to be sure. Another issue might be that the deliver parts and resources would come up damaged or defective, which would probably lead to having a refund and re-ordering the parts and resources or having to find a similar alternative. So far, the materials that have arrived didn't have any noticeable defects. The last issue that could arise is the potential need for additional parts or raw material, which for a few of them would take quite a while for the order to be shipped to the required destination, taking up time in the construction phase of the project. This issue shouldn't arise in the preliminary stages in construction, and there is confidence that the parts and raw material present are sufficient, but this issue should be taken into consideration just in case it arises later.

A minor issue that came up during manufacturing was trying make non-standard cuts with some of the diagonal segments. Originally, most of the cuts have been made using a miter box and a saw, and there wasn't much in the way of issues. But once the manufacturing of diagonal parts had to be done, their design required much different angles than the 30° and 45 °angles provided on the miter box. While a precise angle cut would have been desired, it was decided to go through with the manual angular cuts and try to "ballpark" the angles enough that it can fit into the bridge design with glue, making any adjustments as necessary. So therefore, the issue was resolved.

v. Discussion of Assembly

The three sub-assemblies that will be created for the project will be the bridge design itself, the road deck assembly, and the articulation system. These three assemblies will be combined into a full assembly of the bridge. The assembly that will be completed first for the project is the bridge frame assembly, considering it's the most important assembly and what ties in every other assembly and part into the project. The next assembly that will be completed is the road deck assembly, which will be the component that's lifted by the articulation system and resting on the bottom frame of the bridge. The last sub-assembly will then be the articulation system, which is an external component to the bridge to perform articulation and bridge lifting.

Most of the raw balsa wood material will be measured and shaped, and then cut with saws. The pulleys, handles, and spools wouldn't require much. Probably only need to use a knife to provide the proper length of wire/string for the spools. The steel rod would need a hacksaw to cut it up to proper lengths for the articulation mechanisms and the pivot.

Once the bridge is assembled, it should be ready to test for the requirements stated in the criteria. The only part of the bridge that would require physical operation is the articulation system since it's manually operated and is needed to lift the road deck and lifting the bridge. Being an external component, it should be easily to place and move around to do the articulation requirements.

The predictions regarding the performance of the bridge in testing the requirements are that it should be able to hold a load of at least 18.9 kg, the articulation system would be able to lift the road deck 280 mm above the original position, although the articulation system might be able to lift the bridge for at least 10 seconds for a paper to slide between the bridge and the abutment.

4. TESTING

a. Introduction

For the project, the balsa wood bridge has been tested on several requirements. These requirements include a block (acting as a vehicle) being able to traverse the bridge on the road deck, the articulation system of the bridge being able to raise the road deck 280 mm above the original position, the bridge able to rest on steel wide abutments, adding a 10 gram weight to raise the bridge enough to slide a sheet of paper between the abutment and the bridge, able to support a load between 18.9kg to 20 kg, and the weight of the bridge being under 85 grams (without the articulation system). The bridge must also span an opening at least 400 mm.

b. Method/Approach

For testing the articulation for the bridge, the articulation system would be placed on top of the bridge, with the string looped below the road deck so that it can lift the road deck up to the required height. The other part of the articulation of the bridge would be to raise one side of the bridge for about 10 seconds. To do that, the string looped around the road deck would have to be placed onto the edge of the bridge with the square holes. These would pivot on a steel rod to help with articulation, as shown in Figure 6 of Appendix G1.4. The string would then be tied to the other end of the bridge and would be raised similarly to a draw bridge.

For the load on the center of the bridge, it originally was going to be that the weight of each set of loads must be measured prior to adding it to the bridge either reaching the desired requirements or when it breaks. For the actual test, the actual load was comprised of liquid water on a bucket, in which it was prudent to simply fill the bucket until the bridge breaks (since it was predicted that the bridge wouldn't reach the 20 kg load). Once the bridge breaks then the bucket would be weighed on scale which would then be recorded on the data sheet. Afterwards, calculations and conversion factors would be applied to get the final load on the bridge. That test would be the last one to be done since if the bridge breaks then no other test can be done for the bridge.

For testing the weight of the bridge, a digital scale would be used to determine the weight of the bridge, and the weight's value would be recorded on the data sheet. The other requirements have a simple check off of whether or not the bridge met the requirements, such as resting on the abutments, and the bridge raised for about ten seconds, enough to slide a sheet of paper between the abutment and the bridge itself. Appendix G2 provides a blank data sheet for reference regarding the check offs as well as recording data for other tests.

c. Test Procedure

Fundamentally, the bridge will need to have some abutments to rest on, and its stated that they need to be steel. So, for all the tests besides weight testing the bridge would rest on these steel abutments, and the opening span would be measured prior to the actual test. This is stated in most of the procedures of each test in Appendix G1 from 1.2 to 1.5. This will also require a decent amount of space to do testing, as well as being high enough from the ground to test loads on the bridge. When doing the testing, having at least safety glasses (or standard glasses) would be required in case something goes wrong. There will also be a need for a welded nut, washer, and a rod that can be used to insert the loads onto the bridge.

There were some changes and additions to the testing procedures, primarily for the load testing. It was decided to use water filled into a bucket for testing the load since water was readily available for testing. For the tables, they weren't simply high enough to allow the bucket to be suspended above the ground, so it was decided to add two cinder blocks below each abutment to raise the height. These changes can be seen in Appendix G1.5 with Figure 8. Regarding the usage of safety glasses, it was only used for the load testing since it was the only test to have the danger of fragments. The other tests wouldn't have required the usage of safety glasses.

d. Deliverables

The deliverables that would be required for this project are the data sheet that covers all the requirements, and the videos demonstrating the requirements being tested. The requirements on the data sheet would likely have whether the bridge was able to meet them. For instance, if the vehicle was able to move across the road deck it would be checked off on the sheet, while the amount of load that the bridge was able to hold before breaking or meeting the required test load would be written down. For each of these requirements, video recordings would be needed to demonstrate the bridge's performance during testing whether the bridge succeeded or failed at these requirements. Pictures may also be taken during testing as well, mostly to go with demonstrating the requirements and to be used for other aspects of the project.

The predicted result for the weight testing of the bridge was that it would weigh less than 85 grams, in which the actual weight of the bridge was much less than 85 grams weighing at about 47.81 grams. The reading on the digital scale can be seen in Appendix G1.1, with Figure 2. There wasn't much of an issue involved with this test, all it required was putting the bridge onto a digital scale. However, it does make one think that much more could have been worked with in making the bridge. Some ideas for improvement on the bridge would be to have a bigger design, making the segments and trusses slightly bigger in size as well as making the bridge slightly wider. Another would be to simply add more diagonal supporting beams to reinforce the structure. These suggestions are to try to make most of the available weight while being within limits.

For the second test, the predicted result for the vehicle traversal of the bridge was that it would be able to get across the road deck without issue. The actual result was that the vehicle was able to get through with one minor issue being the center hole on the road deck in which the vehicle hit for a moment, but was able to get to the other side of the bridge regardless. The improvements that can be made to the bridge would be to have the design be wider (as mentioned previously) since there was difficulty grabbing the string to pull the vehicle (on the other hand, the string could have been much longer so it would have been easier to grab). Another improvement would have been to smooth the hole in the center of the road deck, either using a drill to make a cleaner hole, or to use metric drill bits.

For the third test which was the vertical articulation of the road deck, the predicted result was that the road deck would be able to be raised to 280 mm above its original position. The actual result was mixed as while the road deck was being raised it began to roll onto its side. Most of the road deck made it above 280 mm, but the general performance left much to be desired. The improvements that can be made to rectify this was to have better spools to properly coil the string being raised, as the string was also wrapped around the metal rods holding the spools. Another improvement could be to have a better means of lifting the road deck besides looping string around it such as a lifting plate below the road deck.

For the fourth test which was the bridge raising with the articulation system, the predicted result was that the bridge can be raised for longer than 10 seconds with the addition of 10 grams to the lifting mechanism. Also tested was for the paper to be able to slide between the abutment and the raised bridge. The result was that the bridge was able to be raised for longer than 10 seconds, reaching the maximum lift for the articulation mechanism at 14.53 seconds. A paper was able to slide between the abutment and the raised bridge as well. Although the test was a success, there can be a few improvements that can be made primarily based around the articulation system. For all intents and purposes, the articulation system isn't all that practical. It would have been better to have designed a pair of towers to lift the entire bridge, which would have avoided making the bridge unnecessarily tall and simplified the testing process for articulation.

For the fifth test which was the load testing of the bridge, the predicted result was that the bridge would not be able to meet the 20 kg minimum load. The results proved the prediction as the bridge broke under a load of 6.71 kg from both the water and the bucket. Calculations related to this test can be seen in Appendix G4 (it was the only test that needed these calculations). The bridge broke at the bottom frame part, which highlighted that it was the weakest part of the bridge design. Even with the additional supports, it wasn't sufficient to accomplish the task. Improvements that can be done would have been to use thicker balsa wood segments supplemented by a pair of thin balsa wood plates on both the top and bottom of the frame to reinforce that area.

5. BUDGET

a. Parts

The parts that will be used to construct the bridge will be made up of raw balsa wood materials, which will be purchased in bulk. The segments would cost about $14.86. Each segment will be cut up from the raw material into proper sizes and then glued to their spots, like Drawing 20-001 as shown in Appendix C. These segments should have the same thickness of either 3.125 mm or 4 mm. In addition to the segments, raw balsa wood blocks would also be used, costing about $18.75. These blocks would be cut to proper length and width and will have a thickness of 6.35 mm. The road deck will be cut from balsa wood sheet, which costs about $52.70 in bulk, and has a thickness of 3.125 mm. Other parts that will be collected include a 36-inch x 1/8 inch steel rod, costing about $3.30, six spools for the articulation system, which a package of 25 spools costs $8.89, and some sets of string/rope that will be cut to an appropriate length for the spools. For the handles/weights, iron fishing weights will be used, which a 20-piece set of them with various weights will cost $14.79. The set of steel washers/disks that will be a part of the articulation system will cost about $7.29.

In the testing phase of the project, there wasn't a lot in the way of mistakes when performing these tests that presented a cost. Most of the materials needed for testing were already available, only the purchases for the steel abutments, threaded rod and related materials for load testing were needed for load testing to happen. Extra thought and care was put into making sure that all the tests was prepared with the needed materials, the testing space was set up and ready to go, and the materials were put away in a safe place when finished. Even the few issues that arose during testing didn't have much of a big cost, such as smoothing out the hole on the road deck so it would be less likely for the vehicle to get caught on the hole. There were enough materials to spare from the manufacturing phase of the project that any minor problems that could have damaged the bridge or articulation system can be patched up with replacement parts and glue. The bridge only collapsed during load testing, but it was expected and planned since it was the last test that needed to be done and therefore repairs for the bridge wouldn't be needed.

b. Outsourcing

It's doubtful that there will be any processes that will be outsourced, all of it should be done at home. However, there will be parts that will be purchased from outside sources such as Amazon. The balsa wood segments and blocks will be purchased in bulk through Amazon as well as the pulleys and spools, and the steel rods and the string/rope for the articulation system would be purchased at a hardware store.

c. Labor

Most of the labor that will be put into the project will be done by the individual, with potential guidance and assistance from other people as necessary. During the design phase, the labor put into the project (the proposal and related deliverables) averages about 5.75 hours per week. For the construction phase, the average labor that was put into this project is about a little over an hour a week for manufacturing since the parts themselves aren't too hard to make, and maybe another hour for updates and additions on the report.

d. Estimated Total Project Cost

Considering all the financials for the project, the estimated total project cost is about $111.69.

e. Funding Source

The cost of this project is going to be self-funded, there will not be any outside sources for funding the project. However, there were unexpected donations of materials in which some were incorporated into the working device.

f. Actual Cost

The actual cost of all the materials that were required for this project in the construction phase was about $159.09 including shipping and tax (was originally $267.88, however other shipping orders not relevant to the project were accidentally mixed in during calculations), which is much higher than initial estimates. Since the materials were bought in bulk, any mistakes or changes wouldn't be too costly as much of the time any "bad" parts can be salvaged for other parts and there would still be plenty of material to work with. However, making too many mistakes may require additional materials which would cost both time and money, the former more so depending on its availability through online stores. Later on, in the testing phase of the project, an additional $56.95 was made for the purchases on the steel abutments, as well as a threaded rod, weld nut, washer, and other parts for load testing. Therefore, the grand total of the cost of the entire project was $216.04.

g. Effect of Parts on Budget

Much of the parts that needed to be purchased were ones that weren't going to be as easily manufactured such as the fishing weights and the spools. The rest were just raw materials to create most of the parts. Most of the ordered parts themselves didn't cost too much, and only the raw bulk materials made the most of the cost.

h. Part Order History

The parts that have been ordered as of this quarter in chronological order were the 50-002 Baltic Birch Plywood that was going be used to create the blocks for the articulation system (which eventually wasn't used and replaced with balsa wood blocks that were donated to manufacture the parts for the working device), which arrived on Dec. 18, 2020. The next items were 50-007 and 50-008, which were the fishing weights and the disks respectively (also wasn't used on the final working device), both arrived on Dec. 24, 2020. Afterwards, the 50-001 and 50-004 materials arrived which are the raw balsa wood segments and the raw balsa wood sheets for the bridge frame and road deck respectively, these arrived on Dec. 26, 2020. The 50-003 steel rods were purchased on Jan. 9, 2021 at a local Home Depot. Finally, the 50-006 Spools arrived on Feb. 3, 2021.

i. Parts Remaining

There aren't any more parts or raw material that needed to be ordered. All the materials that were needed for the bridge were manufactured, and the materials for the testing phase of the project were purchased.

6. Schedule

a. Design

The schedule for the design phase of the project should all lead to the end of Fall Quarter where the project proposal is completed and all the required deliverables with it. In the first week, the tasks were to upload a resume and design a business card, which were relatively simple tasks and didn't require a lot of time to complete. In the second week, the introduction section of the proposal was worked on, and the website of the project was created. Not much issues with the second week's task, straightforward and completed on time. For the third week, the first analysis had to be worked on for a requirement of the project. There was some initial trouble choosing which requirement for the bridge that was to be analyzed, but in the end decided to focus on the loads affecting the bridge frame, which this analysis was completed on time. For the fourth week, the second analysis was worked on, and the analysis section of the proposal needed to be completed. Like the previous week, there was some trouble with figuring out which requirement to analyze, and eventually settled for looking into the weight of bridge and was completed on time. The analysis section of the proposal was a bit tough, and required a bit of clarifications on certain sections, but was completed on time. In the fifth week, two more analyses had to be worked on, a drawing of a bridge part, and a schedule. In addition, a summary of the analysis for the project website needs to be typed up. Since there was a fair amount of work that needed to be done, it took some time to complete. In the sixth week, two analyses needed to be completed, as well as a parts list and a budget for the proposal. However, due to complications, analysis six was finished the week after. Also, a copy of the schedule needed to be put up on the project website, and a drawing needed to be completed. For the seventh week, two analyses were to be completed, and the testing section of the proposal must be done. An additional drawing must be completed, and a summary of the budget should be on the project website. In the eight week, two additional analyses were to be completed, and the methods section of the proposal was worked on. The summary of the testing section needed to be put up on the project website. An additional drawing had to be worked on as well. For the ninth week, two analyses were to be worked on, however there was another complication, and the twelfth analysis was turned in next week. The construction section of the proposal was worked on. A drawing was worked on the week as well. For the tenth week, an assembly drawing of the project had to be completed for the week, and the discussion section of the proposal needed to be typed up. In the eleventh week, the proposal should be finished and ready to submit.

b. Construction

The schedule for the construction phase of the project should lead to the end of the Winter Quarter where the bridge design is constructed and ready for testing. In the first week, the task was to reupload the proposal, and assembly drawing. As stated by the professors, this was the last time the proposal was going to be a proposal, as carrying on forward it will now be a report. Also, by this time the raw materials to create most of the parts, and a few ordered parts (such as 50-007 and 50-008) are present. For the second week, the tasks were to manufacture some parts, and then present one of them for the MDR. The parts that were manufactured for this week were 20-001 and 20-004, and the former was presented for the MDR. At this time, there was some internal debate if the raw materials for the bridge need to be at least one size larger than what they are, but it was decided to continue with the given raw materials. In the third week, there had to be at least two parts that were manufactured and drawn for MFG01, and the construction and methods sections of the report had to be worked on and updated. The parts that were manufactured were 20-017 and 20-018. The issues that were brought up mostly stemmed from the assembly drawing needing to be updated with a better BOM and a revision table (since a revision was needed for any changes and additions). For the fourth week, the project website had to be updated and expanded upon. Also, the discussion section of the report had to be updated and expanded as well. The parts that were manufactured in that week were 20-005 and 20-021. In the fifth week, for MFG02 about 33% of the manufactured parts for the project needed to be complete with their associated drawings, and the schedule section of the report had to be updated and expanded upon. The parts that were manufactured for this week are 20-003, 20-022 (a recent addition), and 20-013. The issue that was discussed early in the week was the fact that manufacturing the diagonal parts for the bridge would require non-standard angled cuts, which the accepted solution was to roughly cut manually by hand than trying to get a device for those precise angled cuts, costing time and money to obtain. For the sixth week, much of it was only manufacturing. The parts that were manufactured were 20-002, 20-019, and 20-020. It was much easier to construct the diagonal parts since the goal was to “ballpark” the angles that were required for the part. There was a slight issue in that the size of the holes on the road deck were slightly different sizes than what was designed for the road deck due to using Imperial drill bits. In the end, these holes would be sufficient for what they’re supposed to do. In the seventh week, the MFG03 assignment was assigned in that about 75% of the manufactured and ordered parts needed to be completed, as well as the construction and methods section of the report needing updates with new information. The parts that were manufactured for this week was 20-007, as well as parts 20-012 and 20-023 being started in this week. There was also a discussion with mentors on the status on the project and brought up the issue with the Imperial drill bits, which was already resolved. For the eighth week, more parts were manufactured for the week with the goal of having all the required parts completed by the weekend, as well as updating the project website focusing on the construction, budget, and schedule sections in addition to the test section of the report needing updates. The goal of having the parts being completed on that weekend was almost complete, parts 20-012, 20-023, and 20-011 were finished while 20-016 needed a bit more work. In the nineth week, the bridge was going to be assembled with plans to finish it and the last remaining required part 20-016 by Sunday of that said week. On the report, the discussion section needed updates with new information as well. While the bridge wasn’t assembled by Sunday, it was close to completion. For the tenth week, the bridge had to be completed and was a functional, working device and the final upload of the report had to be complete and uploaded. The bridge assembly was completed, with new additions such as 20-024, 20-025, 20-026, and 20-027.

c. Testing

The schedule for the testing phase of the project should lead to the end of the Spring Quarter where the bridge has been tested for the requirements described in the criteria, and the report sheet as well as the deliverables are submitted. For the first week, the tasks were to create an initial abstract draft which explains what the project was about and what occurred in the project, which the assignment will be reviewed by the professors. Afterwards, the abstract will have to be revised considering review comments from the professors and resubmitted. Lastly, the test procedure section of the test report had to be completed for one of the tests that will be done for the senior project, which was done for articulation testing. In the second week, the primary assignments were to conduct testing. The two tests that were done for this week regarding the bridge project were the weight tests and the vehicle traversal testing. They were completed in a timely manner and had only minor issues during vehicle traversal testing with the center hole on the road deck. It was resolved by smoothing the hole so it would be less likely for the vehicle to hit it. In the third week, the tasks were to submit a video recording of testing for the TDR01 assignment and then provide comments for classmates' testing videos. The engineering report's testing section was also updated with new information. For the fourth week, another round of tests was to be completed. The testing that was done for the bridge project was the vertical articulation of the road deck, and the raising of the bridge. There was only a minor issue during vertical articulation testing when the road deck was starting to roll on its side as it was rising, which came down to issues in the design of the articulation system. In addition, a draft of a project poster for SOURCE was completed for the week, as well as the project website and the discussion section of the engineering report were updated. In the fifth week, the completed project poster draft was submitted, and another test recording was submitted for the TDR02 assignment. Also, during this week a final test was conducted for the bridge which was load testing and was completed without issue. Additional tasks were to make a revised version of the project poster to be submitted considering the professors' comments, and then additional revisions as needed before submitting the final draft of the project poster to SOURCE. The testing section of the engineering report also had to be updated with new information from testing the bridge. For the sixth week, the only task was to update the discussion section of the engineering report. Some work was done for the test report, which had to detail the process of at least 3 tests regarding the project. In the seventh week, the test report was completed and submitted, and the project website was also updated with new information regarding testing and the results from them. Also, the schedule section of the engineering report was to be updated with details on the testing phase of the project. For the eighth week, the budget section of the test report was updated. Also, there was an assignment that asked the individual to respond to any comments on their SOURCE video presentations. Unfortunately, there were not any comments, and so the document was submitted simply saying that there weren't any comments with a photo of the empty comment section at that time. In the ninth week, a video presentation using the project website and its relevant pages was submitted, as well as commentary on other classmates' video presentations was completed. In the tenth week, the final version of the project's engineering report will be submitted.

7. Project Management

The risks that can be identified in relation to this project include scheduling issues where other obligations can come up and take up the time needed to work on the project. This has happened a couple times when other obligations took up time that could have been used to work on analyses for the project, which resulted in those analyses being turned in late. The potential solution could be to develop better time management to complete the other obligations earlier so that time can be used for working on the project, and vice versa. Another risk is the availability of the needed materials, which there are potentially points of time where the material may not be able to be purchased and so it would be better to get the materials at the earliest convenience than later. Especially for the raw balsa wood materials, which are vital in getting most of the bridge built. An additional risk could be safety when testing the bridge for the required criteria. The significant safety issue would be when the bridge is loaded with the 18.9 kg to 20 kg load (should not exceed 20 kg of load), and there is a chance that the bridge can fracture and send fragments about, so PPE like safety glasses should be used.

a. Human Resources

The principal engineer will provide most of the physical labor in making the bridge design, the construction of the design, testing the requirements for the design, as well as managing the time, budget, acquisition of materials, and analysis throughout the entire project. An occasional helping hand may be provided as necessary for the project's completion. Dr. Charles Pringle and Dr. John Choi will provide mentorship and guidance throughout the project.

b. Physical Resources

The physical resources that will be used for this project include hand tools such as saws and knives and measuring tools like tape measures and rulers, especially for the construction phase.

When moving to the testing phase, the physical resources will include rulers, scales for weight, pencil and paper for recording data, etc.

c. Soft Resources

The soft resources that will be used for this project include the website Wix for the ability to create the website to present relevant information regarding the balsa wood bridge project. Another soft resource is SolidWorks for designing the parts and assemblies related to the project. Microsoft Word and Excel are also other resources that have been used for the project, creating necessary documents for analysis and testing.

d. Financial Resources

Considering that the project is for all intents and purposes self-funded, just about everything regarding this project will use personal financial resources to work and complete the project.

8. DISCUSSION

a. Design

In the beginning of the design process, the fundamental line of thinking present was that the design had to be simple and straightforward to accomplish the requirements, nothing complicated that would cause unnecessary problems. A simple truss bridge design was needed, the first three sketches of the bridge design were mostly to generate ideas, mostly revolved around the articulation system before it was decided that the said system was most likely going to be an external component for the truss bridge to preserve the strength of its frame. An integrated articulation system would more likely to cause problems when the bridge would be trying to sustain a load.

The truss design was an easy choice in that the balsa wood bridge would be able to distribute the forces across the trusses. For the bottom frames, it was initially conceived that the support beams would cross over each other for better support. However, it didn't seem practical in the end and so were going to be changed into simple straight support beams for the bottom frame. This would still allow a rod to go through the center of the road deck and the bridge frame without going through a balsa wood frame segment, compromising its strength. Another change was the height of the vertical beams, which was an honest oversight and mistake. The original design had an 80 mm height, but since the articulation system needs to raise the road deck to about 280 mm from the original position, the vertical beams on the side frame were 300 mm, the first vertical beams on the rising arcs is 100 mm, and the second vertical beams on the rising arcs would be 200 mm. Lastly, the length segments of the balsa wood bridge frame were changed from 440 mm to 500 mm, this is mostly to allow the articulation system to have a proper position to lift the entire bridge, using a steel rod as a pivot for one of the ends of the bridge. One side of the ends of the length segments will have a fillet to allow the pivot to be set up.

The articulation system design went rather well considering everything else. Since it's an external component, it should allow for it to be placed where it's needed to either lift the road deck or the entire bridge. The articulation system had to be about the same length and width of the side frame portion of the balsa wood bridge since it would rest on top of it to lift the road deck. The only issue that came up was trying to figure out where to place the pivot, which was decided to be integrated to the articulation system so that the system can be placed at one of the ends of the bridge, secured at the fillets, and be able to lift the bridge at the other end. Although the design choice was crude and makeshift out of the circumstance at the time, it's likely to be able to perform the task. There was a relatively bad idea that the articulation system would be used to lift the bridge through bending while placed on top of the articulation system (see Appendix A5), which was scrapped since it would have likely broken the bridge before it would even raise the bridge enough to raise the road deck, and also the positions of where the string/cable would be tied were insufficient.

b. Construction

In the beginning of the manufacturing phase, there wasn't much in the way of issues for creating the parts for the frame of the balsa wood bridge. At the time, there was a bit of internal debate whether the given raw material for the parts is a bit small for what is required for the bridge design. Ultimately, it was decided to continue working with the raw material that's been ordered, but the thought about getting raw material one size larger was kept in mind. It would likely mean that there needs to be consideration into making additional parts to help support the frame. For the articulation system, however, there is some consideration into using slightly larger pieces to comfortably fit the spools, pulleys, and the steel rods. While the hole can be drilled with the raw material purchased, it would be a bit easier if there was a bit more space to work with comfortably, especially with the tight tolerances. In the end, it was decided to go with the current design parameters, and their manufacture turned out to be sufficient to work with. For the most part, the raw materials are sufficient to complete most of the parts that need manufacturing (with the rest being ordered online or in local stores).

Another consideration that needs to be made are with the tools in hand, and their role in the creation of the parts. Most of the parts that were designed for the bridge can most likely be made manually without requiring any advanced processes. The other parts can be ordered to avoid having to do those said processes. An example of this would be the spools used for the articulation of the bridge and the road deck, because presently there aren't any tools or machines immediately available for the creation of spools for smooth operation during testing, and the current raw material for the road deck is fairly large. Therefore, it would be easier to order the spools at the right specifications than attempting to manufacture one because of it, and for the road deck it would have to be trimmed and cut to proper length and width, likely would need an electric saw to do so. An alternative idea would be to widen the bridge design so that it can fit the road deck, therefore only needing to cut to proper length. However, that would also lead to adjusting the bottom frame width segments, and the width of the articulation system. It was decided that this idea wouldn't be implemented since that would use up more raw material, the currently completed parts would become scrap material, and an additional order of raw material would be needed costing time and money. While working on the articulation system's frame, one of the width blocks must have a radius in its design to fit the steel rod that would act as a pivot. To make the radius, a Dremel was used with a sander attachment to make the radius. It got the job done and made the process a lot easier to do than trying to do it with other tools like a saw.

As for any issues related to the construction of the bridge, so far there aren't any at this time. The raw material appears to be in working condition with no significant defects. However, there is one minor issue regarding some of the raw material which is that some of them "feel" different from other ones of the same type. Messing with a few scrap balsa wood segments and some clamps, it was noted that one of the scrap balsa wood depressed when compressed by the clamp, while another scrap balsa wood maintained structural integrity. It's assumed that perhaps the finishes between raw balsa wood vary. It could be a potential concern because that would indicate that some segments on the bridge would fail during load testing because of different finishes, therefore failing earlier than other segments. The issue could potentially be resolved with either being very selective with the individual raw material (and therefore likely needing to order additional raw material, perhaps finding another seller), or compensate it in the revisions of the bridge by adding additional supportive segments and parts into the frame. This will add weight to the bridge frame, but this would still be within tolerance and allowing for more to be added on if necessary. At this point, the supportive segments are more likely to be used for redundant structural support

There have been some design decisions and changes that have occurred throughout the project. For certain, the design for the bridge that came out of the construction phase is somewhat different, yet somewhat the same from what came out of the design phase. More parts were certainly added into the design due to revisions, the availability of raw material, and the need to provide additional support to the design. For the remaining parts, most have remained the same, a few of them required changes in their design but for the most part remained what they were. Two examples regarding the road deck are its length which had to be slightly changed, and since that changed, the position of the holes had to be adjusted as well so that it's not on top of the bottom frame supports. Another example were the articulation frame's width and length blocks. Their width and length respectively were adjusted to better fit onto the top of the bridge. Initially, the side frame supports weren't going to be added due to concerns that it would take up a lot of the raw material due to their length. However, since there was still plenty of raw material it was then put into the design. There was also another addition to the design which is a horizontal support segment that connects the side frame vertical to the rising arc vertical, hopefully adding some structural support.

c. Testing

In the testing phase of the balsa wood bridge project, it started off rather straightforward with working on the abstracts and testing report for the project. To compress the project, the parameters tested, and the results into 150 words wasn't easy but was able to be done with some input from mentors and guest readers. The testing report on the other hand at this point is a continual work in progress, adding stuff to it as the quarter went on.

The first set of testing that was done for the bridge was the weight testing and the vehicle traversal. Testing the weight of the bridge was a simple task, simply place the bridge (without the articulation system) onto the digital scale and read the weight from it. The bridge was certainly less than 85 grams, being about 47.81 grams. However, it got one into thinking on what could have been done to productively add more weight to the bridge while remaining within the requirements.

The vehicle traversal test was straightforward, although it couldn't be started initially because the steel abutments needed to be ordered, and the vehicle representation needed to be manufactured. Once those assets were ready, the test was conducted with little issue. The center hole on the road deck affected the vehicle like a real car hitting a bad pothole. It was still able to get to the other end of the bridge, but the center hole could have been better smoothed so it would minimize the issue, but it may also hinge on how the vehicle was traversing, which was a string pulling on it. Either the bridge needed to be wider, or the string needed to be longer, the issue would have been amended or at the very least minimized.

Another test that was done for the bridge was the vertical articulation of the road deck in which the goal was to raise the road deck 280 mm above its original position. The test was rather mixed, as once the road deck started raising it began to roll to its side. While most of the road deck was raised above 280 mm, it still left much to be desired as it was hoped that the road deck wouldn't have rolled while raising. Some improvements that could be made from this test was to replace the string on the articulation system, as well as using larger spools since the string was wrapping outside of the spools.

The fourth test that was done for the bridge was the bridge raising test with the articulation system positioned at the end of the bridge with the fillets. The test went well all things considered, as it was able to keep the bridge raised for over 10 seconds with the added 10 grams of weight. Also, during that time, a sheet of paper can slide between the abutment and the raised bridge. Although, fundamentally the articulation system isn't that practical of a design and it would have been better to have a pair of towers that were able to raise the bridge instead of the makeshift design used that required placing the articulation system at different places.

The fifth and final test that was completed for the bridge was the loading test, in which a bucket connected to bungee cords to the bridge through a loop attached into a steel rod. The bridge didn’t reach the minimum load of 20 kg, as it broke at 6.71 kg. The area that broke on the bridge was the bottom frame, which makes sense that it was the weakest part considering that its only bringing the two arches together. Something that could have supported it would have been balsa wood plates that were glued above and below the said frame to help with structural reinforcement.

There were some modifications to test procedures that were added to make the tests workable and viable. While much of these processes were going as expected, some of these changes include adding cinder blocks during load testing so that the bucket attached to the bridge can be suspended in the air during testing. This will allow the full load of the water-filled bucket to affect the bridge. Another change was the removal of the floor mat since the only mess was during the load testing when the bridge broke, but the test was done outside so the floor mat wasn’t needed. Partly related was also the lack of use of safety glasses. For most of the tests, safety glasses weren’t used because the tests that were done didn’t warrant such uses. The safety glasses were only be used during load testing since there was a chance that the bridge can break, which it did break, and pieces were scattered below the bridge. Other than that, the test was completed with little to no issues.

In summary of the overall testing phase of the project, the bridge performed well in most of the tests that were conducted but there were some aspects that would require changes in the design because of these tests. Primarily the changes were spurned from the weight testing and the load testing, with the former due to how light the bridge is and how much weight could have been still used, and the latter with the bottom frame breaking while most of the bridge was fine so supports there could have helped. On a different aspect of the bridge, the articulation tests displayed that a different and better articulation system should have been designed and used for testing. The current one is makeshift at best and isn’t a practical design for articulating the bridge. Instead of an external component that must be positioned at different points to do testing, something like a pair of static towers can be used to perform both of those tests in one go.

9. CONCLUSION

This Balsa Wood Bridge project was aiming towards creating a bridge design that's able to articulate the road deck, raise the bridge, weigh less than 85 grams, able to hold a certain amount of weight on its road deck, and allow objects to traverse through the road deck uninterrupted. Through the design process in the analyses, bridge design #4 was chosen out of the other options that were conceived. Some of the analyses that were conducted such as Analysis 3 were important into establishing a working articulation system that would be able to both articulate the road deck and raise the bridge while being portable. Analysis 10 was also an improvement of Analysis 5 in which the aim was to reasonably find a method of being able to raise the entire bridge, which the former relied upon a simple drawbridge-like process. Analysis 4 also investigated the frictional forces that could have potentially had an affect when moving the vehicle across the road deck.

After analyzing the bridge for its requirements, and constructing it, the testing phase was able to show how it all came together. Based on the bridge criteria that was provided for this type of project, there are six requirements that the bridge design was tested for as described in its testing section:

- For the requirement that a vehicle had to traverse the bridge, predicted performance was that the balsa wood block that would represent the vehicle would be able to traverse the bridge without issue. The actual result was that while the vehicle was able to traverse the bridge from one end of the road deck to the other, it hit the center hole of the road deck, but carried on. Therefore, this test was mostly a success besides the minor issue.
- The next requirement is regarding the height of the road deck with the articulation system, in which 50% of the road deck had to be raised at least 280 mm above its original position. The predicted performance was that the road deck would be able to be raised 280 mm above its resting position on the bridge, in which the actual result was that over 50% of the bridge was able to be raised above 280 mm despite it rolling to its side as it was being raised.
- The requirement in which the bridge was able to be resting on abutments was done for all tests except weight testing in which the abutments weren't required. Prior to all the tests being conducted, the bridge was placed on top of steel abutments, and measurements were taken to be sure that the opening span of the bridge was at least 400 mm using a metric ruler.
- The requirement for the addition of 10 grams to the articulation system would allow a gap for a sheet of paper to slide between the abutment and raised bridge, in which the predicted performance was that the sheet of paper can slide between the abutment and the bridge as well as staying raised for at least 10 seconds. The actual result was that the bridge was able to be raised for a sheet of paper to slide between the abutment and the bridge as well as remaining raised for 10 seconds.
- In regards to the next requirement that asked for the bridge to be able to support a load between 18.9 kg to 20 kg, the predicted performance was that the bridge would not be able to support a 20 kg load, let alone reach it. The result from load testing was that the bridge collapsed when it was loaded with a 6.71 kg load.
- And lastly, the requirement for the weight of the bridge being less than 85 grams, the predicted performance was that the bridge would weigh less than 85 grams. After testing, the actual weight of the bridge was 47.81 grams.

The bridge was able to meet most of the testing requirements, with the sole exception being that it couldn’t handle or even reach the required load. One can reason that the bridge design for this project can be considered a failure since it wasn’t able to meet all the requirements for its performance. One can look at the project and see that despite the failure, there’s opportunity for learning about what went wrong and what could have been improved so a potential future design can improve upon the failures of its predecessor.

10. ACKNOWLEDGEMENTS

The principal engineer of this project would like to acknowledge professors Dr. Charles Pringle and Dr. John Choi for providing mentorship and guidance throughout the project, the suggestions, encouragement, and support were greatly appreciated. Appreciation should also be given to Dr. Charles Pringle and Dr. John Choi for providing the project idea that can be worked on at home during the COVID-19 situation, while being able to demonstrate engineering merit. The principal engineer would also like to acknowledge Mr. Nye & Mrs. Nye for constant encouragement, emotional support, and occasional helping hand while working on the project.

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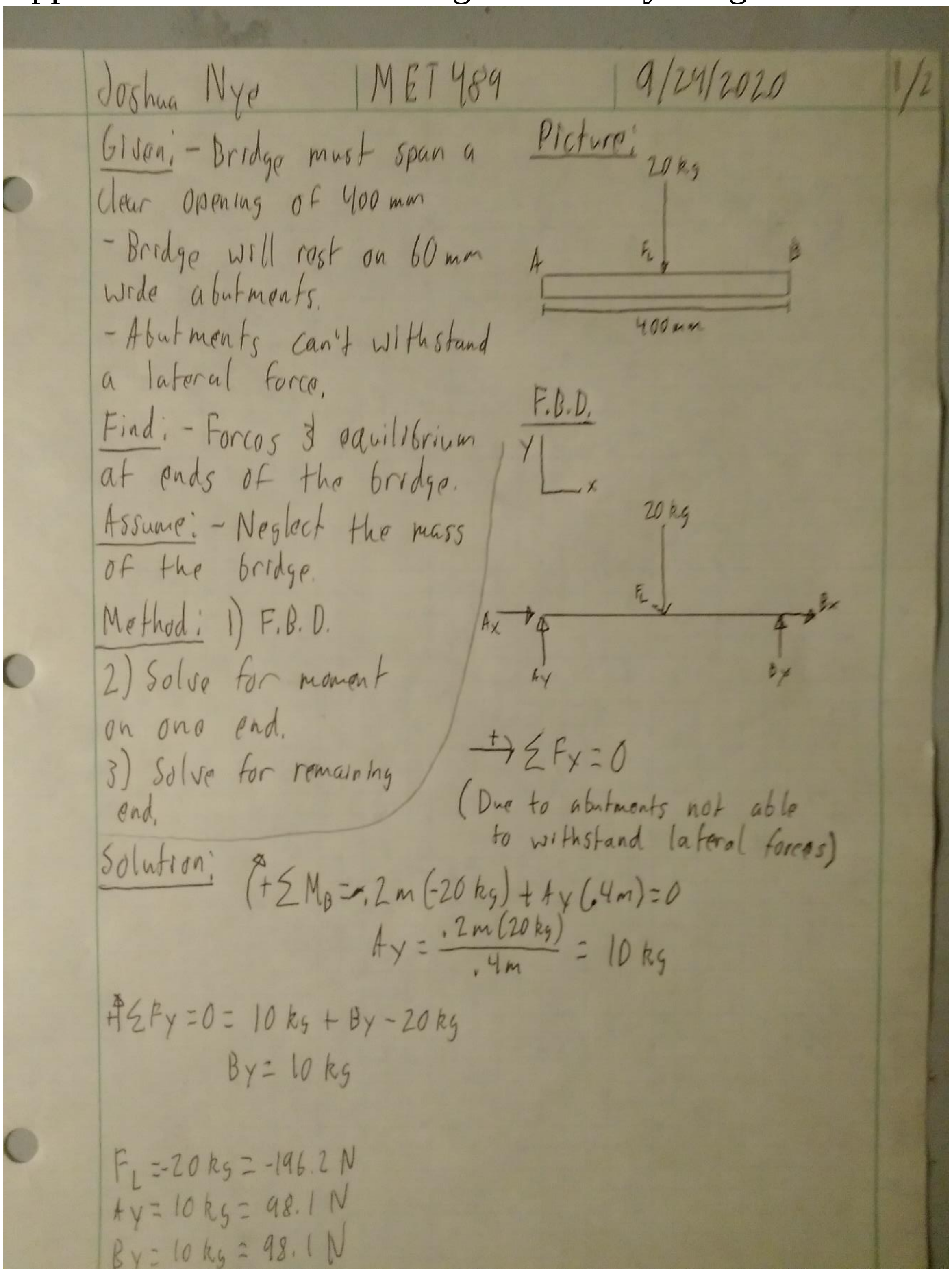
APPENDIX A - Analysis

Appendix A1-1 – Basic Bridge Free Body Diagram



Joshua Nye | MET 489 | 9/24/2020 | 1/2

Given: - Bridge must span a clear opening of 400 mm
- Bridge will rest on 60 mm wide abutments.
- Abutments can't withstand a lateral force.

Find: - Forces & equilibrium at ends of the bridge.

Assume: - Neglect the mass of the bridge.

Method: 1) F.B.D.
2) Solve for moment on one end.
3) Solve for remaining end.

Picture:

F.B.D.

$\xrightarrow{+} \sum F_x = 0$

(Due to abutments not able to withstand lateral forces)

Solution:

$\circlearrowleft + \sum M_B = -.2m(-20\,kg) + A_y(.4m) = 0$

$A_y = \frac{.2m(20\,kg)}{.4m} = 10\,kg$

$+\uparrow \sum F_y = 0 = 10\,kg + B_y - 20\,kg$

$B_y = 10\,kg$

$F_L = -20\,kg = -196.2\,N$

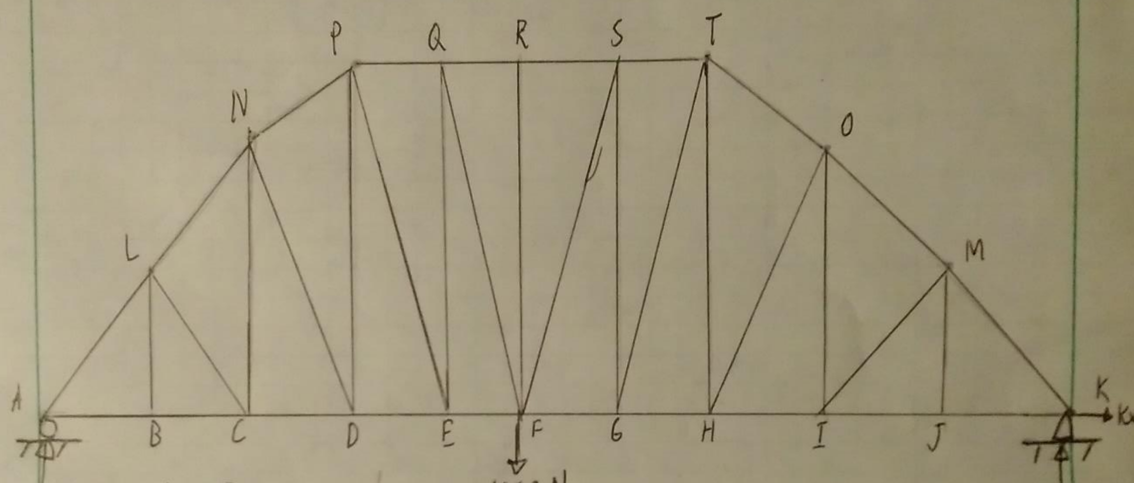
$A_y = 10\,kg = 98.1\,N$

$B_y = 10\,kg = 98.1\,N$

Appendix A1-2 – Bridge MDSolids Truss Analysis

Joshua Nye | MET 489 | 9/25/2020 | 2/2

MDSolids Truss Analysis



Ay MDSolids Truss Parameters
- Horizontal Spacing: 10
  - # of Spaces: 10
- Vertical Spacing: 10
  - # of Spaces: 10

Ky

A_y = 98.1 N
K_y = 98.1 N
K_x = 0.0 N

AB: 32.7 N
AL: -103.4 N
BC: 32.7 N
BL: 0.0 N
CD: 39.2 N
CL: 20.7 N

CN: -19.6 N
DE: 49.1 N
DN: 50.0 N
DP: -49.1 N
EF: 65.4 N
EP: 49.5 N
EQ: -98.1 N
FG: 65.4 N
FQ: 49.5 N
FR: 0.0 N
FS: 49.5 N
GH: 49.1 N

GS: -98.1 N
GT: 49.5 N
HI: 39.2 N
HO: 50.0 N
HT: -49.1 N
IJ: 32.7 N
IM: 20.7 N
IO: -19.6 N
JK: 32.7 N
JM: 0.0 N
KM: -103.4 N
LN: -87.7 N

MO: -87.7 N
NP: -69.4 N
OT: -69.4 N
PQ: -65.4 N
QR: -81.8 N
RS: -81.8 N
ST: -65.4 N

Note: Rounded to 1 Decimal place. Positive is tension, negative is compression

Appendix A2-1 – Volume and Weight Analysis

Joshua Nye | MET 486 | 10/1/2020 | 1/4

Given: - Design Sketch 4 Sheet.

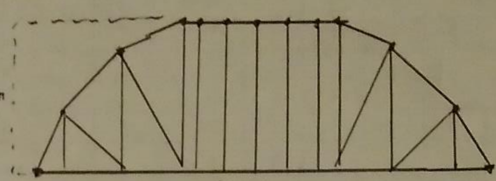
Find: - Density of Balsa Wood
- Approximate weight of bridge design.

Assume: - Balsa wood "segments" are rectangular prisms to simplify calculations.
- Thickness of balsa wood "segments" are about 4mm.

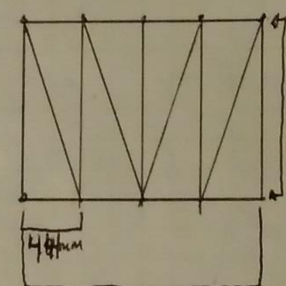
Method:
1) Find Density of Balsa Wood using a source as a reference
2) Section bridge to simplify volume calculations
3) Multiply volume of sections by density
4) Summate the weight.

Picture Note: Not properly scaled

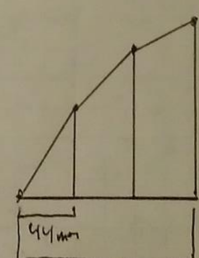
Side Frame



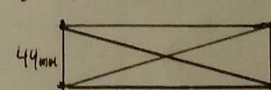
Center Rectangle (side Frame)



Rising Arc (Side Frame) (x2)



Bottom Frame Section (x10)



Solution:

From engineeringtoolbox.com,
- Density of Balsa Wood: 110 – 140 kg/m³

From Marks' Standard Handbook for Mechanical Engineers (pg. 1353)
- Density of Balsa wood, across grain: 117, 141, 320 (kg/m³)

Appendix A2-2 – Volume and Weight Analysis

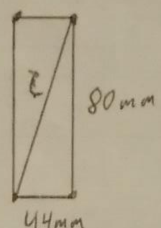
Joshua Nye | MET 486 | 10/2/2020 | 2/4

Solution Cont.

For calculations, the density of balsa wood is 140 kg/m³ (0.00014 g/mm³)

Center Rectangle

Section (x4)



$$C = \sqrt{0.08m^2 + 0.044m^2}$$
$$= 0.091m\ (91.3mm)$$

44 mm · 4 mm · 4 mm = 704 mm³

80 mm · 4 mm · 4 mm = 1280 mm³

91.3 mm · 4 mm · 4 mm = 1460.8 mm³

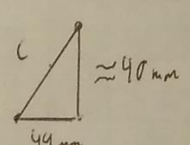
Sum of Volumes in Section: 5428.8 mm³

~~Sum of Volumes in Center Rectangle: -): 21715.2 mm³~~

Sum of Volumes, Center Rectangle: 17879.2 mm³

Rising Arc

Section #1 (x2)



$$C = \sqrt{44mm^2 + 40mm^2}$$
$$C = 59.46mm \approx 59.5mm$$

44 mm · 4 mm · 4 mm = 704 mm³

40 mm · 4 mm · 4 mm = 640 mm³

59.5 mm · 4 mm · 4 mm = 952 mm³

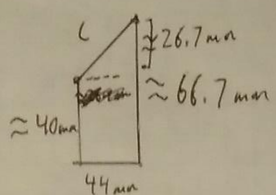
Sum of volumes in Section: 2296 mm³

Appendix A2-3 – Volume and Weight Analysis

Joshua Nye | MET 486 | 10/2/2020 | 3/4

Solution Cont.

Section #2



$c = \sqrt{26.7^2\,\text{mm} + 44^2\,\text{mm}}$

$c \approx 51.5$ mm

$44\,\text{mm} \cdot 4\,\text{mm} \cdot 4\,\text{mm} = 704\,\text{mm}^3$

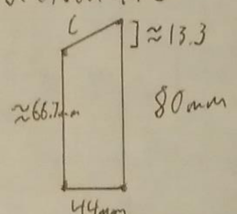
$40\,\text{mm} \cdot 4\,\text{mm} \cdot 4\,\text{mm} = 640\,\text{mm}^3$

$66.7\,\text{mm} \cdot 4\,\text{mm} \cdot 4\,\text{mm} = 1067.7\,\text{mm}^3$

$51.5\,\text{mm} \cdot 4\,\text{mm} \cdot 4\,\text{mm} = 824\,\text{mm}^3$

Sum of Volumes in section: $3235.7\,\text{mm}^3$

Section #3



$c = \sqrt{13.3^2\,\text{mm} + 44^2\,\text{mm}}$

$c \approx 46$ mm

Sum of volumes in section: 3787.7

$80\,\text{mm} \cdot 4\,\text{mm} \cdot 4\,\text{mm} = 1280\,\text{mm}^3$

$46\,\text{mm} \cdot 4\,\text{mm} \cdot 4\,\text{mm} = 736\,\text{mm}^3$

Sum of Volumes in Rising Arc: $7611.7\,\text{mm}^3$

For both sides: $15223.4\,\text{mm}^3$

Total Volume for side frame: $30538.6\,\text{mm}^3$

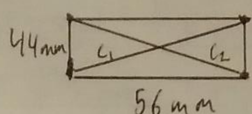
Total for both side frames on bridge: $61077.2\,\text{mm}^3$

Appendix A2-4 – Volume and Weight Analysis

Joshua Nye | MET486 | 10/2/2020 | 4/4

Solution Cont.

Bottom Frame Section (x 10)



$C_1 = C_2$

$C = \sqrt{56^2 mm \cdot 44^2 mm}$

$C \approx 71.2\ mm$

$71.2\ mm \cdot 4\ mm \cdot 4\ mm = 1139.2\ mm^3$

$44\ mm \cdot 4\ mm \cdot 4\ mm = 704\ mm^3$

$56\ mm \cdot 4\ mm \cdot 4\ mm = 896\ mm^3$

Sum of volumes, Bottom frame section: $5478.4\ mm^3$

Sum of volumes of all bottom frame sections: $45824\ mm^3$

Total approximate volume of ~~[illegible]~~ the bridge: $10690l.2\ mm^3$

Weight: $10690l.2\ mm^3 \cdot 0.00014\ g/mm^3 \approx 15\ g$

Thoughts: I am thinking that while this is all calculated, the bridge would actually be heavier. But, I do guess that I still have some usable weight where I can likely make additions like adding connecting segments to both side frames. Again, this is all approximate, and human error may have some play in the result.

Appendix A3-1 Articulation System Analysis

Joshua Nye | MET 486 | 10/8/2020 | 1/3

Given: - Sketch #2 of Articulation System
- Previous Analysis Sheets

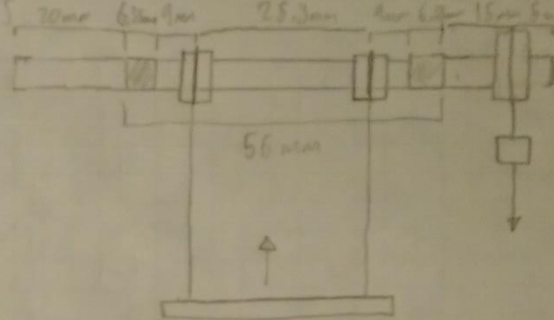
Find: - Forces & Equilibrium
- Weight of Road Deck (and therefore the handle/weight of pulley)
- Weight of entire articulation System

Assume: - Rods are Plain, Cold Rolled Steel
- Pulleys, Spools, and rope/string are weightless
- Road deck is a solid rectangular Prism.

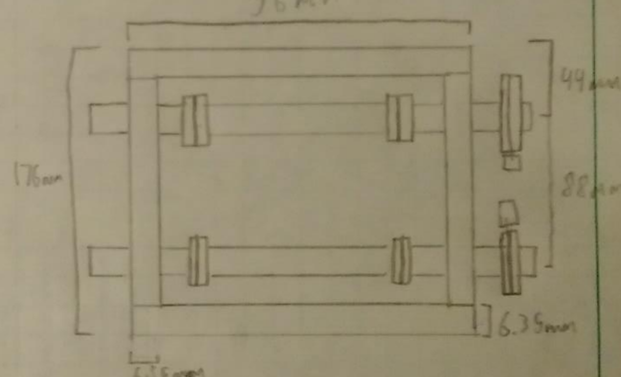
Method: 1) F.B.D.
2) Forces & Equilibrium
3) Road Deck weight
4) System weight

Picture

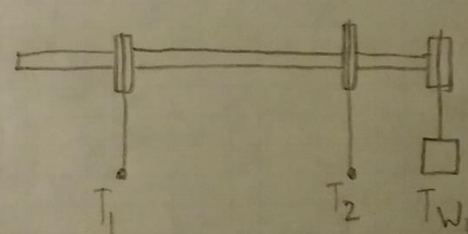
Front (Rod, Spool, Pulley) x2



Top View (Entire System)



F.B.D. (Front)



$T_1 + T_2 = T_{RD_1}$

$T_1 = T_2$

$T_{RD_1} = T_{W_1}$

Appendix A3-2 Articulation System Analysis

Joshua Nye | MET 486 | 10/8/2020 | 2/3

Solution:

Density of Balsa Wood $\approx$ 140 kg/m^3 (0.00014 g/mm^3)

Dimensions of Road Deck: 440mm X 38mm X 4mm

Weight of Road Deck: (0.00014 g/mm^3)(66880 mm^3) = 9.36g $\approx$ 10g

$$T_1 = T_2 = \frac{T_{RD}}{4} = \frac{10g}{4} = 2.5g$$

Note: 2 Sets of articulation, 4 spools attached to Road Deck.

$$+\uparrow \sum F_y = 0 = 2.5g + 2.5g + T_{W_1}$$

$$T_{W_1} = -5g$$

Note: Same with other articulation, $T_{W_1} = T_{W_2}$, 5g + 5g = 10g ($T_{W_1} + T_{W_2} = T_{RD}$)

Weight of Entire System (Without Road Deck)

- Balsa Wood Blocks

(56mm · 6.35mm · 6.35mm) = 2258.06mm^3

↳ 2258.06mm^3 (0.00014 g/mm^3) = 0.32g

↳ 2 blocks of type = 0.64g

(163.3mm · 6.35mm · 6.35mm) = 6584.66 mm^3

↳ 6584.66mm^3 (0.00014 g/mm^3) = 0.92g

↳ 2 blocks of type: 1.84g

Appendix A3-3 Articulation System Analysis

Joshua Nye | MET 486 | 10/8/2020 | 3/3

Density of Steel: 7680 kg/m^3 (0.00768 g/mm^3)
- From Mott, Machine Elements in Mechanical Design

Volume of Steel Rods

$$V = \pi r^2 h$$
$$= \pi \left(\frac{3.125\,mm}{2}\right)^2 (96\,mm) = 471.24\,mm^3$$

Weight of Steel Rods: $471.24\,mm^3\,(0.00768\,g/mm^3)$
$= 3.62\,g$

2 Steel Rods: $2(3.62\,g) = 7.24\,g$

2 Weights: $5g + 5g = 10\,g$

Total Weight of System: 19.72 g

Note: The weight components is to get an idea on how the articulation system can affect the frame of the bridge.

Appendix A4-1 Block Traversal/Road Deck Analysis

Joshua Nye | MET 486 | 10/8/2020 | 1/2

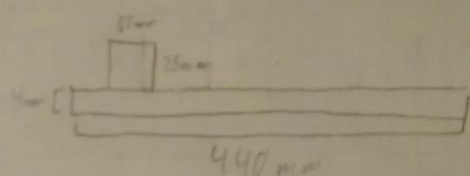
Given:
- Road deck will be 440 mm long and 38 mm wide.
- Traversing block is 32mm wide and 25mm high.
- Abutments can't withstand a lateral force.

Find:
- Static Friction of Balsa wood
- Kinetic Friction of Balsa wood
- Forces acting on Block

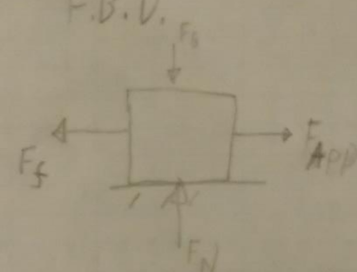
Assume:
- Block is balsa wood.
- Block is not wheeled.
- Road deck thickness is 4mm

Method:
1) Obtain friction values
2) F.B.D.
3) Frictional forces calculation
4) Applied force calculation

Picture:



F.B.D.



Solution:

Volume of block:

$V_{Block} = 38mm \cdot 38mm \cdot 25mm = 36100\ mm^3$

Density, Balsa: $140\ kg/m^3 \approx 0.00014\ g/mm^3$

Mass $= 36100\ mm^3 \cdot 0.00014\ g/mm^3$

$= 5.054\ g$

Appendix A4-2 Block Traversal/Road Deck Analysis

Joshua Nye | MET 486 | 10/8/2020 | 2/2

Solution Cont.

No friction values for balsa wood specifically, going for wood on wood friction.

Static Friction: 0.25 - 0.5

Kinetic Friction: 0.2

(Found on physlink.com)

$F_{grav} = m\,a = 5.054\,g\,(-9.81\,m/s^2) = -49.57\ g\cdot m/s^2$

$F_N = -F_{grav} = 49.57\ g\cdot m/s^2$

$f_{s_{min}} = 0.25(49.57\,N) = 12.39\ g\cdot m/s^2$

$f_{s_{max}} = 0.5(49.57\,N) = 24.78\ g\cdot m/s^2$

$f_k = 0.2(49.57\,N) = 9.914\ g\cdot m/s^2$

The applied force has to be at least (for $f_{s_{max}}$) 24.78 $g\cdot m/s^2$ to cause the block to move (assuming larger value for friction), and 9.914 $g\cdot m/s^2$ to keep it moving.

Appendix A5-1 Bridge Lifting Analysis

Joshua Nye | MET 486 | 10/15/2020 | 1/2

Given: - Previous Analysis Sheets
- Sketch #2 of Articulation System

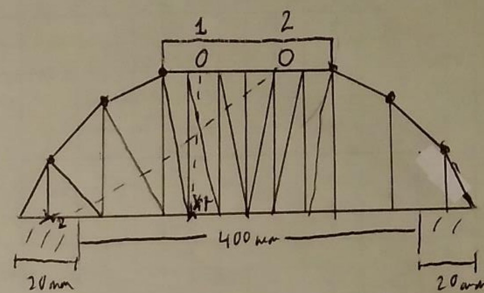
Find: - Forces & Equilibrium
- Determine if additional 10 grams can lift one end of bridge high enough to slip paper below.

Assume: - Articulation System is secure on top of bridge.
- No external forces affecting bridge

Method: 1) F.B.D.
2) Forces & Equilibrium
3) Assess if bridge can be lifted.

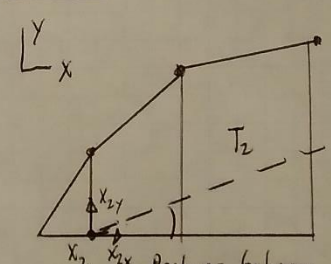
Picture Note: Not properly scaled

Side Frame with Articulation System



X - String Connections (Proposed) for lifting bridge.

F.B.D. X_2



Perhaps between $30° - 45°$
Assume $37.5°$

Solution

From previous analyses
- Bridge weight: $\approx 15g$
- Handle/Weight: $\approx 5g$

Distance (Horizontal) from 2 to X2: 264mm

Height: $80mm + \frac{1}{2}(6.35mm) = 83.175mm$

Appendix A5-2 Bridge Lifting Analysis

Joshua Nye | MET 486 | 10/15/2020 | 2/2

Direct distance from 2 to X_2

$$C^2 = (83.179\,mm)^2 + (264\,mm)^2 \approx 276.8\,mm$$

$$T_2 = 5g\ (\text{initial}) + 10g\ (\text{additional}) = 15g$$

$$0.015\,kg \cdot 9.81\,m/s^2 = 0.147\,N$$

$$+\uparrow \sum F_y = 0 = -X_{2y} + \cos(37.9)(0.147\,N)$$

$$X_{2y} = 0.117\,N$$

$$0.117 \cdot \frac{1000\,g}{1\,kg} \div \frac{1}{9.81\,m/s^2} = 11.927\,g$$

$$\xrightarrow{+} \sum F_x = 0 = -X_{2x} + \sin(37.5)(0.147\,N)$$

$$X_{2x} = 0.089\,N$$

$$0.089\,N \cdot \frac{1000\,g}{1\,kg} \div \frac{1}{9.81\,m/s^2} = 9.12\,g$$

The articulation system would likely be able to lift the bridge enough for a paper to slip between.

Appendix A6-1 Torque Analysis

Joshua Nye | MET489 | 10/21/2020 | 1/2

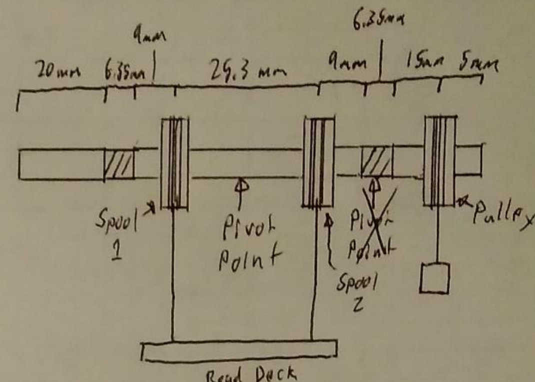
Given:
- Picture of articulation mechanism
- Mass of weight/handle is 5 grams.
- Articulation System is manually operated.
- Length of steel rod is 96 mm total.

Find:
- Forces acting on the pulley & Spools.
- Torque at pulley & spools.

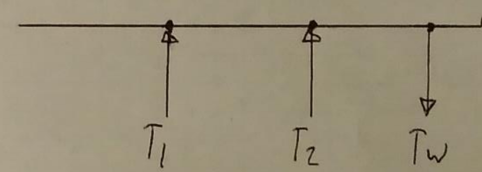
Assume:
- Second articulation mechanism is designed the same, therefore calculations should be the same.
- Pulley & spools are weightless.

Method:
1. F.B.D.
2. Forces & Equilibrium
3. Torque at Pulley & Spools

Picture Note: Not to Scale



F.B.D.



Solution

Data from previous analysis

$T_1 + T_2 = \frac{T_{RD}}{2} = T_w$

$T_1 = T_2$

$T_1 = 2.5\ g$

$T_2 = 2.5\ g$

$\frac{T_{RD}}{2} = 5\ g$

Appendix A6-2 Articulation Mechanism Torque Analysis

Joshua Nyo | MET 489 | 10/21/2020 | 2/2

Solution Cont.

Gravity: $9.81\ m/s^2$

$$F_{T_W, \frac{T_{RD}}{2}} = 5g\left(\frac{1kg}{1000g}\right)(9.81\ m/s^2) = 0.049\ N \approx 0.05\ N$$

$$F_{T_1,T_2} = 2.5g\left(\frac{1kg}{1000g}\right)(9.81\ m/s^2) \approx 0.025\ N$$

$$+\uparrow \sum F_y = \overset{T_1}{0.025\ N} + \overset{T_2}{0.025\ N} - \overset{T_W}{0.05\ N} = 0$$

Note: Re-affirming calculations from previous analysis, only in Newtons in this case.

Torque

Note: Referencing the picture, the center of the ~~right balsa wood block~~ Steel Rod will be the pivot point.

$$T_{O\,pulley} = r \cdot F$$
$$= 43\ mm \cdot -0.05\ N = 2.15\ N \cdot mm \quad CW$$

$$T_{O\,Spool_2} = r \cdot F$$
$$= 12.65\ mm \cdot 0.025\ N = 0.316\ N \cdot mm \quad CCW$$

$$T_{O\,Spool_1} = r \cdot F$$
$$= 12.65\ mm \cdot 0.025\ N = 0.316\ N \cdot mm \quad CCW$$

Appendix A7-1 Articulation Mechanism Torsion Analysis

Joshua Nye | MET 489 | 10/21/2020 | 1/2

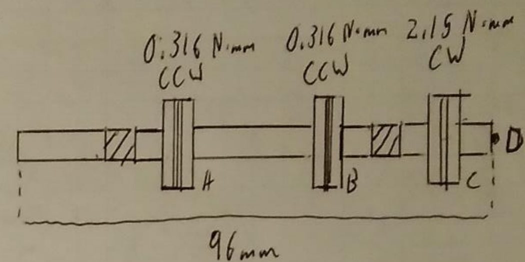
Given:
- Picture of Articulation Mechanism
- Articulation System is manually operated.
- Length of Steel Rod is 96 mm
- Diameter of Steel Rod is 3.125 mm
- Torque From Previous analysis
- $G = 11.5 \cdot 10^6$ psi for Steel (80 GPa)

Find:
- Shear Stress due to Torsion
- Torsional Deformation

Assume:
- Second Articulation mechanism is designed the same, therefore the calculations should be the same.
- Pulley & Spools are weightless

Method:
1) Picture w/ Torque Values
2) Torsion at each section
3) Torsional Deformation on mechanism.

Picture:



Solution

$$c = \frac{1}{2}D = \frac{1}{2}(3.125\ \text{mm}) = 1.56\ \text{mm}$$

$$J = \frac{\pi D^4}{32} = \frac{\pi (3.125\ \text{mm})^4}{32} = 9.36\ \text{mm}^4$$

$$\tau_{A\,max} = \frac{Tc}{J} = \frac{(0.316\ \text{N·mm})(1.56\ \text{mm})}{9.36\ \text{mm}^4} = 0.0526\ \text{N/mm}^2$$

$$\tau_{B\,max} = \frac{Tc}{J} = \frac{(0.316\ \text{N·mm})(1.56\ \text{mm})}{9.316\ \text{mm}^4} = 0.0526\ \text{N/mm}^2$$

Appendix A7-2 Articulation Mechanism Torsion Analysis

Joshua Nye | MET 489 | 10/22/2020 | 2/2

Solution Cont.

$$\tau_{Cmax} = \frac{Tc}{J}$$

$$= \frac{-2.15 \text{ N·mm} (1.56 \text{ mm})}{9.316 \text{ mm}^4}$$

$$= -0.360 \text{ N/mm}^2$$

Torsional Deformation

$$\theta_{All} = \frac{(0.316 \text{ N·mm} + 0.316 \text{ N·mm} + 2.15 \text{ N·mm})(96 \text{ mm})}{(8 \cdot 10^{10} \text{ Pa})(9.316 \text{ mm}^4)}$$

$$= 3.58 \cdot 10^{-4} \text{ rad} \cdot \frac{180}{\pi} = 0.0205^{\circ}$$

Appendix A8-1 Pulley and Spools Tension Analysis

Joshua Nye | MET 489 | 10/22/2020 | 1/2

Given: - Mass of road deck is 9.36 g $\approx 10\,g$
- Mass of weight/handle is 5 g

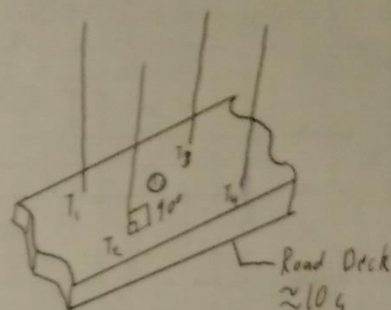
Find: - Tension on all cables

Assume: - Articulation System is secure on top of bridge.

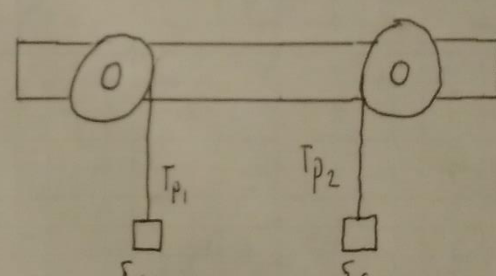
Method: 1) Force Calculation
2) Tension acting from Road Deck
3) Tension acting from Weights/handles

Picture:

Road Deck (Isometric, Sectioned)



Pulley's (Side View, Articulation System)



Solution:

$$T_{RD} = m\,a = 10\,g\,(9.81\,m/s^2) = 98.1\,g\cdot m/s^2 \approx 0.0981\,N$$

$$T_{P_1,P_2} = m\,a = 5\,g\,(9.81\,m/s^2) = 49.05\,g\cdot m/s^2 = 0.04905\,N$$

Appendix A8-2 Pulley and Spools Tension Analysis

Joshua Nye | MET 489 | 10/22/2020 | 2/2

$T_1 + T_2 + T_3 + T_4 = T_{RD}$

$T_1 = T_2 = T_3 = T_4$

$4T_{1,2,3,4} = TRD$

$4T_{1,2,3,4} = 0.0981\ N$

$T_{1,2,3,4} = 0.024525\ N$

$\approx 0.025\ N$

Appendix A9-1 Pivot Pin Analysis

Joshua Nye | MET 489 | 10/29/2020 | 1/2

Given:
- Pivot is a steel rod
- Bridge is about 500 mm long, and weighs 15 g
- Articulation System is 6.35 mm long, and weighs about 19.72 g
- Both bridge & articulation System press against pivot

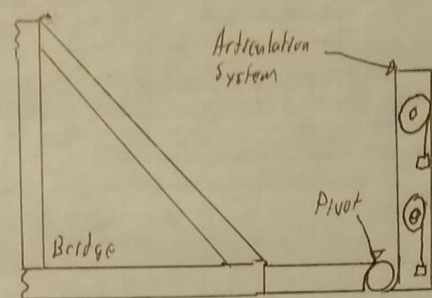
Find:
- Forces & Equilibrium at pivot
- Torque at Pivot

Assume:
- Pivot is secured at its position
- No other external forces

Method:
1) F.B.D.
2) Forces & Equilibrium at pivot
3) Torque

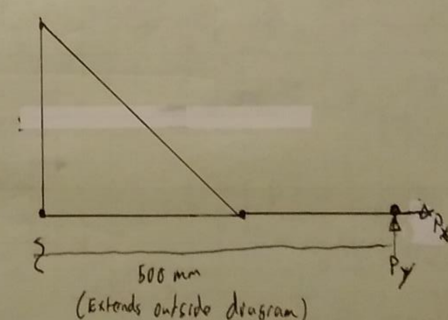
Picture Note: Not to scale

Area around Pivot, side View

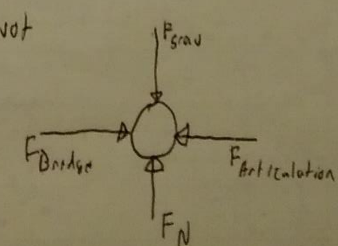


Note: Bridge ends extended by 30 mm on each side, totalling to 500 mm. Recent addition. Also, articulation System was given additional use in holding the pivot in place.

F.B.D.



Pivot



Appendix A9-2 Pivot Pin Analysis

Joshua Nyo | MET 484 | 10/29/2020 | 2/2

Solution

Length of Steel Rod, Pivot: 96 mm

Volume of Steel Rod, Pivot:

$$V = \pi r^2 h = \pi \left(\frac{3.125\,mm}{2}\right)^2 (96\,mm) = 471.24\,mm^3$$

Density of Steel (in grams/mm³): 0.00768 g/mm³

Weight: $471.24\,mm^3 (0.00768\,g/mm^3) = 3.62\,g$

$$F_{grav} = 3.62\,g \left(\frac{1\,kg}{1000\,g}\right)(9.81\,m/s^2) = 0.0355\,N$$

$$F_N = F_{grav} = 0.0355\,N$$

$$+\uparrow \sum F_y = -0.0355\,N + 0.0355\,N = 0$$

Note: When at rest, F_{Bridge} & $F_{Articulation}$ would equal 0 N, so $\xrightarrow{+} \sum F_x = 0$

Torque (At the moment the bridge will raise)

$$T = F \cdot L$$

$$F = 15\,g \cdot \left(\frac{1\,kg}{1000\,g}\right)(9.81\,m/s^2) = 0.14715\,N$$

$$L = 500\,mm$$

$$T = 0.14715\,N \cdot 500\,mm = 73.57\,N \cdot mm$$

Appendix A10-1 Forces on Crank/Pulley (Bridge Raising) Analysis

Joshua Nyo | MET489 | 10/29/2020 | 1/3

Given:
- Bridge is about 500 mm long and weighs 15 g
- Articulation System is 6.35 mm long and 176 mm tall.
- The relevant articulation mechanism set is 132 mm tall

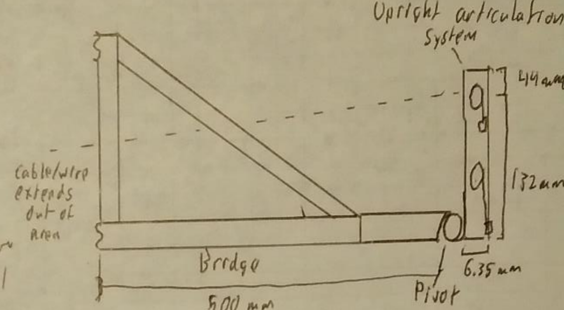
Find:
- Forces acting on the crank/pulley
- Force on crank/pulley needed to lift the bridge.

Assume:
- Cable on articulation system is properly tied/connected to width segment on opposite end of bridge
- Pivot is secured at its location.

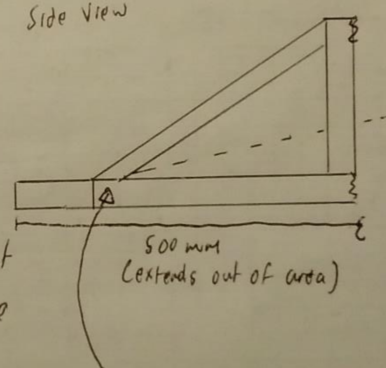
Method:
1) F.B.D.'s
2) Forces on Crank/Pulley
3) Force needed to lift bridge.

Picture Note: Not to scale

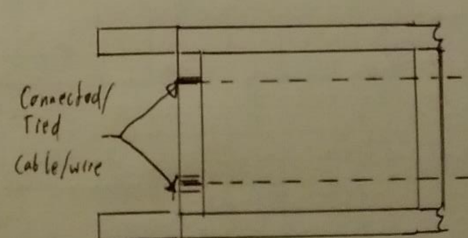
Area around pivot, side view



Area around connected cable/wire side view



Connected cable/wire, top view



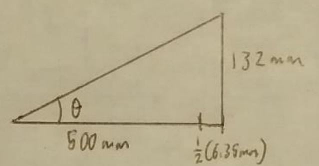
Note: Articulation mechanism is set up the same for each spool, values should be equal

Appendix A10-2 Forces on Crank/Pulley (Bridge Raising) Analysis

Joshua Nye | MET 489 | 10/29/2020 | 2/3

Solution Cable/wire

Find θ



$$\tan\theta = \frac{132\ mm}{503.175\ mm}$$

$$\theta = \tan^{-1}\frac{132\ mm}{503.175\ mm} = 14.69^\circ$$

$$F_W = 15\ g\left(\frac{1\ kg}{1000\ g}\right)\left(9.81\ m/s^2\right) = 0.14715\ N$$

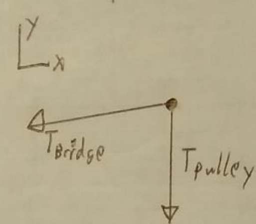
$$F_W = F_N = 0.14715\ N$$

Note: Since articulation system is on opposite side of the bridge from connection, it will carry the full weight of bridge to lift it.

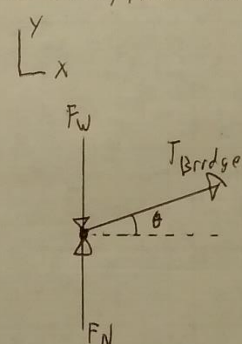
$$T_{Bridge} = \frac{F_W}{\cos\theta} = \frac{0.14715\ N}{\cos 14.69^\circ} = 0.15212\ N$$

F.B.D.

Articulation Mechanism (Pulley & Spool combined)



Connected/Tied Cable/wire



Appendix A10-3 Forces on Crank/Pulley (Bridge Raising) Analysis

Joshua Nye | MET 489 | 10/29/2020 | 3/3

Solution Cont.

Articulation Mechanism

$T_{Bridge} = 0.15212\ N$

$$T_{pulley} = 5g\left(\frac{1kg}{1000g}\right)(9.81\ m/s^2) + 10g\left(\frac{1kg}{1000g}\right)(9.81\ m/s^2)$$

$$= 0.14715\ N$$

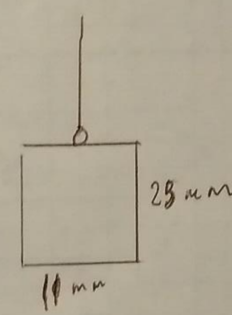
Note: Articulation mechanism initially has a **5 gram** weight that also acts as a handle, but the addition of 10 g weight per Bridge criteria makes it equal to weight of bridge (roughly). Likely will need an additional weight or human input to exceed 0.15212 N to lift the bridge.

Appendix A11-1 Forces and Stress on Handle/Weight

Joshua Nye | MET 489 | 11/5/2020 | 1/2

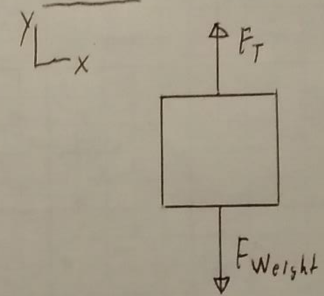
Given:
- A 7g weight/handle from Articulation System
- 25 mm in height
- 11 mm in diameter
- Iron Material

Picture



Find:
- Forces on Weight/Handle
- Normal Stress

F.B.D.



Assume:
- Weight/Handle is Cylindrical
- Gravity is $9.81 \, m/s^2$
- In Tension from cable

Method:
1) F.B.D.
2) Forces on Weight/Handle
3) Normal Stress

Note: Decided to increase the weight/handles from 5g to 7g as a result from a previous analysis.

Solution:

$$F_{weight} = 7g \left(\frac{1kg}{1000g}\right)(9.81 \, m/s^2) = 0.06867 \, N$$

$$F_T = F_{weight} = 0.06867 \, N$$

$$+\uparrow \sum F_y = -0.06867 \, N + 0.06867 \, N = 0 \, N$$

Appendix A11-2 Forces and Stress on Handle/Weight

Joshua Nye | MET 489 | 11/6/2020 | 2/2

Solution cont.

Normal Stress

$$A = \frac{\pi D^2}{4} = \frac{\pi (11mm)^2}{4} = 95.03\, mm^2$$

$$\sigma = \frac{F}{A} = \frac{0.06867\ N}{95.03\ mm^2} = 7.23 \cdot 10^{-4}\ N/mm^2$$

$$\approx 723\ Pa$$

Appendix A12-1 Lifting Hole Locations, Size, Washer Size

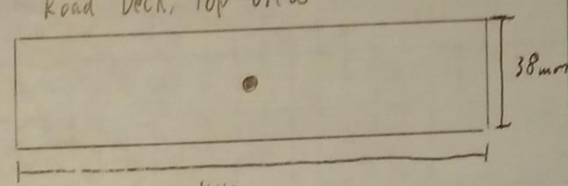
Joshua Nye | MET489 | 11/12/2020 | 1/4

Given: - Road deck is 440 mm by 38 mm by 3,179 mm

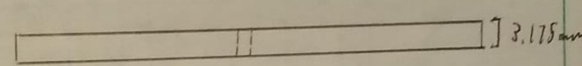
- 8 mm hole on center of road deck for load testing (220 mm, 19 mm)

Picture

Road Deck, Top View



Road Deck, Side View



Find: - Position of holes to raise road deck

- Determining size of holes for lifting road deck.

- Size of washer or disk to lift road deck.

Assume: - Articulation mechanisms are directly vertical from position of holes.

- All holes completely go through the road deck.

Method: See Find

Appendix A12-2 Lifting Hole Locations, Size, Washer Size

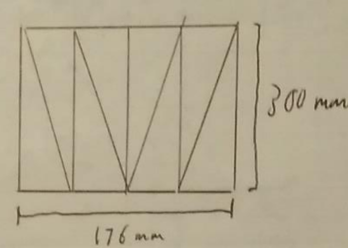
Joshua Nye | MET 489 | 11/12/2020 | 2/4

Solution:

From previous analysis (in addition to adjustments)

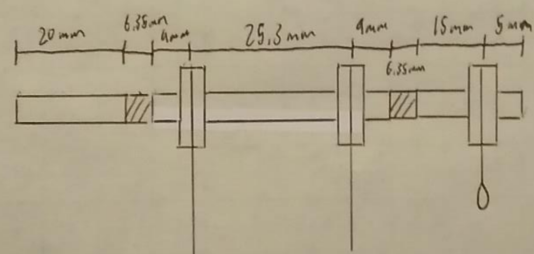
- Side frame length: 176 mm
- Side frame height: 300 mm
- Position of hole relative to side frame: 88 mm (length)

Side Frame

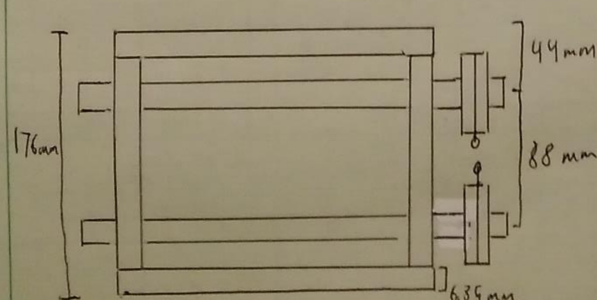


From another previous analysis

Articulation Mechanism



Entire System (Top View)



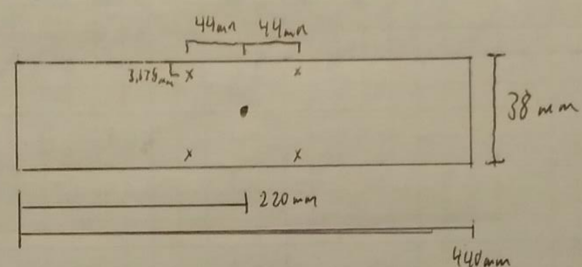
Appendix A12-3 Lifting Hole Locations, Size, Washer Size

Joshua Nye | MET 489 | 11/12/2020 | 3/4

Solution Cont.

Based from previous analyses, the holes for lifting the road deck should be 44 mm away from center hole, and about 12.175 from side frame (3.175 mm from Road deck's side)

Road Deck, Top View, Proposed Hole locations



Note: May need to make holes 2-4 mm closer to the center of the road deck to have reasonably sized holes

Hole Size

Should be slightly smaller than center hole, and a standard size.

Based on position (including potential changes) the hole diameter should be at most, 5mm

Appendix A12-4 Lifting Hole Locations, Size, Washer Size

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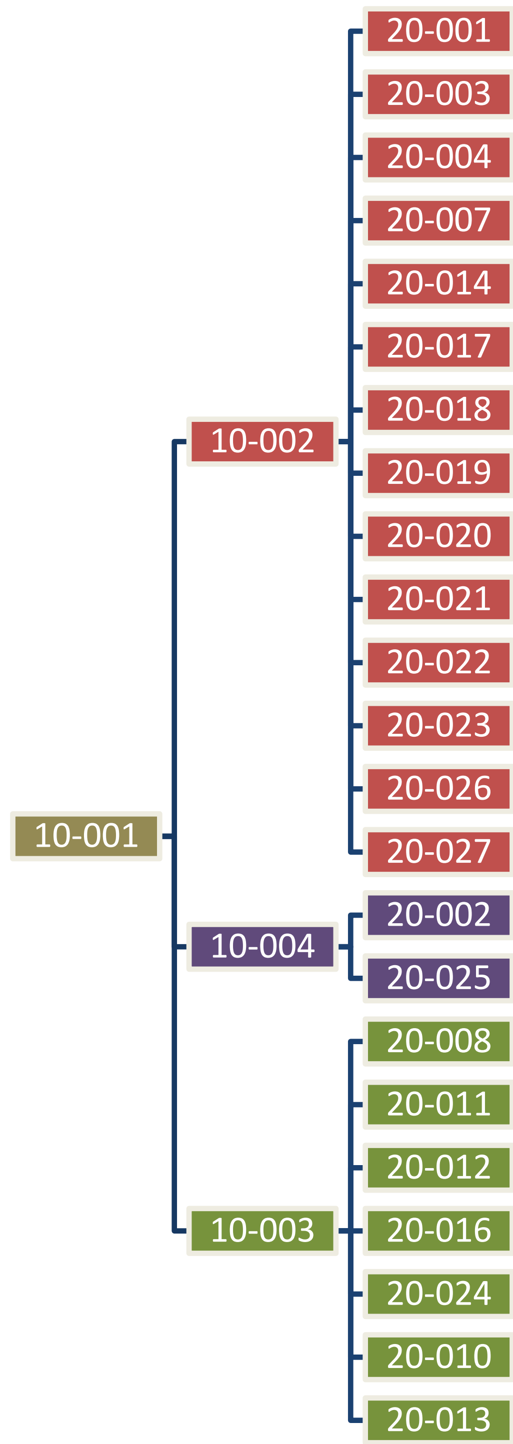
Size of Washer or Disk

The washer or disk should have a hook of sorts to allow the cable to be tied to it, then it will lift the washer/disk lifting the road deck.

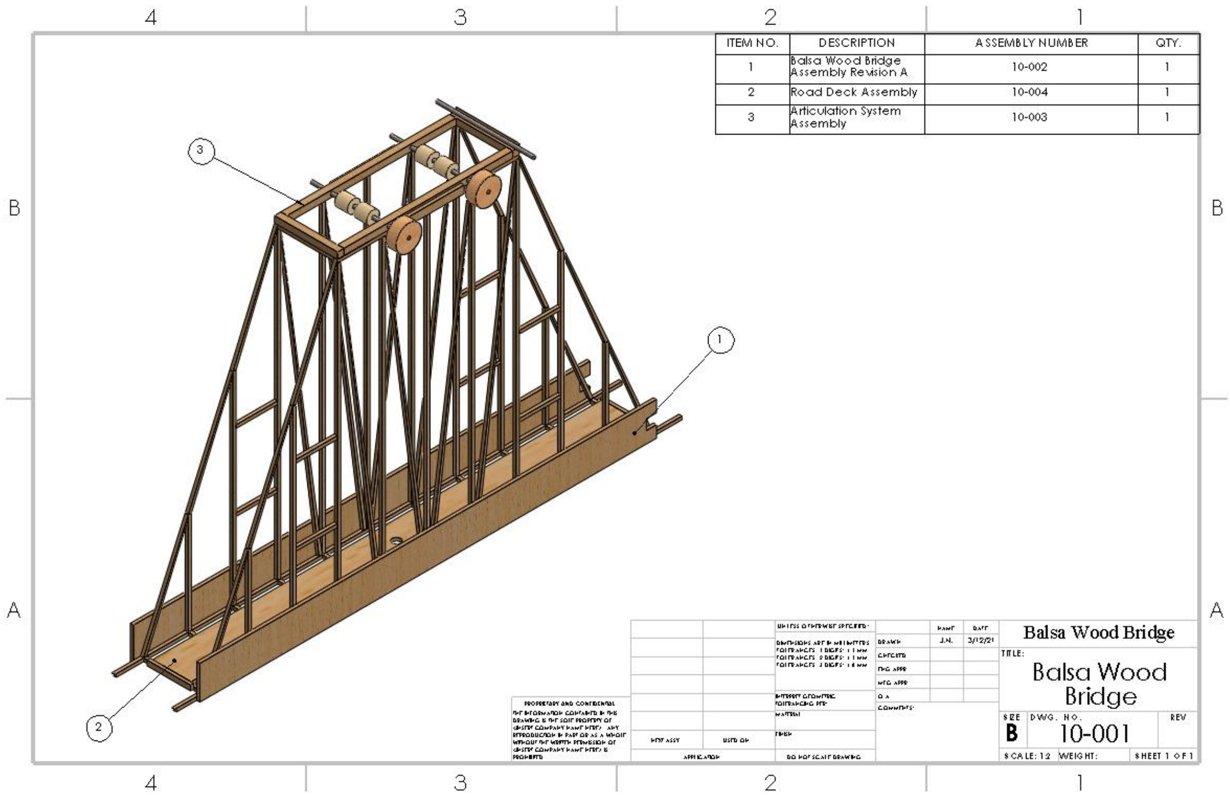
Since it will have to be bigger than 5mm in diameter, the washer or disk has to be around 7 - 8 mm.

APPENDIX B - Drawings

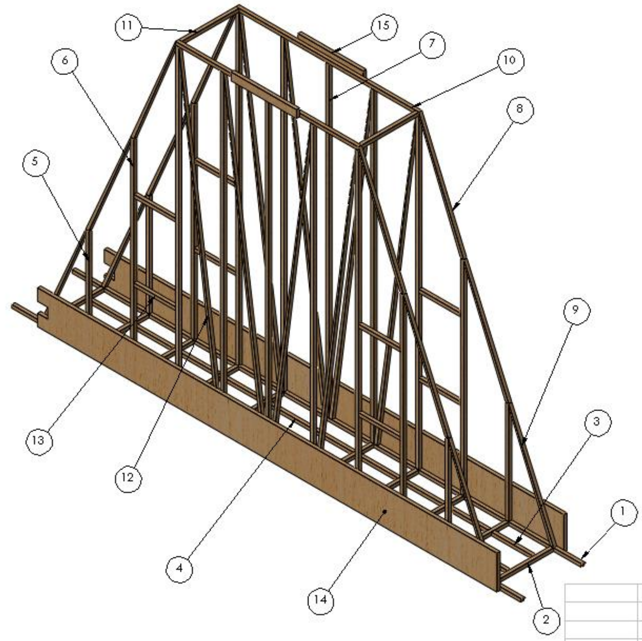
Appendix B – Drawing Tree



Appendix B – 10-001 “Balsa Wood Bridge Assembly”



Appendix B – 10-002 “Balsa Wood Bridge Frame Assembly”



ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
1	Bridge Bottom Frame Length	20-004	2
2	Bridge Width End Segment	20-001	10
3	Bridge Bottom Frame Support	20-003	16
4	Bridge Bottom Frame Long Support	20-022	2
5	Rising Arc First Vertical	20-017	4
6	Rising Arc Second Vertical	20-018	4
7	Bridge Side Frame Vertical	20-010	10
8	Rising Arc Diagonal	20-019	4
9	Rising Arc Short Diagonal	20-020	8
10	Bridge Side Frame Horizontal	20-021	2
11	Bridge Across Frame Segment	20-014	2
12	Bridge Side Frame Support	20-007	8
13	Bridge Side Frame Horizontal Support	20-023	8
14	Bridge Structure Flat Support	20-027	2
15	Side Frame Holder	20-026	2

REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	REMADE BRIDGE FRAME ASSEMBLY DRAWING	3/12/2021	J.N.
	B	RE-INTEGRATED PART 20-007 ADDED PARTS 20-022 20-023 20-026 20-027	N/A	J.N.

	NAME	DATE
DRAWN	J.N.	3/12/21
CHECKED		
ENG APPR		
MFG APPR		
Q.A.		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

MATERIAL: Balsa

COMMENTS:

PROPRIETARY AND CONFIDENTIAL

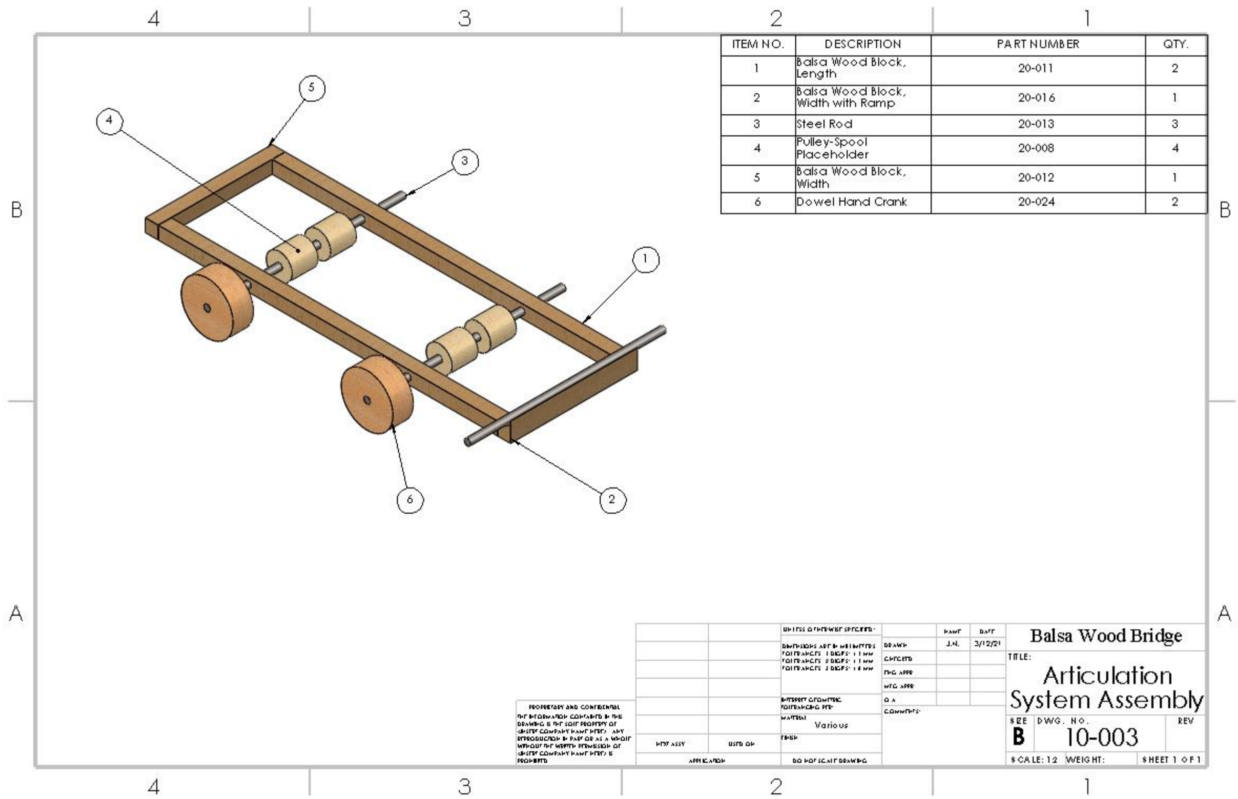
NEXT ASSY | USED ON | APPLICATION | DO NOT SCALE DRAWING

TITLE: Balsa Wood Bridge Frame Assembly

SIZE: B | DWG. NO. 10-002 | REV: A

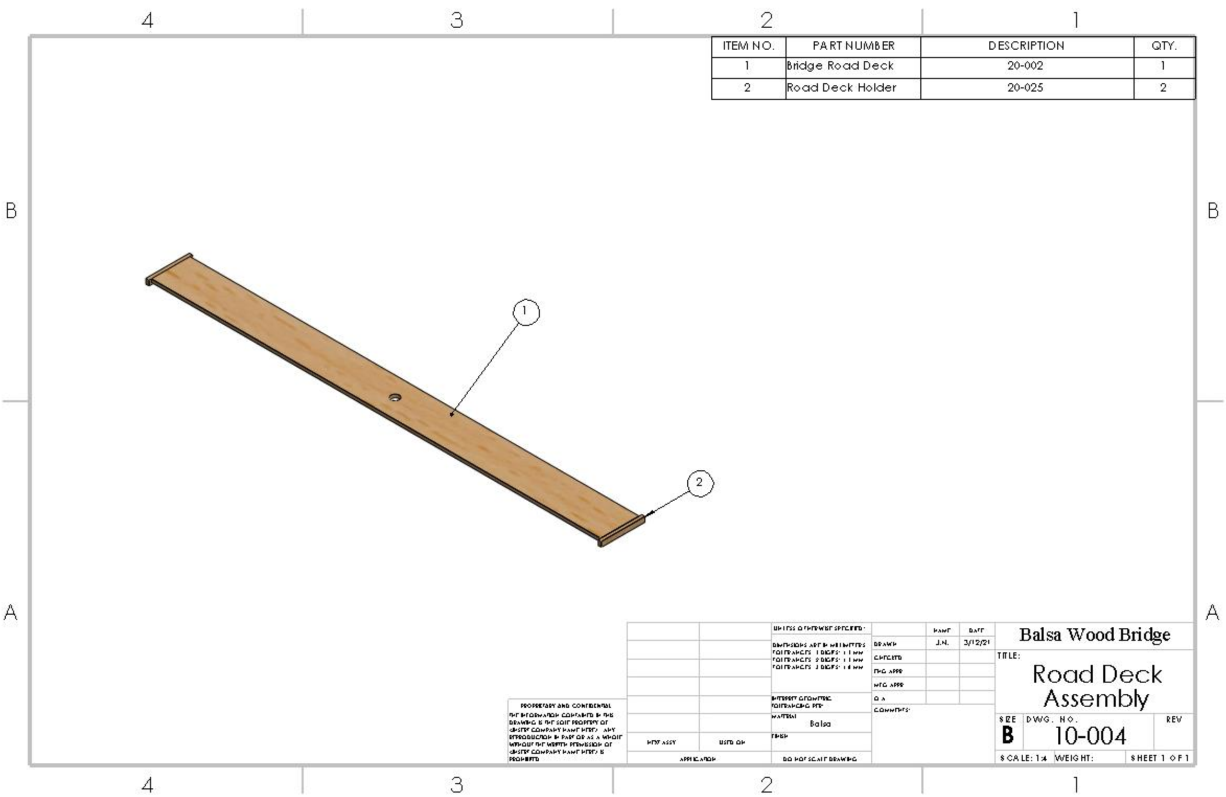
SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

Appendix B – 10-003 “Articulation System Assembly”

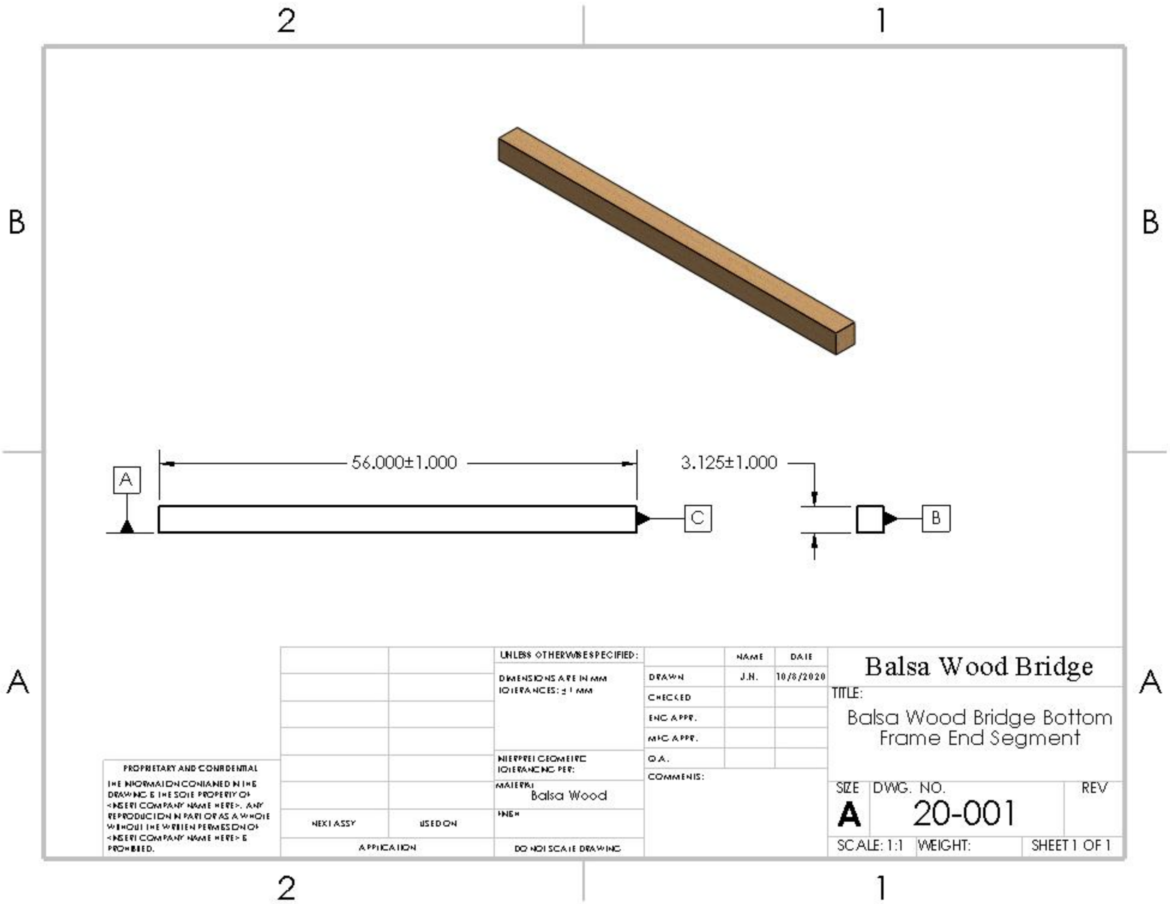


ITEM NO.	DESCRIPTION	PART NUMBER	QTY.
1	Balsa Wood Block, Length	20-011	2
2	Balsa Wood Block, Width with Ramp	20-016	1
3	Steel Rod	20-013	3
4	Pulley-Spool Placeholder	20-008	4
5	Balsa Wood Block, Width	20-012	1
6	Dowel Hand Crank	20-024	2

Appendix B – 10-004 “Road Deck Assembly”

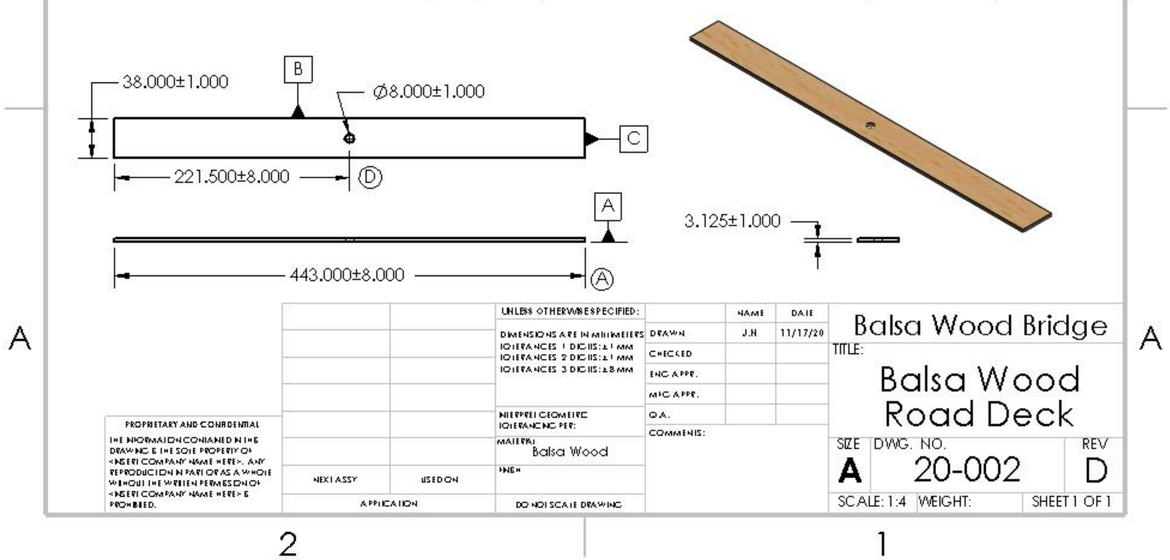


Appendix B – 20-001 “Balsa Wood Bridge Bottom Frame End Segment”

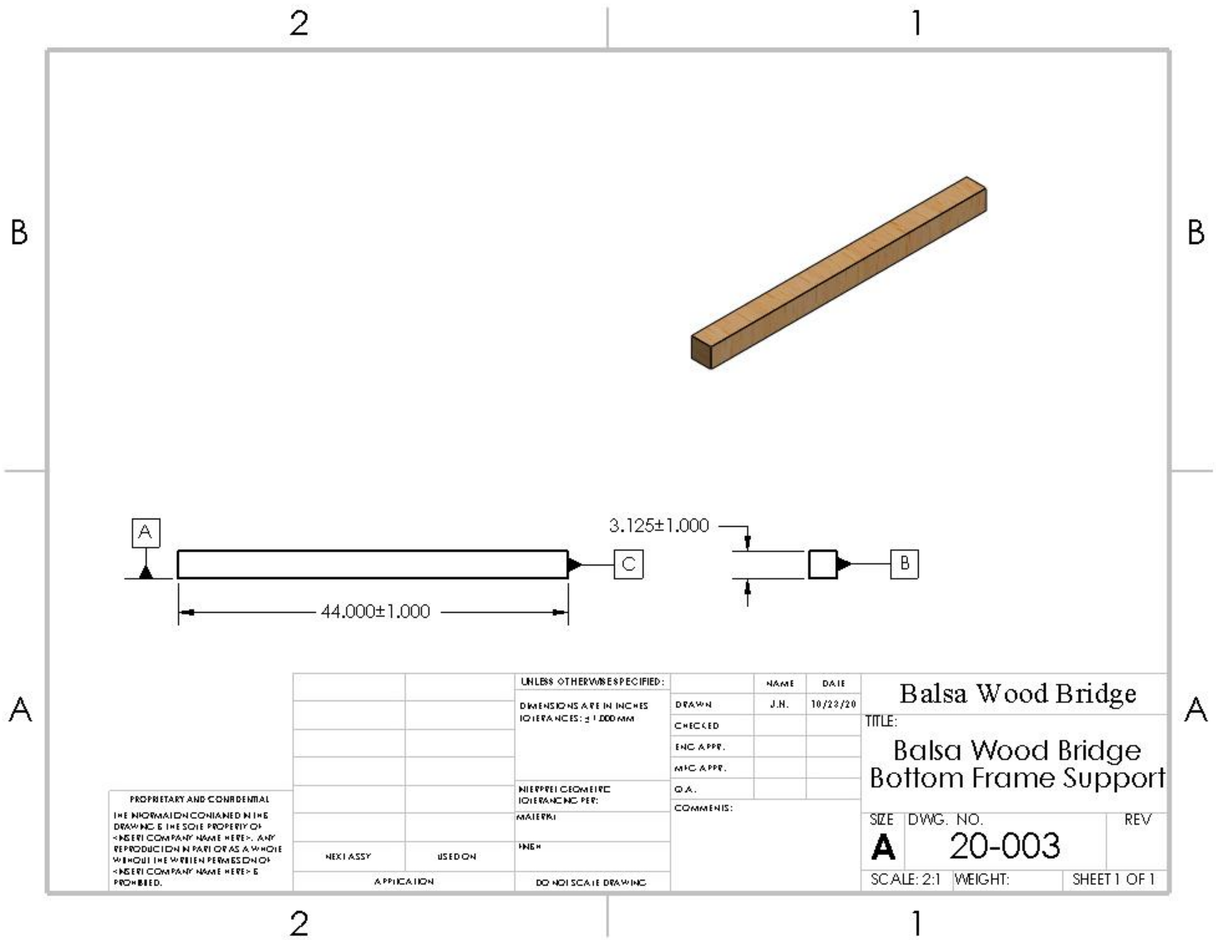


Appendix B – 20-002 "Balsa Wood Road Deck"

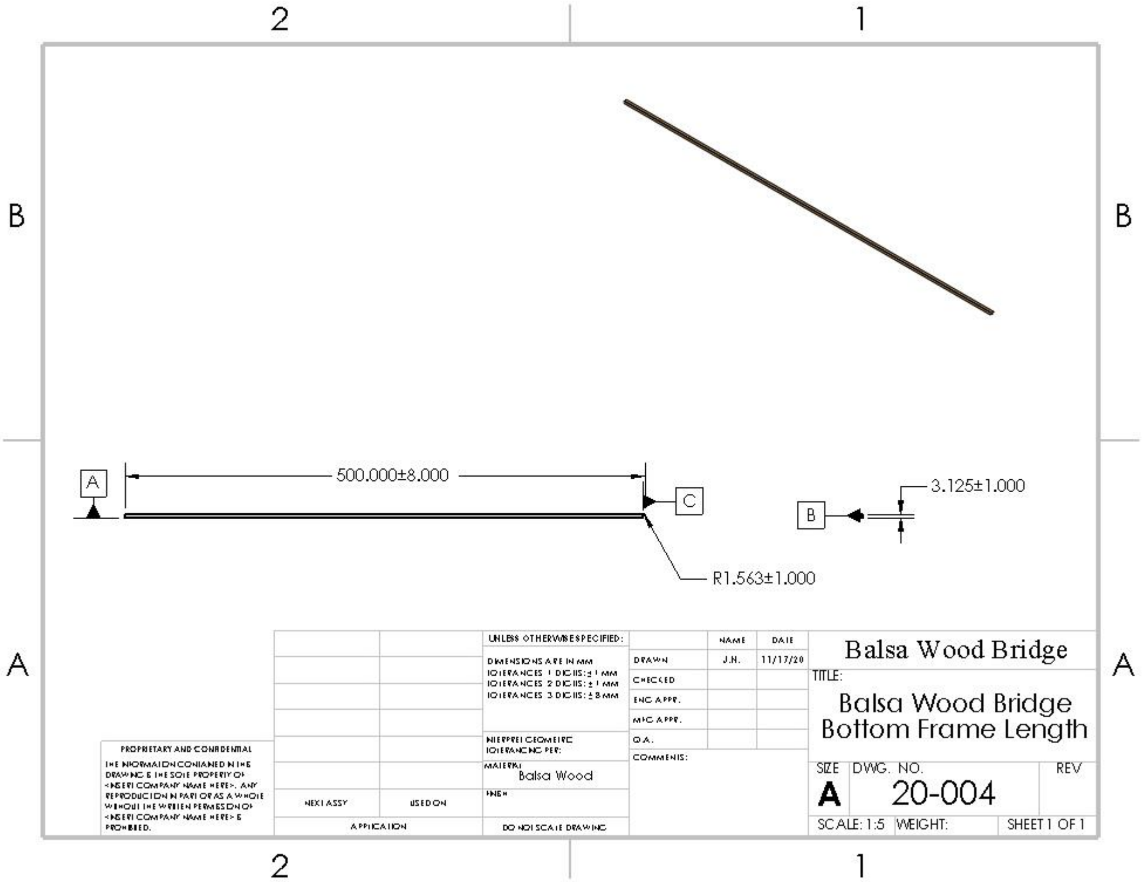
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
A1	A	LENGTH CHANGED FROM 440 MM TO 443 MM	2/14/2021	J.N.
	B	DISTANCE FROM 7.125 MM TO 10.250 MM	2/14/2021	J.N.
	C	DISTANCE FROM 44 MM TO 38 MM	2/15/2021	J.N.
A2	D	REMOVED SMALLER HOLES, REMOVED REVISION SYMBOLS B & C ASSOCIATED WITH SAID REMOVAL, ADDED LENGTH TO CENTER HOLE	3/12/2021	J.N.



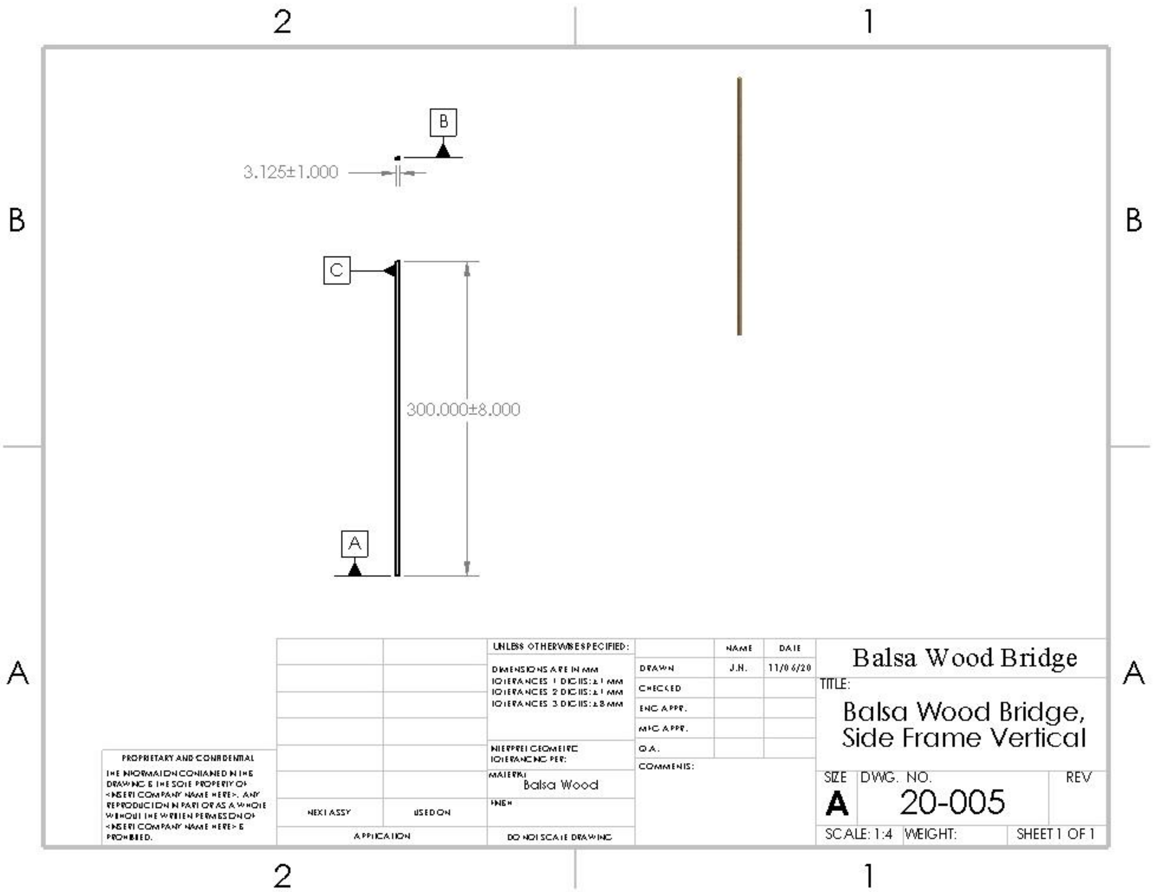
Appendix B – 20-003 "Balsa Wood Bridge Bottom Frame Support"



Appendix B – 20-004 "Balsa Wood Bridge, Bottom Frame Length"



Appendix B – 20-005 “Balsa Wood Bridge, Side Frame Vertical”



APPENDIX C – Parts List and Costs

Appendix C - Parts List

Part Number	Qty	Part Description	Source	Cost	Disposition
20-001	11	Balsa Wood Bridge, Bottom Frame Width	Amazon	See 55-001	Manufactured
20-002	1	Balsa Wood, Road Deck	Amazon	See 55-004	Manufactured
20-003	20	Balsa Wood Bridge, Bottom Frame Support	Amazon	See 55-001	Manufactured
20-004	2	Balsa Wood Bridge, Bottom Frame Length	Amazon	See 55-001	Manufactured
20-005	10	Balsa Wood Bridge, Side Frame Vertical	Amazon	See 55-001	Manufactured
20-006	24	Balsa Wood Bridge, Side Frame Arch	Amazon	See 55-001	Not in Service
20-007	8	Balsa Wood Bridge, Side Frame Supports	Amazon	See 55-001	Manufactured
20-008 (Service Number Change), 50-006	6	Spools	Amazon, https://www.amazon.com/25-Pack-CleverDelights-Spools-Unfinished/dp/B08284XC3K/ref=sr_1_65?dchild=1&keywords=CleverDelights+spools&qid=1611164062&sr=8-65	$8.89	Delivered on Feb. 3, 2021
20-009	2	Pulleys			Not in Service
20-010 (Service Number Change), 50-007	2	Handles/Weights, Iron Fishing Weights (7 g)	Amazon, https://www.amazon.com/Yosoo-Health-Gear-Saltwater-Freshwater/dp/B08CRM7442/ref=sr_1_4?dchild=1&keywords=yosoo+20+pcs+fishing+weights&qid=1605613711&sr=8-4	$14.79 (20 Piece Set)	Delivered Dec. 24, 2020, Not in Service
20-011	2	Balsa Wood Block, Length Block	Amazon	See 55-002	Manufactured
20-012	1	Balsa Wood Block, Width Block	Amazon	See 55-002	Manufactured

55-001		Balsa Wood Segments, 1/8 in x 1/8 in x 36 in	Amazon, https://www.amazon.com/Balsa-Wood-Shop-36in-18/dp/B00YV6SUNS/ref=sr_1_5?dchild=1&keywords=balsa+wood&qid=1602775937&refinements=p_72%3A2661619011&rnid=2661617011&sr=8-5	$14.86	Delivered on Dec. 26, 2020
55-002		Baltic Birch Plywood Blocks, 1/4 in x 12 in x 12 in	Amazon, https://www.amazon.com/6MM-Baltic-Birch-Plywood-Engraving/dp/B07HBC8NQ9/ref=sr_1_35?dchild=1&keywords=balsa+wood+block+thin&qid=1602776923&sr=8-35	$18.75	Delivered on Dec. 18, 2020, Not in Service, Wrong Material
55-003		Steel Rods, 1/8 in x 48 in	Home Depot, https://www.homedepot.com/p/Everbilt-1-8-in-x-48-in-Plain-Steel-Cold-Rolled-Round-Rod-801567/204273942	$3.30	Purchased
55-004		Balsa Wood Sheet, 1/8 in x 3 in x 36 in	Amazon, https://www.amazon.com/Balsa-Wood-Shop-36in-10/dp/B00YV6YCTY/ref=sr_1_11?dchild=1&keywords=balsa+wood+sheet+long&qid=1602776548&sr=8-11	$52.70	Delivered on Dec. 26, 2020
55-005	2	Lengths of Rope/String	Home Depot	$3.98	Donated
20-013	3	Steel Rod, Cut	Home Depot	See 55-003	Manufactured
20-014	2	Balsa Wood Segment, Across Frame	Amazon	See 55-001	Manufactured
20-015 (Service Number Change), 50-008	4	Washer/Disk	Amazon, https://www.amazon.com/Shapenty-Stainless-Stamping-Pendants-Specialized/dp/B07X1HP39G/ref=sr_1_3?dchild=1&keywords=sharpenty+small+round+stainless+steel+stamping&qid=1605613900&sr=8-3	$7.29 (100 Piece Set)	Delivered Dec. 24, 2020, Not in Service
20-016	1	Balsa Wood Block, Width with Ramp	Amazon	See 55-002	Manufactured
20-017	4	Rising Arc First Vertical	Amazon	See 55-001	Manufactured
20-018	4	Rising Arc Second Vertical	Amazon	See 55-001	Manufactured
20-019	4	Rising Arc Diagonal	Amazon	See 55-001	Manufactured
20-020	8	Rising Arc Short Diagonal	Amazon	See 55-001	Manufactured
20-021	2	Bridge Side Frame Horizontal	Amazon	See 55-001	Manufactured

20-022	2	Bridge Bottom Frame Long Support	Amazon	See 55-001	Manufactured
20-023	8	Bridge Side Frame, Horizontal Supports	Amazon	See 55-002	Manufactured
55-006	4	Balsa Wood Blocks, 8.25 in x 1.25 in x 0.25 in	Donator Purchase	Donated	Donated
55-007	1	Wood Dowel, 1" X 48"	Home Depot, Donator Purchase	Donated	Donated
20-024	2	Dowel Hand Crank	Home Depot	See 55-007	Manufactured
20-025	2	Road Deck Holder	Amazon	See 55-004	Manufactured
20-026	2	Side Frame Holder	Amazon	See 55-004	Manufactured
20-027	2	Bridge Structure Flat Support	Amazon	See 55-004	Manufactured

APPENDIX D – Budget

Appendix D - Project Budget

Item	Qty	Description	Cost
Labor	N/A.	Physical & mental work on project.	113.6 hours (at least)
Shipping	6	Cost to deliver the materials.	$17.42
Taxes	6	Additional costs for the purchases.	$12.43
Raw Material and Ordered Parts	6	Total Cost of the required raw materials and ordered parts.	$159.09
Testing Phase Materials	5	Total Cost of materials for the testing phase of the project.	$56.95

APPENDIX E – Schedule

Project Title: Balsa Wood Bridge
Principal Investigator: Joshua Nye

Task ID	Description	Duration (Hrs) Estimated	Actual	% Completed	September / October / November / December / January / February / March / April / May / June
1	Proposal				
1a	Introduction/Outline	3	3	100	X X Started on time, ended on time.
1b	Analysis 1	5	4	100	X Started on time, ended on time.
1c	Analysis 2	5	3	100	X Started on time, ended on time.
1d	Analysis (a-e)	5	3	100	X Started on time, ended on time.
1e	Analysis 3	4	3	100	X Started on time, ended late.
1f	Analysis 4	4	2	100	X Started on time, ended late.
1g	Schedule	2	2	100	X Started on time, ended late.
1h	Analysis 5	4	2	100	X Started on time, ended on time.
1i	Analysis 6	4	3	100	X Started late, ended late.
1j	Parts List	2	2	100	X Started on time, ended on time.
1k	Budget	2	2	100	X Started on time, ended on time.
1l	Analysis 7	3	3	100	X Started on time, ended on time.
1m	Analysis 8	3	3	100	X Started on time, ended on time.
1n	Testing	2	2	100	X Started on time, ended on time.
1o	Analysis 9	3	4	100	X Started on time, ended on time.
1p	Analysis 10	3	3	100	X Started on time, ended on time.
1q	Methods	2	2	100	X Started on time, ended on time.
1r	Analysis 11	3	2	100	X Started on time, ended on time.
1s	Analysis 12	3	2	100	X Started late, ended late.
1t	Construction	2	3	100	X Started on time, ended on time.
1u	Discussion	2	3	100	X Started on time, ended on time.
1v	Proposal Assembly (Winter)	1	1	100	X Started on time, ended on time.
	totals	67	57		
2	Website Components				
2a	Project Website Creation	1	1	100	X Started on time, ended on time.
2b	Project Website: Introduction	2	1	100	X Started on time, ended on time.
2c	Project Website: Analysis Summary	2	1	100	X Started on time, ended on time.
2d	Project Website: Schedule	1	1	100	X Started on time, ended on time.
2e	Project Website: Budget	1	1	100	X Started on time, ended on time.
2f	Project Website: Testing	1	1	100	X Started on time, ended on time.
	totals	8	6		
3	Drawings				
3a	Drawing 1	1	1	100	X Started on time, ended late.
3b	Drawing 2	1	1	100	X Started on time, ended on time.
3c	Drawing 3	1	1	100	X Started on time, ended on time.
3d	Drawing 4	1	1	100	X Started on time, ended on time.
3e	Drawing 5	1	1	100	X Started on time, ended on time.
3f	Assembly	3	3	100	X Started on time, ended on time.
	totals	8	8		
4	Construction & Part Arrivals				
4a	Arrival: 50-002	N/A	N/A	100	X Arrived.
4b	Arrival: 20-010	N/A	N/A	100	X Arrived.
4c	Arrival: 20-015	N/A	N/A	100	X Arrived.
4d	Arrival: 50-001	N/A	N/A	100	X Arrived.
4e	Arrival: 50-002	N/A	N/A	100	X Arrived.
4f	Const: 20-001	1	0.5	100	X Started, and Completed.
4g	Const: 20-004	1	0.5	100	X Started, and Completed.
4h	MDR	1	1	100	X Started on time, ended on time.
4i	Const: 20-017	0.5	0.1	100	X Started, and Completed.
4j	Const: 20-018	0.5	0.1	100	X Started, and Completed.
4k	Mfg01	0.1	0.1	100	X Assignment Complete.
4l	Const: 20-005	0.5	0.5	100	X Started, and Completed
4m	Const: 20-021	0.1	0.1	100	X Started, and Completed
4n	Arrival: 50-006	N/A	N/A	100	X Arrived.
4o	Const: 20-013	0.5	0.2	100	X Started, and Completed.
4p	Const: 20-022	0.1	0.1	100	X Started, and Completed.
4q	Const: 20-002	0.5	0.5	100	X X Started, and Completed.
4r	Const: 20-019	0.5	0.5	100	X X Started, and Completed.
4s	Mfg02	0.5	0.2	100	X Assignment Complete.
4t	Const: 20-020	0.2	0.2	100	X Started, and Completed.
4u	Const: 20-007	0.5	0.5	100	X X Started, and Completed.
4v	Mfg03	0.2	0.2	100	X Assignment Complete.
4w	Const: 20-012	0.2	0.2	100	X X Started, and Completed.
4x	Const. 20-023	0.2	0.2	100	X X Started, and Completed.
4y	Const: 20-011	0.5	0.5	100	X Started, and Completed.
4z	Const: 20-016	0.3	0.2	100	X X Started, and Completed.
4za	Working Device	2	2.5	100	X Started, and Completed.
4zb	Const: 20-024	0.1	0.3	100	X Started, and Completed.
4zc	Const: 20-025	0.1	0.1	100	X Started, and Completed.
4zd	Const: 20-026	0.1	0.1	100	X Started, and Completed.
4ze	Const: 20-027	0.5	0.1	100	X Started, and Completed.
	totals	11.7	9.5	100	
5	Testing & Evaluation				
5a	Abstract Draft	0.5	1	100	X Started on time, ended on time.
5b	Abstract Revised	0.5	0.5	100	X Started on time, ended on time.
5c	Test Procedure	1	2	100	X Started on time, ended on time.
5d	Bridge Testing: Weight	0.5	0.5	100	X Started, and Completed
5e	Bridge Testing: Vehicle Travel	1	1	100	X X Started, and Completed.
5f	TDR01 Video	0.5	0.5	100	X Started on time, ended on time.
5g	TDR01 Comments	1	2	100	X Started on time, ended on time.
5h	Bridge Testing: Vertical Articulation	0.5	0.5	100	X Started, and Completed.
5i	Bridge Testing: Bridge Raising	0.5	0.5	100	X Started, and Completed.
5j	Project Poster Draft	2	1.25	100	X Started on time, ended on time.
5k	TDR02	0.5	0.5	100	X Started on time, ended on time.
5l	TDR02 Comments	3	2	100	X Started on time, ended on time.
5m	Poster Revision Submission	0.5	1	100	X Started on time, ended on time.
5n	Poster SOURCE Submission	1	1.5	100	X Started on time, ended on time.
5o	Bridge Testing: Load	1	1	100	X Started, and Completed.
5p	Test Report	2	4.75	100	X X X X X Started on time, ended late.
5q	FE Response	0.5	0.5	100	X Started on time, ended on time.
5r	SOURCE Assignment	0.1	0.1	100	X Started on time, ended on time.
5s	Presentation Video	2	4	100	X Started on time, ended on time.
5t	Presentation Comments	3	4	100	X Started on time, ended on time.
5u	Engineering Report - Final Draft	3	4		X Started, and Completed.
	totals	24.6	33.1		

APPENDIX F – Expertise and Resources

Appendix F1 – Decision Matrix

Criterion Item	Weight 1 to 3	Best Possible 3	Design #1	Score x Weight	Design #2	Score x Weight	Design #3	Score x Weight	Design #4 (Current)	Score x Weight	
Weight	1	3	2	2	2	2	3	3	3	3	
Non-Complex	3	9	3	9	1	3	2	6	3	9	
Length	2	6	2	4	2	4	2	4	3	6	
Articulation	3	9	1	3	1	3	2	6	2	6	
Design to Standards	1	3	1	1	1	1	1	1	3	3	
Load will distribute across Truss Beams?	2	6	1	2	2	4	1	2	3	6	
Total	12	36		21		17		22		33	
Normalize the Data		2.777777778		58.33333333		47.22222222		61.11111111		91.66666667	Percent
										64.58333333	Average
										19.02659499	Std. Dev.

Weighting/Scoring Scale	
1	Worst
2	Median, Unsure
3	Best

Good Bias: Std. Dev. is 2 or more digits
Poor Bias: Std. Dev. is 1 or less digits

Criterion	
Weight	Lighter Weight (< 85 g) will meet requirements
Non-Complex	A simple and straightforward design will get the job done, overcomplicating it puts unneeded stress on both bridge and designer
Length	The bridge has to be able to span at least 400 mm in the opening, and be able to rest on top of the abutments.
Articulation	Is the articulation system feasible? Will it be able to lift the road deck? Raise the bridge enough to slide a sheet between the abutment and bridge?
Design to Standards	How conforming the design is to the requirements and dimensions of the bridge's criteria.
Load will Distribute Across Truss Beams?	The truss beams being able to distribute the load will allow it to hold itself together without bending and breaking.

Comments

Design #1 was scored as poorly as it was because it was mainly designed to be fairly simple to produce, and considering not much else. The articulation system wouldn't be conforming to the requirements, since it requires the bridge to be put into different pieces which would be bad for load distribution. The truss system was fairly basic.

Design #2 was also scored poorly because it added another complexity to the articulation system, totalling to 4 pulley mechanisms that would be needed to create the entire system. The bridge design is still two different pieces, and the truss system was still fairly basic, but only slightly better than Design #1 in that regard. It doesn't conform to design standards

Design #3 was scored the way it was because it seemed better in terms of overall weight, and was fairly simple, and the articulation system seemed fairly doable, but still requiring 4 pulley mechanism sets to work. However, unlike the previous two designs the bridge lacks a truss system to make way for the road deck articulation system, and it would not be able to raise the bridge itself. This design doesn't conform to design standards.

The current design, Design #4 was the better choice out of the rest as well as the one being analyzed. The weight of the bridge (without the articulation system) conforms to standards and still allows room to add more should there be any changes. The entire truss bridge isn't really complex at all, and so it's fairly doable. The length of the bridge allows it to rest comfortably on the abutments and maintaining the opening span. The articulation system is a separate attachable component that would rest on top of the bridge to raise the road deck, and also can be moved to one of the ends of the bridge to raise the bridge. This design comforms to the standards to most, and the truss beams will be able to distribute the load thanks to the combination of vertical and diagonal supports.

APPENDIX G – Testing Report

Appendix G1.1 - Introduction: Weight Testing

This test will cover the requirement for the bridge being designed to weigh less than 85 grams without the articulation system attached to it. The parameter of interest for this requirement would be simply be the bridge's weight. The predicted performance of the bridge design is that it will weigh less than 85 grams excluding the articulation system. The data for this will be collected using a digital scale, and it will be recorded in a data sheet as a value for weight in grams.

Method

The resources that would be used for testing the balsa wood bridge would include some assistants to help with minor aspects of the testing such as video recording and a helping hand with something like a ruler or tape measure. The hard resources for this test would be a digital scale for measuring weight. The soft resources that will be used for testing are Microsoft Word for creating the data sheet, and photographs of the testing process will be made using a tablet.

For using the digital scale to test the weight of the bridge, it will be measured in grams with the precision being within ± 0.01 grams, and to ensure accuracy the scale will be zeroed prior to testing. The operational limits for the bridge during weight testing are that the bridge must be roughly centered on the digital scale to obtain an accurate weight measure.

The recording of the data was done on the data sheet with a pencil, additional thoughts and observations were typed onto the results of both the testing report, and the testing & discussion sections of the engineering report.

The data will be presented as paragraphs, as much of the requirements don't provide much to justify things such as charts or spreadsheets. Mostly it revolves around the performance of the bridge on specific variables.

Test Procedure

The following procedure will document the process of testing the balsa wood bridge for its weight. The data here will be a numerical value for the weight of the bridge and a checkoff whether or not the bridge weighed less than 85 grams.

Testing of the bridge's weight was conducted on April 5th, 2021 in the time between 9:30 AM and 9:35 AM. Setting up the bridge for weight testing was done quickly, as about a minute was put to prepare the digital scale, and another minute to place the bridge onto the scale as well as to record the data in the data sheet.

Equipment needed for testing:

- Balsa Wood Bridge
- Tablet for photographs and video recording
- Data Sheet
- Writing Utensil
- Digital Scale

The amount of risk during testing the bridge's weight was minimal, the biggest consideration is to not break the bridge at any point during testing. Recording devices for videos and/or photographs must be charged prior to testing. Safety glasses aren't needed for this kind of test.

The test procedures for weight testing are as follows:

1) Setup Equipment, See Figure 1:
    a. Bridge
    b. Tablet or smartphone
    c. Data sheet and writing utensil
    d. Digital Scale

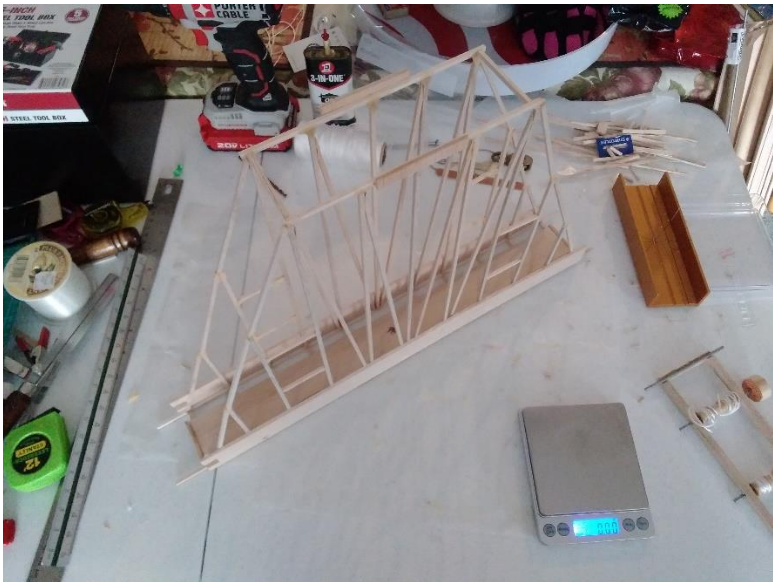


Figure 1: Weight Testing Setup

2) Turn on the digital scale, zero it, and ensure it is set to grams.
3) Once the digital scale is ready, place and center the bridge on the scale.
4) Record the value given on the scale into the data sheet, see Figure 2.

Figure 2: Digital Scale Weight Reading

Deliverables

The predicted result for the weight testing of the bridge was that it would weigh less than 85 grams. The result of this test has the bridge weighing at 47.81 grams. Because of this result, the test can be considered a success since it meets the requirements. There was no calculation needed for this test since the digital scale was able to read the weight in grams. It also meets the success criteria as well for it being under 85 grams. However, the weight of the bridge does bring into thought of what else could have been done for the bridge since there is a large gap between the required weight and the actual weight. Perhaps the bridge could have had additional structural reinforcements, or maybe even thicker balsa wood segments could have been used.

Appendix G1.2 - Introduction: Vehicle Traversal

This test will cover the requirement for a vehicle to be able to traverse across the road deck of the bridge. In this test, the parameter of interest would be the performance of the vehicle during its traversal. The predicted performance of the bridge during vehicle traversal testing is that the vehicle can traverse the road deck without any issues. The data for these tests is determined by the performance of the vehicle as it traverses across the road deck, and it will be recorded in a data sheet comprised of checkoffs.

Methods

The resources that would be used for testing the balsa wood bridge would include some assistants to help with minor aspects of the testing such as video recording and a helping hand with something like a ruler or tape measure. The hard resources for test would be a ruler for measuring the opening span of the bridge prior to testing, and a block to represent a vehicle. The soft resources that will be used for testing are Microsoft Word for creating the data sheet, and videos and photographs of the testing process will be made using a tablet.

There isn't any required numerical measurement for testing the vehicle, so the only thing that would be recorded is a checkoff of its performance and any issues that occurred. The operational limits during vehicle traversal testing are that it the bridge when placed on the abutments must have an opening span of 400 mm for this test. Another limit is that the vehicle must start on one end of the bridge and stop at the other end of the bridge.

The recording of the data was done on the data sheet with a pencil, additional thoughts and observations were typed onto the results of both the testing report, and the testing & discussion sections of the engineering report.

The data will be presented as paragraphs, as much of the requirements don't provide much to justify things such as charts or spreadsheets. Mostly it revolves around the performance of the bridge on specific variables.

Test Procedure

The following procedure will document the process of testing the balsa wood bridge for vehicle traversal. Much of the data is comprised of check offs for dimensional testing, vehicle testing, and some articulation testing, and raw numerical data for loads and articulation height.

Testing for the vehicle traversal was done on April 13th, 2021 between the times 10:45 PM and 11:00 PM at the principal engineer's home in Marysville, WA. Setting up the bridge took about 10 minutes prior to testing, which included placing the tables in the center of the living room, placing the abutments on the tables, placing the bridge and measuring its opening span, and then readying the vehicle. The test was recorded on a tablet, and the test was conducted in the span of a few minutes. Afterwards, the rest of the time was spent discussing the performance of the test for the video, and then tear down of the testing area.

Equipment needed for testing:

- Balsa Wood Bridge
- Tablet for photographs and video recording
- 2 Abutments
- Ruler/Tape Measure (for opening span measurements)
- Block (Vehicle)
- Two Tables
- Data Sheet
- Writing Utensil

The amount of risk during testing the bridge’s weight was minimal, the biggest consideration is to not break the bridge at any point during testing. Another slight concern was that the friction between the block and the road deck might cause disruption during testing. Recording devices for videos and/or photographs must be charged prior to testing. Safety glasses aren’t needed for this kind of test. Keep the bridge in a safe location to prevent any damage prior to testing. Having additional personnel for testing is optional, can act as observers or assistants in a limited capacity (i.e. taking the photographs and recordings, holding an end of a tape measure, sliding a sheet of paper, etc.)

Test Procedure for Vehicle Testing

1) Setup Equipment, See Figure 3:
    a. Abutments
    b. Bridge
    c. Tablet or smartphone
    d. Data sheet and writing utensil
    e. Vehicle

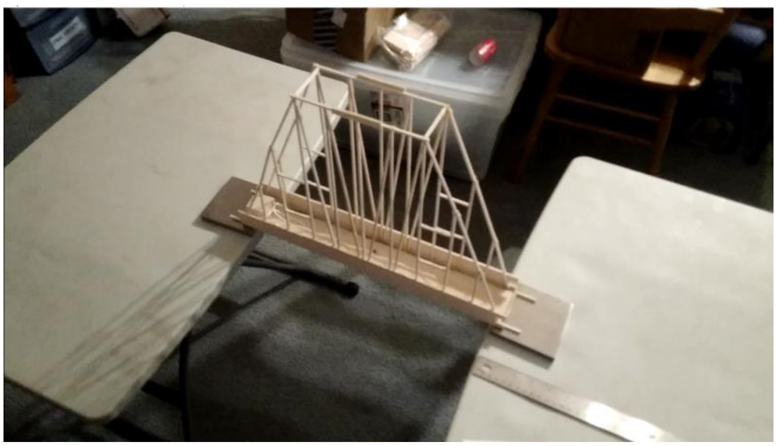


Figure 3: Vehicle Traversal Setup

2) Place and position the bridge on the abutments.
3) Adjust the bridge and abutments as needed, the bridge must span an opening of at least 400 mm across.
4) For this test, the vehicle is a balsa wood block pulled by a string. Place the vehicle on one side of the bridge. See Figure 4.

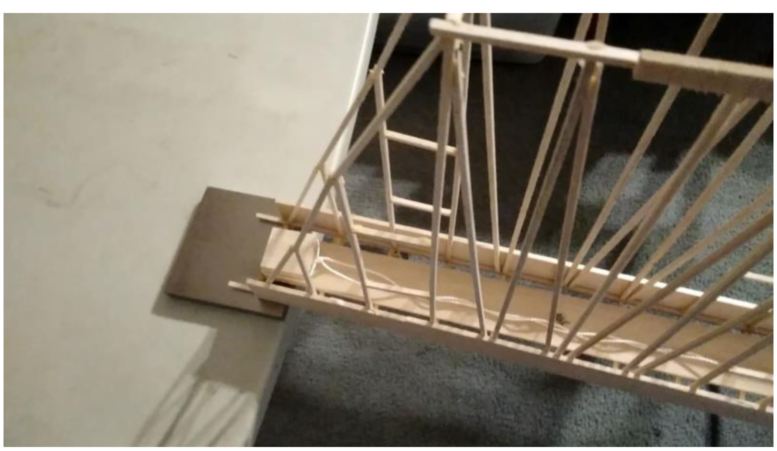


Figure 4: Vehicle Placement

5) When ready, pull on the string to drag the vehicle across the road deck.
6) If it gets to the other side of the road deck without trouble (either for the bridge or vehicle), then the test would be considered a success. Check off the requirement on the data sheet.

Deliverables

For this test, the predicted result for the vehicle traversal of the bridge was that it would be able to get across the road deck without issue. The result of the testing was that the vehicle had a slight issue when traversing the bridge since it hit the center hole of the road deck, causing it to flip. Despite that setback, it was able to traverse the bridge. The test can be considered mostly a success considering this issue and in relation to the requirements. There were no calculations needed for this test, as its solely the observation of the performance of this test. But this also means that it didn't meet the success criteria of crossing the bridge without an issue. The hole on the center of the road deck was fairly larger than normal considering that it was made with a slightly larger imperial drill bit, as well as not being smoothed out.

Appendix G1.3 - Introduction: Vertical Raising

This test will cover the requirement of at least 50% of the road deck being raised at least 280 mm from its original position, which will be done with the articulation system on the top of the bridge. In this test, the parameter of interest for it would be height of the road deck from its original position. The predicted performance of the vertical raising of the road deck is that the articulation system would be able to raise the road deck to 280 mm from its resting position. The data for these tests is determined by the measured height the road deck is relative to its former position, and it will be recorded in a data sheet.

Method

The resources that would be used for testing the balsa wood bridge would include some assistants to help with minor aspects of the testing such as video recording and a helping hand with something like a ruler or tape measure. The hard resources for test would be a ruler measure for measuring the height and the bridge's opening span prior to testing. The soft resources that will be used for testing are Microsoft Word for creating the data sheet, and videos and photographs of the testing process will be made using a tablet.

For measuring devices like a ruler or tape measure, it will be measured in millimeters and have a precision of ± 1 mm. The accuracy will depend on the initial placement of the ruler or tape measure relative to the road deck.

The height of the road will be recorded with a metric ruler, a reference point will be made using a cut piece of a sticky note in which the topmost end of it will be at 280 mm. The operational limits for the vertical raising of the road deck are that it must not slide off the loops of the string during testing, so the articulation system must raise the road deck in sync.

The recording of the data was done on the data sheet with a pencil, additional thoughts and observations were typed onto the results of both the testing report, and the testing & discussion sections of the engineering report.

The data will be presented as paragraphs, as much of the requirements don't provide much to justify things such as charts or spreadsheets. Mostly it revolves around the performance of the bridge on specific variables.

Test Procedure

The following procedure will document the process of testing the balsa wood bridge for its vertical articulation of the road deck by raising it to 280 mm or more. Much of the data is comprised of check offs such as for dimensional and vehicle testing, and raw numerical data for load testing and vertical articulation testing.

Testing for vertical articulation was done on April 22nd, 2021 between the times 9:16 PM and 9:30 PM at the principal engineer's home in Marysville, WA. Setting up the bridge took about 10 minutes prior to testing, which included placing the tables in the center of the living room, placing the abutments on the tables, placing the bridge and measuring its opening span, and then setting up the articulation system around the road deck. The test was recorded on a tablet, and the test was conducted for several minutes. Afterwards, the rest of the time was spent discussing the articulation system's performance for the video and deconstructing the testing area.

Equipment needed for testing:

- Balsa Wood Bridge and Articulation System
- Tablet for photographs and video recording
- 2 Abutments

- Ruler/Tape Measure
- Two Tables
- Data Sheet
- Writing Utensil

The risks in relation to testing are that a clear and open space must be made for testing to prevent any obstructions, and extra care must be made during testing to ensure the bridge does not break. Recording devices for videos and photographs must be charged prior to testing. Keep the bridge in a safe location to prevent any damage prior to testing. Having additional personnel for testing is optional, can act as observers or assistants in a limited capacity (i.e. taking the photographs and recordings, holding an end of a tape measure, sliding a sheet of paper, etc.)

The test procedure for testing the articulation system is as follows:

1) Setup Equipment
    a. Abutments
    b. Bridge and articulation system
    c. Tablet or smartphone
    d. Data sheet and writing utensil
2) Place and position the bridge on the abutments.
3) Adjust the bridge and abutments as needed, the bridge must span an opening of at least 400 mm across.
4) Place the articulation system on top of the bridge and loop the string around the road deck. See Figure 5.

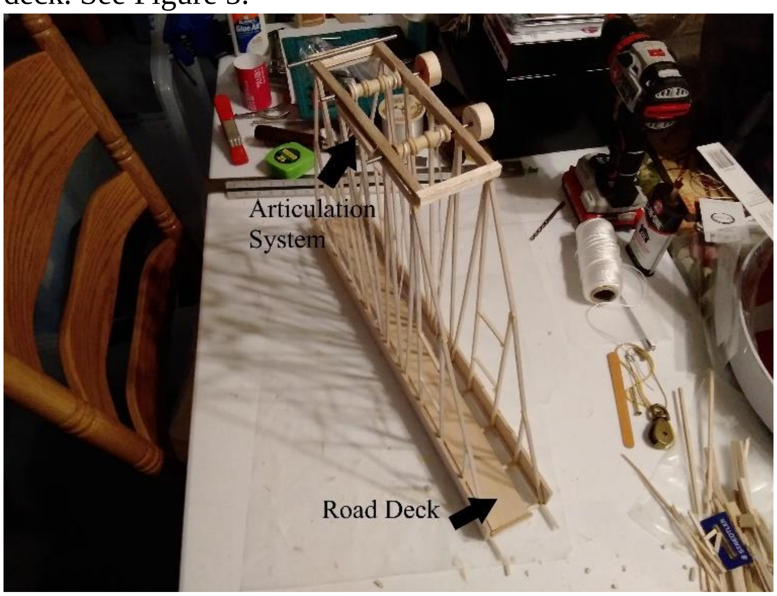


Figure 5: Vertical Articulation Setup

5) Using both dowels on the articulation system, raise the bridge to about 280 mm above from the original position, synching the rotation of the dowels.
6) Using a tape measure or a ruler, check to see if the road deck meets about 280 mm. Record the measurement into the data sheet.
7) Lower the road deck back down to its original position.

Deliverables

In this test, the predicted result for the vertical raising of the road deck was that it can be raised to at least 280 mm from its original position. The result that came about from this test was that the road deck was able to be mostly raised above 280 mm, as while the road deck was being raised it was also slowly rolling to its side. This was an issue since the string was coiling outside of the spool. Despite this issue, the test was a success in that it was able to raise above 280 mm. It also meets the success criteria since over 50% of the road deck was able to be raised 280 mm or more. The issue could be resolved with improvements such as larger spools to keep the string coiled, and perhaps a better lifting component to raise the road deck.

Appendix G1.4 - Introduction: Bridge Raising

This test will cover the requirement of the bridge being raised in that the addition of 10 grams to the lifting component will allow a sheet of paper to slide between the abutment and the raised bridge. Additional data would include the time the bridge took to raise up and if the bridge was able to stay raised for at least 10 seconds. The parameters of interest for raising the bridge will be the ability of the sheet to slide between the abutment and the bridge, the performance of the bridge during raising and staying raised for at least 10 seconds. The predicted performance of the bridge for the bridge raising test is that it will be able to keep the bridge raised for 10 seconds, which will allow a sheet of paper to slide between the abutment and the raised bridge. The data for this will be collected using a digital scale, rulers, tape measures, etc. and it will be recorded in a data sheet as a checkoff for how long the bridge was raised and if a sheet of paper was able to slide through. Additional data that can be considered optional is the time it took to raise the bridge.

Method

The resources that would be used for testing the balsa wood bridge would include some assistants to help with minor aspects of the testing such as video recording and a helping hand with something like a ruler or tape measure. The hard resources for test would be a ruler to measure the opening span of the bridge prior to testing. The soft resources that will be used for testing are Microsoft Word for creating the data sheet, and videos and photographs of the testing process will be made using a tablet.

While much of this test is regarding the performance of the bridge during raising, the time it took to raise the bridge is to also be accounted for. The precision for using a stopwatch from a phone is will be within ± 0.01 seconds, accuracy might vary due to human error when the bridge starts to immediately raise.

The operational limits of the bridge during bridge raising are that the articulation system must be operated by the principal engineer throughout the entire testing to keep the bridge raised via the pivot. The bridge also must be placed on the abutments with an opening span of 400 mm for this test.

The recording of the data was done on the data sheet with a pencil, additional thoughts and observations were typed onto the results of both the testing report, and the testing & discussion sections of the engineering report.

The data will be presented as paragraphs, as much of the requirements don’t provide much to justify things such as charts or spreadsheets. Mostly it revolves around the performance of the bridge on specific variables.

Test Procedure

The following procedure will document the process of the bridge during its bridge raising testing. Much of the data will be comprised of checking off requirements and then recording the time it took to raise the bridge, which the latter is optional.

Bridge raising testing was conducted on April 25th, 2021 between the times 9:30 PM and 9:45 PM at the principal engineer’s home in Marysville, WA. Setting up the bridge for testing took about 10 minutes to do, which included setting up the tables and abutments, placing the bridge on the abutments and measuring the opening span, and setting up the articulation system to raise the bridge with a 10 gram weight. The test was recorded on a tablet, and the test was conducted for several minutes. Afterwards, the rest of the time was spent discussing the articulation system’s performance for the video and deconstructing the testing area.

Equipment needed for testing:

- Balsa Wood Bridge and Articulation System
- Tablet for photographs and video recording
- 2 Abutments
- Ruler/Tape Measure
- 2 Table
- Data Sheet
- Writing Utensil
- 10-gram Weight (for raising component)
- A sheet of Paper
- Phone (for stopwatch)

The risks in relation to testing are that a clear and open space must be made for testing to prevent any obstructions, and extra care must be made during testing to ensure the bridge does not break. Recording devices for videos and photographs must be charged prior to testing. Keep the bridge in a safe location to prevent any damage prior to testing. Having additional personnel for testing is optional, can act as observers or assistants in a limited capacity (i.e. taking the photographs and recordings, holding an end of a tape measure, sliding a sheet of paper, etc.)

Test Procedures for Bridge Raising

1) Setup Equipment
    a. Abutments
    b. Bridge and articulation system
    c. Tablet or smartphone
    d. Data sheet and writing utensil.
2) Place and position the bridge on the abutments.
3) Adjust the bridge and abutments as needed, the bridge must span an opening of at least 400 mm across.
4) Place the articulation system onto the end of the bridge with the fillets. Ensure the attached pivot fits into the fillets. Add 10 g to the articulation system. See Figure 6.

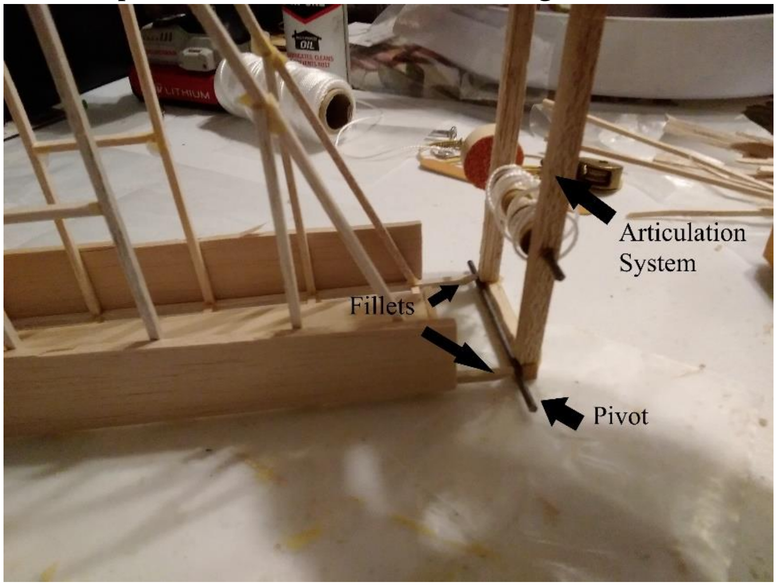
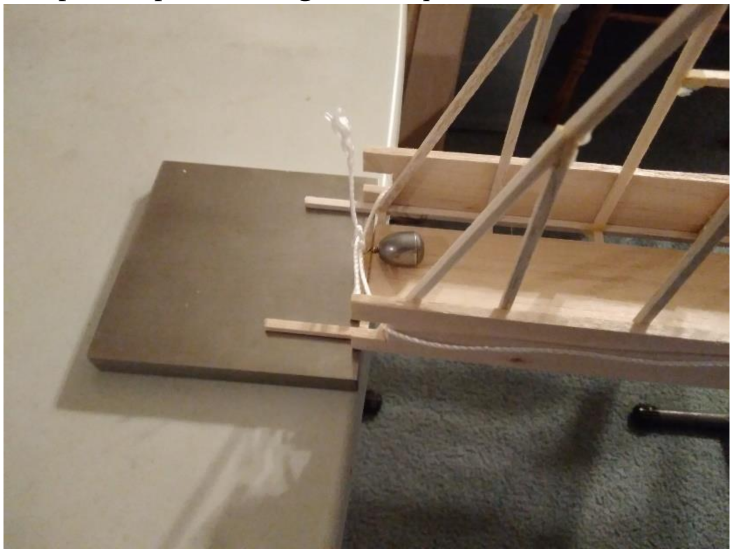


Figure 6: Bridge Articulation System Setup

5) Wrap the topmost string to the square holes at the other end of the bridge See Figure 7.



6) Firmly holding the articulation system, slowly rotate the dowel to coil the string which should raise the opposite end of the bridge. Raise it so that about half of the road deck is 280 mm above its original position.
7) Keep the bridge raised for about 10 seconds, slide a sheet of paper between the abutment and the raised end (may require an assistant). Check off the requirement on the data sheet.
8) Slowly lower the bridge with the articulation system until its resting on the abutment again.

Deliverables

In this test, the predicted result was that the bridge can remained raised for about 10 seconds, and that a sheet of paper can slide between the abutment and the road deck. The result of this test was that the bridge can remained raised for more than 10 seconds, and that the sheet of paper was able to slide between the abutments and the raised bridge. In addition, the time that it took to raise the bridge was about 14.53 seconds. The testing of the bridge for this requirement can be considered a success. The performance during this testing also meets the success criteria with the addition of 10 grams to the lifting component, and the sheet of paper sliding between. Still, it does bring into thought that even with the performance that occurred during the test, that the articulation system used is unpractical, and that a better design could have been made such as a pair of towers to raise it similar to that of other bridges in actuality.

Appendix G1.5 – Introduction: Load Testing

This test will cover the requirement that the bridge must be able to handle a load of at least 20 kg. The parameters of interest for raising the bridge will be its ability to handle a heavy load. The predicted performance of the bridge for the loading test is that it will not be able to take a 20 kg load, let alone reach it. The data for this will be collected using a digital scale, a weight scale, rulers, tape measures, etc. and it will be recorded in a data sheet with the values of the load it was able to take and necessary conversion factors.

Method

The resources that would be used for testing the balsa wood bridge would include some assistants to help with minor aspects of the testing such as video recording and a helping hand with something like a ruler or tape measure. The hard resources for test would be a ruler to measure the opening span of the bridge prior to testing, and scales to measure the load of the bucket. The soft resources that will be used for testing are Microsoft Word for creating the data sheet, and videos and photographs of the testing process will be made using a tablet.

The measuring devices that would be used in this test are a digital scale and a weight scale. The digital scale will have a precision of ± 0.01 lbf while the weight scale will have a precision of ± 1 lbf. Conversions would be needed to acquire the value in kg.

The operational limits of the bridge load testing are that the bucket must be suspended in the air throughout the test so that the full load is applied in the center of the bridge. The bridge also must be placed on the abutments with an opening span of 400 mm for this test.

The recording of the data was done on the data sheet with a pencil, additional thoughts and observations were typed onto the results of both the testing report, and the testing & discussion sections of the engineering report.

The data will be presented as paragraphs, as much of the requirements don't provide much to justify things such as charts or spreadsheets. Mostly it revolves around the performance of the bridge on specific variables.

Test Procedure

The following procedure will document the process of the bridge during load testing. The data will be comprised of recorded values and calculations.

Load testing for the bridge was conducted on April 29th, 2021 between the times 6:30 PM and 7:00 PM at the principal engineer's home in Marysville, WA. Setting up the bridge for testing took about 30 minutes to do, which included setting up the tables, placing cinder blocks to raise the position of the bridge, placing the bridge on the abutments and measuring the opening span, setting up and attaching the bucket to the bridge, and getting the digital scales. The test was recorded on a tablet, and the test was conducted for several minutes. Afterwards, the rest of the time was spent discussing the articulation system's performance for the video and deconstructing the testing area.

Equipment needed for testing:

- Balsa Wood Bridge
- Tablet for photographs and video recording
- 2 Abutments
- Ruler/Tape Measure
- 2 Tables
- Data Sheet
- Writing Utensil

- 4 Cinder Blocks
- Digital Scale
- Weight Scale
- Bucket for Loading
- Bucket for Storing Water
- Bungee Cord
- Threaded Rod
- Washer
- Weld Nut
- Coupling Nut
- Loop
- Measuring Cups (To insert water to the bucket for loading)

The risks in relation to testing are that a clear and open space must be made for testing to prevent any obstructions, and extra care must be made during testing to ensure the bridge does not break prior to testing. Eye protection must be worn by the individual directly loading the bridge, in the case that fragments of the bridge would fly off when it breaks. Recording devices for videos and photographs must be charged prior to testing. Having additional personnel for testing is optional, can act as observers or assistants in a limited capacity (i.e. taking the photographs and recordings, holding an end of a tape measure, sliding a sheet of paper, etc.), they must keep their distance to minimize any potential injuries during load testing.

Test Procedures for Load Testing:

1) Setup Equipment
    a. Abutments
    b. Cinder Blocks
    c. Bridge and loading bucket.
    d. Tablet or smartphone
    e. Data sheet and writing utensil
2) Place and position the bridge on the abutments on top of the cinder blocks.
3) Adjust the bridge and abutments as needed, the bridge must span an opening of at least 400 mm across.
4) Measure the loading bucket for its weight.
5) Insert the threaded rod through the welding nut. Place the washer on top of the center hole of the road deck and insert the rod through it. Afterwards, attach a coupling nut and insert the loop on the other end of the coupling nut.

6) Insert the bungee cord through the loop and secure it onto the bucket. Make sure the loading bucket is suspended in the air. See Figure 8.

Figure 8: Load Testing Setup

7) Fill another bucket with water, this will be used to store water to insert to the loading bucket. See Figure 9.

Figure 9: Bucket for Storing Water, insert water to other bucket with measuring cups.

8) Using measuring cups, gradually insert water to the loading bucket.
9) Once the bridge reaches the required load, or if the bridge breaks before reaching the required load, measure the loading bucket with water.
10) Apply conversion factors for the measurements to get the value in kg.

Deliverables

In this test, the predicted result was that the bridge would not be able to take a load of 20 kg, or even reach that value. The result of this test was that the bridge collapsed when the water-filled bucket was 6.71 kg. The testing of the bridge for its requirement can be considered a failure. The performance of the bridge doesn't meet the success criteria either, despite at least meeting what was predicted. It does bring into mind that the bridge likely needed a lot more support on the bottom frame since that was where it collapsed. Perhaps a better design that was slightly larger with added reinforcements could have improved its performance in this test.

Appendix G2 – Blank Data Sheet

<u>Balsa Wood Bridge Project Data Sheet</u>

By Joshua Nye

Date of Test: __________

1. Was the vehicle able to cross the road deck of the bridge without issues, yes or no?

    a. How much time did the vehicle take to cross?

Date of Test: __________

2. What was the height that the road deck was raised vertically though the articulation system?

    a. Did it raise to 280 mm or more?

Date of Test: __________

3. Is the bridge able to rest on the abutments, yes or no?

Date of Test: __________

4. Can the articulation system keep the bridge raised for about 10 seconds?

    a. Can a sheet of paper slide through between the abutment and the raised bridge?

Date of Test: __________

5. What was the load that the bridge was able to carry?

    a. Did it reach the minimum load of 18.9 kg? Did it reach 20 kg?

Date of Test: __________

6. What was the weight of the bridge on the digital scale?

    a. Is the weight of the bridge below 85 grams?

Appendix G3 – Raw Data Sheets

Balsa Wood Bridge Project Data Sheet

By Joshua Nye

Date of Test: 4/13/21 10:45 PM

1. Was the vehicle able to cross the road deck of the bridge without issues, yes or no?

   Yes

   a. How much time did the vehicle take to cross?

      N/A, Optional

Date of Test: 4/22/21 9:16 PM

2. What was the height that the road deck was raised vertically though the articulation system?

   299 mm

   a. Did it raise to 280 mm or more?

      Yes, but it didn't raise correctly. Went on the side.

Date of Test: 4/13/21 10:45

3. Is the bridge able to rest on the abutments, yes or no?

   Yes

Date of Test: 4/25/21 9:30 PM 11.30 g

4. Can the articulation system keep the bridge raised for about 10 seconds?

Yes 14.53 g

a. Can a sheet of paper slide through between the abutment and the raised bridge?

Yes

Date of Test: 4/29/21 6:30 PM Bucket w/stuff

5. What was the load that the bridge was able to carry? 0.81 lbf

$$\left(0.81\ \text{lbf} + 14\ \text{lbf} \cdot \frac{4.448\ \text{N}}{1\ \text{lbf}}\right) \div 9.81\ \text{m/s}^2 = 6.71\ \text{kg}$$

a. Did it reach the minimum load of 18.9 kg? Did it reach 20 kg?

No

Date of Test: 4/5/21 8:30 AM

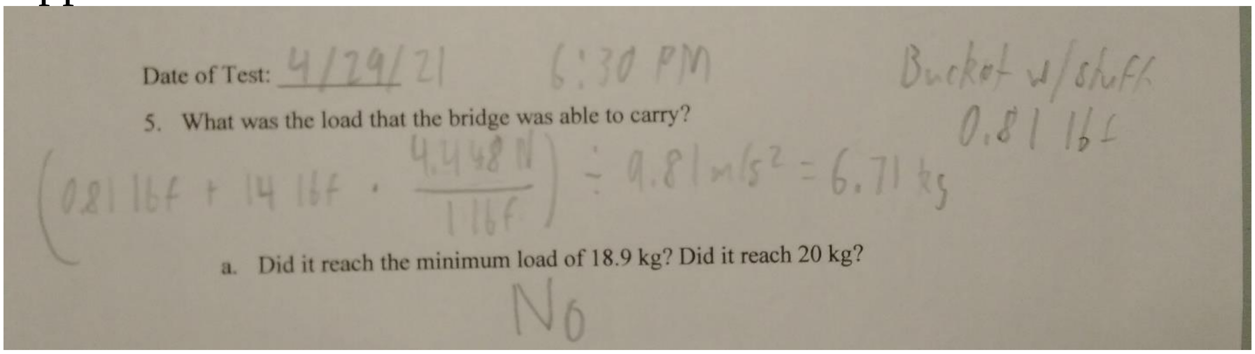
6. What was the weight of the bridge on the digital scale?

47.81 grams

a. Is the weight of the bridge below 85 grams?

Yes

Appendix G4 – Evaluations



Date of Test: 4/29/21 6:30 PM

Bucket w/stuff 0.81 lbf

5. What was the load that the bridge was able to carry?

$$\left(0.81\ lbf + 14\ lbf \cdot \frac{4.448\ N}{1\ lbf}\right) \div 9.81\ m/s^2 = 6.71\ kg$$

a. Did it reach the minimum load of 18.9 kg? Did it reach 20 kg?

No

Note: The calculations were done on the data sheet, the initial weight of the bucket with the connecting components is 0.81 lbf, and the weight of the water was 14 lbf (these values were separated to denote their differences from the combined value). The conversion factor was provided by the textbook *Machine Elements in Mechanical Design.*

Reference:

Mott, Robert M, et al. *Machine Elements in Mechanical Design.* Pearson, 2018.

Appendix G5 – Testing Schedule

Project Title: Balsa Wood Bridge
Principal Investigator: Joshua Nye

Task ID	Description	Duration (Hrs)												
		Estimate	Actual	% Completed	September	October	November	December	January	February	March	April	May	June
1	Proposal													
1a	Introduction/Outline	3	3	100	X X Started on time, ended on time.									
1b	Analysis 1	5	4	100	X Started on time, ended on time.									
1c	Analysis 2	5	3	100	X Started on time, ended on time.									
1d	Analysis (a-e)	5	3	100	X Started on time, ended on time.									
1e	Analysis 3	4	3	100		X Started on time, ended late.								
1f	Analysis 4	4	2	100		X Started on time, ended late.								
1g	Schedule	2	2	100		X Started on time, ended late.								
1h	Analysis 5	4	2	100		X Started on time, ended on time.								
1i	Analysis 6	4	3	100		X Started late, ended late.								
1j	Parts List	2	2	100		X Started on time, ended on time.								
1k	Budget	2	2	100		X Started on time, ended on time.								
1l	Analysis 7	3	3	100		X Started on time, ended on time.								
1m	Analysis 8	3	3	100		X Started on time, ended on time.								
1n	Testing	2	2	100		X Started on time, ended on time.								
1o	Analysis 9	3	4	100		X Started on time, ended on time.								
1p	Analysis 10	3	3	100		X Started on time, ended on time.								
1q	Methods	2	2	100		X Started on time, ended on time.								
1r	Analysis 11	3	2	100			X Started on time, ended on time.							
1s	Analysis 12	3	2	100			X Started late, ended late.							
1t	Construction	2	3	100			X Started on time, ended on time.							
1u	Discussion	2	3	100			X Started on time, ended on time.							
1v	Proposal Assembly (Winter)	1	1	100					X Started on time, ended on time.					
	totals	67	57											
2	Website Components													
2a	Project Website Creation	1	1	100	X Started on time, ended on time.									
2b	Project Website: Introduction	2	1	100	X Started on time, ended on time.									
2c	Project Website: Analysis Summary	2	1	100		X Started on time, ended on time.								
2d	Project Website: Schedule	1	1	100		X Started on time, ended on time.								
2e	Project Website: Budget	1	1	100		X Started on time, ended on time.								
2f	Project Website: Testing	1	1	100		X Started on time, ended on time.								
	totals	8	6											
3	Drawings													
3a	Drawing 1	1	1	100		X Started on time, ended late.								
3b	Drawing 2	1	1	100		X Started on time, ended on time.								
3c	Drawing 3	1	1	100		X Started on time, ended on time.								
3d	Drawing 4	1	1	100		X Started on time, ended on time.								
3e	Drawing 5	1	1	100			X Started on time, ended on time.							
3f	Assembly	3	3	100			X Started on time, ended on time.							
	totals	8	8											
4	Construction & Part Arrivals													
4a	Arrival: 50-002	N/A	N/A	100				X Arrived.						
4b	Arrival: 20-010	N/A	N/A	100				X Arrived.						
4c	Arrival: 20-015	N/A	N/A	100				X Arrived.						
4d	Arrival: 50-001	N/A	N/A	100					X Arrived.					
4e	Arrival: 50-002	N/A	N/A	100					X Arrived.					
4f	Const: 20-001	1	0.5	100					X Started, and Completed.					
4g	Const: 20-004	1	0.5	100					X Started, and Completed.					
4h	MDR	1	1	100					X Started on time, ended on time.					
4i	Const: 20-017	0.5	0.1	100					X Started, and Completed.					
4j	Const: 20-018	0.5	0.1	100					X Started, and Completed.					
4k	Mfg01	0.1	0.1	100					X Assignment Complete.					
4l	Const: 20-005	0.5	0.5	100						X Started, and Completed				
4m	Const: 20-021	0.1	0.1	100						X Started, and Completed				
4n	Arrival: 50-006	N/A	N/A	100						X Arrived.				
4o	Const: 20-013	0.5	0.2	100						X Started, and Completed.				
4p	Const: 20-022	0.1	0.1	100						X Started, and Completed.				
4q	Const: 20-002	0.5	0.5	100						X X Started, and Completed.				
4r	Const: 20-019	0.5	0.5	100						X X Started, and Completed.				
4s	Mfg02	0.5	0.2	100						X Assignment Complete.				
4t	Const: 20-020	0.2	0.2	100						X Started, and Completed.				
4u	Const: 20-007	0.5	0.5	100						X X Started, and Completed.				
4v	Mfg03	0.2	0.2	100						X Assignment Complete.				
4w	Const: 20-012	0.2	0.2	100						X	X Started, and Completed.			
4x	Const: 20-023	0.2	0.2	100						X	X Started, and Completed.			
4y	Const: 20-011	0.5	0.5	100							X Started, and Completed.			
4z	Const: 20-016	0.3	0.2	100							X X Started, and Completed.			
4za	Working Device	2	2.5	100							X Started, and Completed.			
4zb	Const: 20-024	0.1	0.3	100							X Started, and Completed.			
4zc	Const: 20-025	0.1	0.1	100							X Started, and Completed.			
4zd	Const: 20-026	0.1	0.1	100							X Started, and Completed.			
4ze	Const: 20-027	0.5	0.1	100							X Started, and Completed.			
	totals	11.7	9.5	100										
5	Testing & Evaluation													
5a	Abstract Draft	0.5	1	100								X Started on time, ended on time.		
5b	Abstract Revised	0.5	0.5	100								X Started on time, ended on time.		
5c	Test Procedure	1	2	100								X Started on time, ended on time.		
5d	Bridge Testing: Weight	0.5	0.5	100								X Started, and Completed. April 5th, 2021 at 8:30 AM		
5e	Bridge Testing: Vehicle Travel	1	1	100								X X Started, and Completed. April 13th, 2021 at 10:45 PM		
5f	TDR01 Video	0.5	0.5	100								X Started on time, ended on time.		
5g	TDR01 Comments	1	2	100								X Started on time, ended on time.		
5h	Bridge Testing: Vertical Articulation	0.5	0.5	100								X Started, and Completed. April 22nd, 2021 at 9:16 PM		
5i	Bridge Testing: Bridge Raising	0.5	0.5	100								X Started, and Completed. April 25th, 2021 at 9:30 PM		
5j	Project Poster Draft	2	1.25	100								X Started on time, ended on time.		
5k	TDR02	0.5	0.5	100									X Started on time, ended on time.	
5l	TDR02 Comments	3	2	100									X Started on time, ended on time.	
5m	Poster Revision Submission	0.5	1	100									X Started on time, ended on time.	
5n	Poster SOURCE Submission	1	1.5	100									X Started on time, ended on time.	
5o	Bridge Testing: Load	1	1	100									X Started, and Completed. April 29th, 2021 at 6:30 PM	
5p	Test Report	2		75								X X	X X	
	totals	16	15.75											

APPENDIX H – Resume

Joshua Nye
12200 39th Ave NE, Marysville, WA 98271 ♦ (360)-630-8384 ♦ j.nye14@yahoo.com

Objective

An entry level position with potential for growth and obtain experience.

Skills

- Organized.
- Willingness to learn.
- Beginner level experience with Autodesk CAD and SolidWorks.

Experience and Extracurricular

2012 to 2016

Marysville NJROTC

- Appointed assistant of the Battalion Administration Officer. Organized, filed, and recorded various documents pertaining to other cadets (2014-2015).
- Appointed assistant of the Battalion Operations Officer, helped make permission forms and sign-up sheets for various events (2015-2016).
- Participated and lead the Marysville Marksmanship Team. Helped teammates prepare for competitive matches, offered insight and at times, concern for their performance.

Education

September 2012 to June 2016

Marysville Getchell Academy of Construction and Engineering, Marysville, WA 480678.

- Graduated in June of 2016
- 2015-2016 GPA: 3.729

September 2016 to Current

Central Washington University, Ellensburg, WA 98926

- Currently enrolled full time.
- Class of 2021
- Major: Mechanical Engineering Technology (Design)
- GPA as of Fall 2020: 3.246

Awards

Dean's List for Winter 2020 and Spring 2020

- Received for academic excellence. Received for the Winter 2020 and Spring 2020 quarters.