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# Articulating Balsa Wood Bridge

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By

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# ABSTRACT

The objective of this project was to design, construct and test an articulating balsa wood bridge. It needed to fit certain requirements such as maintaining the bridge structure and articulation structure weight under 85g, being able to articulate 140mm, and be able to withstand a load of 20kg at the middle. The aim was to both create a product, but also give the student a chance to demonstrate their practical knowledge in engineering and going through the processes.

To complete this project as mentioned the student began by creating an initial design and performing a series of analyses on the components. This determined whether or not the bridge would fit the necessary minimum requirements. Other design processes were followed such as using decision matrices to determine the best process to use for manufacturing components. With the design completed, manufacturing could commence, involving creating components and final bridge assembly.

After completing testing of the bridge, it preformed as designed. It was able to withstand the required load of 20kg before fracturing down the middle of the bridge where the beams were at the most stress. It was also able to fully articulate 140mm at reasonable speeds and maintain the 140mm articulation for 10 seconds. The bridge also fit the design weight and dimension specifications. It was determined that the bridge was successful in meeting the requirements of the project, fitting all the necessary requirements while maintaining low costs and easy manufacturability.

# Contents

# 1. INTRODUCTION

## a. Description

The objective of this engineering project was to plan, design, and test an articulating balsa wood bridge. It had to be able to span a gap of 400mm, with a 38mm wide road deck. This would allow for a block to pass across the bridge to the other side with no obstructions. It also had to be able to articulate 140mm vertical from the center to allow a "tall boat" to pass underneath the bridge. The goal of this project was to demonstrate a student's ability to engineer a design, manufacture said design, test the design, and learn from the results to create a better product in the future. The planning stage took place during the fall quarter, the manufacturing and analysis section was during the winter term, and the testing and results were completed in the spring term. This was finished off by presenting the findings to the professors and analyzing what could have been improved upon.

## b. Motivation

The motivation for this project was that a bridge was needed to span across a 400mm gap. It needed to both be able to support 20kg as well as articulate 140mm. This would demonstrate the student's ability to take a design into practice, collect data from it, which could then be used in the future to create a better, more refined product.

## c. Function Statement

The bridge allows for passage over normally impassable terrain.

## d. Requirements

There are some requirements that the bridge had to adhere to pass. It was the student's task to consider all these requirements when building the bridge and ensure it would meet all the standards, as would be done in a professional field.

1. The bridge and articulating structure must only be made from balsa wood and wood glue (not including articulation components).
2. The bridge needed to span across a 400mm gap.
3. The bridge must allow a 100 mm object (perpendicular and above the abutment plane) to traverse the width of the bridge.
4. The bridge needed to be slightly longer than 400mm to rest on 60mm wide steel abutments.
5. The total weight of the bridge and Articulating structure may not exceed 85g (not including articulation components).
6. This road deck must be within 12 mm of the top surface of the abutment. The end of the road deck must be withing 12 mm of the vertical surface of the abutment.
7. The bridge must have a solid balsa wood deck with only an 8mm diameter hole in the center for testing.
8. The bridge deck must be 38mm wide, to allow a 32mm wide by 25mm high block to pass through the bridge free of obstruction and at a constant velocity.
9. The bridge must not deflect more than 25mm.

10. The bridge must be able to articulate 140mm vertical at the center and hold in place for 10 seconds.
11. Ascend and descend must be done by the push of a button and take less than 60 seconds.
12. The bridge must be able to support 20kg about the center.

## e. Engineering Merit

The completed balsa wood design passed through a variety of engineering methods before being put into practice. This includes Statics, Mechanics of Materials, and Mechanical design. The statics are used in calculating the reaction forces to keep the bridge at equilibrium. Mechanics of Materials is used in calculating the Necessary dimensions of the beams in order to handle the tension and compressive forces. Mechanical design is used when determining how the bridge will react under different stressed. It was initially sketched out on a green sheet, with FBD used to determine the forces acting on the bridge and how it would react (calculated forces and stresses upon beams). After a design had been formed that would appropriately function, follow the requirements, and be capable of handing the forces and stresses acting upon it, the bridge could be fully developed. This step was completed using paper at first and then created on CAD software. After the final design was created in CAD, the physical bridge was constructed and toleranced to be as close to the design as realistically possible. The final design was then analyzed to solve for the max forces exerted on the structure as well as predicting possible weak spots and how the bridge would react to the tests. After analysis, the bridge was tested, and data was collected to then be examined, compiled, and presented.

## f. Scope of Effort

The overall project took less than 500 hours to engineer, construct, and test. The materials for the bridge were projected to be less than $150. This was all done using the facilities at Central Washington University with mentorship and guidance from the professors at CWU.

## g. Success Criteria

Success of the project was determined by whether the bridge design adhered to the requirements, how well the student did in managing their time, whether the student adhered closely to the initial plan, and whether they were able to learn from the project and put their skills into practice, creating a design and using experimental data to find areas of improvement.

## h. Stakeholders

The stakeholder for the project was the student as well as the professors. This is a self-funded project with no extra assistance, so all materials will be purchased by the student with their own funds. The professors provide the facilities and tools needed to manufacture the part.

# 2. DESIGN & ANALYSIS

## a. Approach: Proposed Solution

The aim of this project was to create an articulating balsa wood bridge that would span across a gap that would otherwise be uncrossable. When first looking at designs for the bridge there were 3 ideas that were chosen between. There was the Warren Design(Figure 1.1) due to its symmetry with using isosceles triangles. There was also the Warren Design with Vertices(Figure 1.2), which would have been added support to the other design. Neither of these designs were chosen though, as the design that was picked for the bridge was the Pratt style(Figure 1.3).

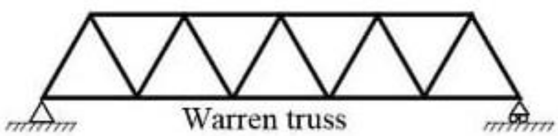



Figure 1.1: Warren

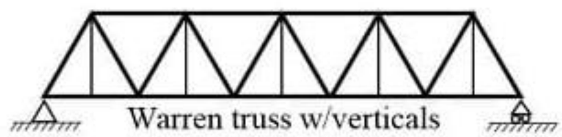



Figure 1.2: Warren with Verticals

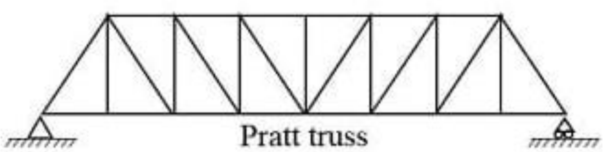



Figure 1.3: Pratt

| Criterion | Weight 1 to 3 | Best Possible 3 | Warren | Score x Wt | Warren W/V | Score x Wt | Pratt | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | |
| Weight | 2 | 6 | 3 | 6 | 2 | 4 | 2 | 4 | |
| Prediction Precision | 2 | 6 | 3 | 6 | 2 | 4 | 3 | 6 | |
| Confidence - Failure loc | 3 | 9 | 1 | 3 | 2 | 6 | 3 | 9 | |
| Prismatic vs non Prismatic | 2 | 6 | 3 | 6 | 3 | 6 | 3 | 6 | |
| Manufacturability | 3 | 9 | 3 | 9 | 3 | 9 | 3 | 9 | |
| Total | 13 | 39 | | 33 | | 31 | | 36 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 2.56 | | 84.6 | | 79.5 | | 92.3 | Percent |

Figure 1.4: Project Decision Matrix(Complete Matrix in Appendix F)

## b. Design Description

The design that was chosen for this project was the Pratt Design. It utilizes a combination of vertical and diagonal top support for the bridge. All the diagonals angle from bottom to top towards the ends of the bridge. They all converge at a vertical in the center of the bridge. The zero force members for the bridge are minimal as it is only the two end verticals and the center vertical.

## c. Benchmark

This design could be a small-scale replica for larger designs that could be used in cities that have rivers that shipping boats might need to pass through. Having these bridges there would allow for both cars and boats to utilize the space, allowing for more options for shipping and receiving.

Similarly, there have been similar projects done in the past by graduated seniors. One design that was used two standing beams. This was one of the designs initially considered for the bridge, however it was rejected due to the number of materials needed to make it function. While the requirements of the project had not changed much between the old senior's project and the current. The difference between the two designs was the use of different truss setups, and the use of 1 vs 2 lifting points.

## d. Performance Predictions

The bridge was expected to meet the requirements. It was able to both span across the 400mm gap as well as support the 20kg weight without fracturing. This can be seen in the calculations in appendix A. It was also able to be lifted 140mm to allow tall boats to pass underneath.

## e. Description of Analysis

The Analysis for this bridge will include finding the force values for the bridge. It is necessary to calculate the tension and compressive forces acting on the bridge as this will highlight the weak spots in the design. This will give an idea for where the bridge will break. It is assumed when calculating the bridge is at equilibrium. Other pieces that will be analyzed are the bridge's ability to be lifted, the tension and compressive forces acting on the side of the bridge, as well as what the best design for the bridge would be to meet the requirements. This will use a variety of statics, mechanics of materials, and material design elements to determine whether it meets or fails.

Other areas of this bridge that require analysis include determining the minimum dimensions based on the max tensions and compression forces, the mass of the bridge based on the dimensions of the bridge and the density of the wood, the force needed for the articulation structure to lift the bridge, as well as the minimum dimensions for the structure and its associated weight. The deflection of the bridge could also be looked at to determine how much the bridge will sag. Then the material used to connect the joints will need to be analyzed as it needs to be able to keep the bridge under the weight requirements but also be strong enough to withstand the pressures of the joints. Another piece that needs analysis is the motor, both how much power it needs to pull the bridge and how it will be secured to pull the bridge.

## f. Scope of Testing and Evaluation

The bridge was tested by laying it across a 400mm gap, then supporting a 20kg weight from a hole in the middle of the bridge. It was then tested to see if it was able to articulate up and down at the press of a button. Then was tested to see if a block could pass uninterrupted across the bridge to simulate a car. If the bridge could withstand all these tests, then it passes and it would be a success.

# g. Analysis

## i. Analysis 1 – Bridge Side Calculations

In Analysis 1, calculations for the compressive and tension forces acting on the bridge can be seen in Appendix A-1. The only load acting on the bridge was the 20kg load downward in the middle, so the bridge had symmetry in its calculations. Statics would be used in this instance to calculate the reaction forces at the ends of the bridge as the result should have the bridge in equilibrium. To find this, the sum of moment and sum of forces was used. Then using those values, the method of joints was used to calculate the tension and compressive values in each beam. This was determined using the sum of forces, and provided useful data to use in later sections.

## ii. Analysis 2 – Dimensions of Beams + Total Volume

Using the data from Analysis 1, the bridge can be examined to find where the max compression and tension forces are. This allows the area to be calculated using the ultimate tensile strength as well as the compressive strength. Using the stress equation, the minimum area to hold the mass could be calculated. As wood is sold in standard sizes, the height of the bridge beams can be solved for by using the standard thickness as one measurement. Using this cross-sectional area, the volume could be solved for. This was done in sections and added up at the end, getting a total weight that is far below the weight constraints.

## iii. Analysis 3 – Side Forces/Dimensions

Similar to Analysis 1 and 2, equilibrium in the part was found using the sum of moments and sum of forces assuming the bridge is static. This gave the max force the cross beams would undergo which could then be used to calculate the minimum cross-sectional area the beams could be to support the bridge. This was accomplished using the stress equation and the ultimate tensile and compression strengths. This was done to ensure that the force of the weight on the bridge would not cause the cross beams to buckle and collapse in on themselves, so performing analysis to determine the max force it will undergo allows the student to design accordingly.

## iv. Analysis 4 – Articulation Cable Position and Structure Dimensions

Per the documented requirements, the bridge must be able to articulate 140mm vertically about the middle of the bridge. One major part of the articulation structure is the positioning of the cable, which would affect the component force on the cable as well as the height of the articulation structure. Two different positions for the cable were considered in the design, with one being at the far top end of the bridge and the other in the top middle. Calculations were done for both of these positions to determine the height of the structure necessary for the bridge to be lifted the required 140mm, and what the force acting on the cable would be. A major factor that was considered was the amount of material needed to support the structures as to keep it under the 85g limit. The height was calculated using Pythagorean theorem, and the forces were calculated by the sum of moment and sum of forces of a static part. What was found was that the cable being attached to the top middle would be better suited than the far side. The top middle allows for less material to be used on the structure as it would not need to be as tall and the increase in tension on the cable was not a significant enough increase to be of concern.

v. Analysis 5 – Articulation Forces

When designing the articulation structure for the bridge, one major aspect that needed to be analyzed was how the force of the cable will affect the lifting structure. This is vital to the success of the bridge as if it is unable to withstand the forces of the bridge, the articulation structure could collapse, and the bridge would no longer be able to articulate. To begin, it can be assumed that the cross member the cable will pass over to get to the motor acts as a pully, so the acting force from the cable will face downward. Using this, the reaction forces on the cross member can be calculated to get the forces acting on the trusses. This assumes the lifting structure is a static member and can be calculated by using the sum of forces. It should also be assumed that the structure is symmetrical so calcs for one side of the structure will be mirrored to the other side. Calculations can be seen in Appendix A05 Figure 5.1.

Once the reaction forces have been calculated, this force can be used on the truss for the articulation structure. The structure was given a safety factor of 2 to ensure that it does not crumple during testing. It can also be assumed that it is a static member and is going to be at equilibrium. The force in each member of the truss was calculated by finding the reaction forces at the base, as well as using the method of joints to solve for the rest of the members. Once all the forces were calculated, the max compression and tension forces were found. Calculations can be seen in Appendix A05 Figure 5.2.

vi. Analysis 6 – Articulation Cross Sectional Areas + Weight

Now that the forces in the articulation structure truss have been calculated, using the max compression and tensions forces as well as the ultimate tensile and compression strength of balsa wood, the minimum cross-sectional area for the beams can be calculated. The cross-sectional area was solved using the stress equation. It was found that the beams would need to be 0.2796mm^2 for the cross beam, with a safety factor of 1.5, and 0.14068mm^2 for the truss. To use a standard size, the articulation structure will use 1/8" balsa wood, as material will already be purchased for the road deck, and while it will be overkill, it will reduce the purchased wood waste. Calculations can be seen in appendix 6 figure 6.1. With these minimum cross-sectional areas of the beams, the weight can now be calculated for the articulation structure.

Using the density and the volume of balsa wood in the articulation structure, the weight was found to be 1.40 grams. When this is added to the weight of the bridge it is still far below the weight requirement (1d 5).

vii. Analysis 7 – Joint Connection Material

The requirements this analysis will solve is d1, d8, and d12. As the balsa wood for the bridge was cut into pieces to be assembled, there needed to be a way to join two pieces of wood together. The method that was chosen was to use wood glue to mate the two together. A concern going in was that the joints would be a weak spot for the bridge, so choosing a material to minimize weak spots was vital to success. Wood glue was chosen for this over pins as for one it is easier to manufacture with wood glue, but it is also plenty strong for holding the bridge together. To demonstrate, the compression and tension strengths of balsa wood on its own is 7MPa and 14Mpa respectively, where wood glue has a compressive and tension strength of 30MPa and 70MPa. As long as the mating surfaces are prepped properly, the wood glue will easily be able to withstand the forces acting on the bridge. The thought process can be seen in appendix A07.

viii. Analysis 8 – Motor Power

The requirement this Analysis will solve is the 140mm vertical articulation. It was decided that the articulation would be done using a motor and pully system. An important piece of this system is ensuring that the motor will have enough power to pull the bridge and place it back down. Power if found by the equation P=Fd/t where F is the force acting on the motor, d is the distance traveled, and t is the time it takes to travel that distance. The force acting on the cable was determined in analysis 4, that being 2.61N tension. The distance was determined by seeing the change in length of the cable from when the bridge is at resting position to when it is fully articulated which was found to be 147.86 mm. The time it takes to travel that distance was 10 seconds as that was the value given in the project requirements (d11). When plugging these values into the equation, it was found that the motor needs to output 0.0386 watts to satisfy the requirements. Calculations can be seen in appendix A08 Figure 8.1.

The motor that was chosen for was a 6v Dc motor. From there, determining whether it had enough power to raise and lower the bridge could be done. It was found on the part description sheet that it was a 6v DC motor with a max current of 2.6A. These values could then be used in the basic electricity equations to solve for power. Using P=VI, and V=6 volts and I = 2.6 Amps, power was found to be 15.6 Watts which is much greater than the needed 0.0386 watts. This determined that the motor would be plenty to run the bridge articulation. Calculations can be seen in appendix A08 Figure 8.2

ix. Analysis 9 – Motor Housing/Mounting Design

The requirement this Analysis will solve is the 140mm vertical articulation. To successfully lift the bridge, the motor needs to be mounted securely to a base, which in this case was the Arduino housing. As the bridge needs to articulate, one component of that is creating a mounting point for the motor to the bridge. This was done using PLA filament to create a housing that would encase both the motor and the brain for the motor. To ensure that the mount is sturdy enough, the stress equation was used to find the minimum cross-sectional area of the housing. Using the max tensile stress of PLA (37 MPA), and the force acting on the PLA (2.61N from the cable), it was found that the minimum cross-sectional area would be 0.0705mm^2, which when put with a safety factor of 2 to ensure it is sturdy and won't break, the area becomes 0.141mm^2. Calculations can be seen in appendix A09 Figure 9.1.

The final design for the mount places the motor in a bracket mounted on top of the brains housing. This can then sit beneath the articulation structure and pull the cable vertically downward.

x. Analysis 10 – Articulation Spool Dimensions

A requirement of the bridge is that it can articulate 140mm vertically about the center. In order for the motor to pull the cable, it must have something for the cable to rest on. This is where the spool came in. It allowed for the cable to reel in during articulation and not get tangled which would lead to issues with repetitive use. To solve for the dimensions, the circumference was found to be 22.054mm assuming a diameter of 7.02mm was used. Then, using a width of 4mm as that is the width of the gear on the motor, the number of cable reels that could sit side by side on the motor were found. This was done by dividing the width by the diameter of the cable(0.5mm) which came to be 8mm. As the width is constrained to be 4mm for size purposes, the height of the lip was adjusted to account for possible overlap of cable. This was determined by finding the number of cable spools the length of cable would create. This was done by dividing the length of cable(147.86mm) by the circumference(22.054mm) which came to be 6.704 spools. Because 6.704(caused by cable) < 8(allowable due to width), the cable will not have to overlap to account for the total length. Because of this a Safety Factor of 3 was put in place, that being 3 cable reels. This allowed the size of the lip to be determined, coming to be 1.5mm lip. This created an outer diameter of 10.2mm. Calculations can be seen in appendix A10.

xi. Analysis 11 - Weight to Counteract Tipping

In order for the bridge to be able to fulfil the requirement of articulating 140mm vertically about the center, there structure needs be able to withstand the weight without tipping over (Section 1d Requirement 10). This was done by taking the moment about the end of the articulation structure. It was found that due to the moment of the weight of the bridge (17g *9.81m/s^2*220mm), the reacting moment would be –(9.81m/s^2 * 75mm * w(bridge)). With the bridge being at equilibrium, it was found that the weight to keep the articulation structure from tipping over would be 74.1g. As the Arduino (45.4g) and the weight of the battery (33.9g) combined result in 79.3g. This does not account for the addition of the motor or the Arduino and motor housing, so the result is no additional weight would have to be added to keep the structure from tipping over. Calcs can be seen in appendix A11.

xii. Analysis 12 – Vertical Deflection

One of the requirements for the bridge to pass was that it needed to deflect less than 25mm (Section 1d Requirement 9). Using a cross sectional area of 6.35mm^2 and a Young's Modulus of 3.12GPa. Finding the deflection of a truss is done by calculating the (sum of NnL)/AE where N = the sum of the force in the Y, n equals the sum of the force in the x, L equals the length, A equals the cross-sectional area, and E is the young's modulus of the material. This involved solving for each of the forces in each of the joints. Using the dimensions decided on for the bridge, the force of 20kg about the middle and inputting the values into an online calculator (Jade Hochschule), it was found that the force causes a max deflection of 6.869mm. This is much less than the required 25mm, so the design of the bridge will work and support the required load. Calculations and Inputs can be seen in appendix A12.

xiii. Analysis 13 – Articulation Cycle Time

One requirement of the bridge is that it needs to be able to preform a full cycle in under 60 seconds. This includes raising, lowering, and pausing at the peak for 10 seconds per section 1d requirement 10. Using the circumference equation and unit cancelation, the circumference of the cable reel could be found using the diameter of the reel, and then as RPMs of the motor were given, unit cancelation could be used to get from RPMs to seconds. It was determined that the cycle time of the bridge would be 17.4 seconds which is under the required 60 seconds. Work for this can be seen in appendix A13.

# h. Device: Parts, Shapes, and Conformation

The structure of the bridge will be constructed completely from balsa wood. For the bridge design, a Pratt structure was chosen due to its use of both vertices and diagonal, while still maintaining a limited amount of material for weight savings. The force acting on each member was calculated using the method of joints and assuming the bridge was static and at equilibrium. It also has very few zero force members, meaning all the resources are useful. The safety factor used was 1.5, as it increases the bridge's load capacity, while still allowing for a small number of materials used. If the safety factor was any larger, ¼" thick wood would not be able to be used, which will create a potential difficult time finding materials and staying under the weight constraints. The tolerances for the beams is within -0.05 + 0.1 as the beam should not be any skinnier as it would then not be able to support the forces. Assembling the bridge will be done with glue as it will create a strong bond between the beams and keeping it lightweight.

# i. Device Assembly

A balsa wood bridge will be constructed to span the distance thus connecting the two abutments. The bridge design consists of a hybrid of horizontal, vertical, and diagonal beams creating a series of triangles. There are two of these sections connected by beams along the top and bottom connecting to joints. There will also be a flat piece at the bottom to allow for smooth travel. The joints will be connected by wood glue allowing for strong bonds.

The bridge also must articulate to allow tall objects to pass that would not otherwise be able to when the bridge is in its horizontal position. The articulation was incorporated in the assembly by an Arduino that provides data to a motor that will pull a cable running over a tower that will pull the bridge up and lower the bridge down.

# j. Technical Risk Analysis

A technical risk associated with the bridge is keeping it under the weight requirements. The lighter the bridge, the less material that can be used. This means that the bridge structure will become weaker. The goal is to find a balance between strength and weight, where the bridge is able to hold as much weight as possible while still remaining under the weight constraints.

Other technical risks could be the use of mechanical parts for articulation. The more moving components a part has, the more potential spots for failure. To reduce this risk, having as few moving parts as possible to raise and lower the bridge will ensure reliability. The thought process can be seen in appendix A10.

## k. Failure Mode Analysis

The failure modes the bridge will undergo are static and dynamics stress, as well as normal stress and max shear. The beams on the bridge will be under tension or compression with the load being placed on the bridge. Balsa wood has a Compression strength of 7.0MPa, an Ultimate Tensile Strength of 14 MPa, and a Shear Modulus of 0.23 GPa. This will be tested in both real world practice as well as in simulation.

## l. Operation Limits and Safety

The bridge is designed to hold a max load of 20 kg. Loading more than this rated weight could lead to failure. Similarly, the articulation structure of the bridge is only rated to lift the weight of the bridge, so trying to lift extra weight on the bridge could lead to failure. The opening on the bridge for cars to pass through is only 100mm tall, so vehicles over this height will not be able to pass safely.

The articulation components of the bridge will include electronics. Modifying them without power being shut off could lead to shock.

# 3. METHODS & CONSTRUCTION

## a. Methods

The project was conceived, designed, and manufactured at CWU. Due to the constraints of the CWU machinery, the articulating balsa wood bridge was manufactured using a laser cutter and a 3-d printer. For wood components for the structure of the bridge, a laser cutter was used due to the precision and ease of manufacturing. It allows for the straightest lines and the least material waste. For articulation components, a 3-d printer was used, provided by the student, as it is cheap to manufacture parts. This also allowed for prototypes to be made cheaply and remanufactured to create the best results.

I. Process Decision

One process that was used for manufacturing was 3-d printing. The decision matrix can be seen in appendix F Figure 6.1.8. This was chosen for its ease of manufacturing as well as being fast and cheap. Because of the low cost and speed of manufacturing it was easy to create prototypes for the designs, see how they fit on the final design, and remanufacture with refinements to create the best possible result. Another big factor in this decision was that the student already had a 3-d printer, so parts can be manufactured in house which allows for no wait times and scheduling flexibility. As the student has a busy schedule, the ability to manufacture parts in house will greatly increase the amount of testing and prototyping that could be done as parts can be started at the beginning of the day and tested at the end of the day. As the components being printed are complex shapes it would not make sense to cut them out of wood, and per the project requirements, articulation components cannot be made out of metal. This leaves plastics as a great option as they will not be under a huge load and will keep the costs of the project down. As plastics were used and the shapes are complex, 3-d printing was the most viable option. While it is mostly a perfect option, there are some things to consider while the student is manufacturing components. The main issue is that PLA will slightly downsize the holes being created as it is melted plastic. This can be accounted for by upsizing the holes while in solid works, or drilling or sanding the holes to create clearance for the parts. For this project, the student will use both methods of slightly upsizing for components that do not need a press fit, and sanding and drilling for parts that need a tighter clearance.

To manufacture the wood components of the bridge, a laser cutter was used. This is due to the precision it was able to maintain. The other options were a band saw and a hand saw, which can be seen in appendix F figure 6.1.2. In the end, the laser was decided on due to its precision. The saws would result in potentially crooked lines and take more time to manufacture. The laser must be monitored as it cuts, where the saws take a person to cut the wood. The student must schedule time to go in and use the laser cutter, however, this can be worked around to not be an issue. As the bridge and articulation structure are the main support structures, they need to be as rigid as possible. This entails having a solid connection. As wood glue was used as the primary adhesive material, it functions best when the mating surfaces are as flat as possible. Lazer cutting was the best option to achieving this.

There were also decisions made to determine what materials would be used in the manufacturing process. This involved what type of wood would be used (Figure 6.1.5), what adhesive would be used (Figure 6.1.6), and what material would be used for the lifting components (Figure 6.1.7). It was determined that low density balsa wood would be used due to its low cost and light weight. Wood glue would be used as the adhesive component because of its high strength and being specific to the material. The lifting components will be made out of plastic because of the low cost and ease of manufacturing. Most will be able to be 3-d printed, so the plastic that will be used is PLA as it is cheap and strong enough for the processes.

One process that has been added is sanding for the winter term. Some of the components were slightly undersized after 3-d printing, so rather than reprint at a different size, the components were sanded slightly to remove small amounts of material. This allowed for the proper fit and less time than the reprint would take, saving costs in time and wasted materials. Reprinting would result in an entire scrapped part, where slightly modifying the part allows for much less waste, saving the student money.

# b. Construction

## i. Description

The project consists of 18 parts and 4 sub-assemblies. Most of these components will be purchased from Amazon as they are cheaper there. PLA was purchased from Creality. The wood will be able to be laser cut at CWU using their machine, and the 3-D printing will be done in-house with the student's personal printer. The project was broken into two sub-categories, being the bridge and the articulation system. The bridge was done in two parts, the creation of the sides and the connecting of the two sides. The articulation system was done in three parts. First, the sides were assembled for the structure, which then can be connected using the cross beams and the deck. This creates the final articulation structure which can then have the brain and motor mounted to create the final assembly. The final articulation structure and the final bridge assembly can then be brought together to create the final assembly.

## ii. Drawing Tree, Drawing ID’s

The device was constructed in a few different sections. The first section is the side pieces of the bridge(the Truss), which will be laser cut out in one big piece to maintain a uniform part. The other opinion was to glue every joint together which increases the chances of error, so creating it all in one cut allows for as little imperfections as possible. This connected the vertical beams, upper and lower beams, diagonals, and ends into one uniform assembly part becoming the side assembly.

Connecting the side pieces were the cross beams which were placed perpendicular to each of the joints, as well as placing the road deck on top of the lower cross beams. They were connected using wood glue to create a strong bond between the parts. This creates the second assembly of the bridge structure.

The articulation structure was the next assembly which connected the articulation beams into the final assembly. Unlike the prior truss assembly, as this one will not be under as much force, it can be glued together piece by piece to save materials. Then once the structure has been assembled, the articulation brain housing can be mounted to the deck, the reel put on the top bar, and the cable run between the motor, over the reel, and connected to the bridge.

The bulk of the manufacturing was performed using CWU machinery, with the exception being the 3-D printing which was done in-house with the student's personal printer.

### iii. Parts

The parts that were used in this project were ¼" and ⅛" low-density balsa wood sheets, ⅛" balsa wood dowels, PLA, an Arduino, breadboard, the Arduino Starter Kit Motor, Various Wires and resisters(Most contained in the Arduino starter kit due to value), and Wood Glue. The wood was laser-cut for the most precise measurements. Sheets were used rather than sticks because of the ability to use the laser cutter to get precise cuts on the wood, but also to cut out the entire side assembly at once to minimize the chances of error. The PLA will be 3-D printed into the Motor Mount and Arduino Housing. This is due to the low cost of the materials, and the machine being student owned, so all parts could be manufactured whenever available. All parts can be seen in Appendix C. The ¼" balsa was used in only the bridge structure due to its load requirements. Two sheets will be cut to form the side components of the bridge, while another will be cut into the cross beams to connect the two trusses. The ⅛" balsa sheet and dowels were used in mostly the articulation structure as it will be under much less stress, with the exception being the bridge road deck as it does not need to be made from ¼" balsa due to the deck height needed to be under 12mm. PLA is a cheap plastic, so as the motor does not undergo much force, and its purpose is to hold a brain, it does not need to be a strong plastic, so PLA was more than enough for the project.

In winter, there was no major changes to the projected parts list for the project. Only thing that was changed was the total amount of wood needed was found to be less than initially estimated, which in turn brought the total cost of the project down. Other than the decrease in the amount of parts the 70lb fishing wire was found to not be flexible enough, so it was replaced with twine that the student already owned, so no change in cost. The overall parts were kept the same, with just decreases in amounts being found, which lead to saving costs and minimizing waste.

### iv. Manufacturing Issues

Issues that could arise in manufacturing are mostly related to lack of training and accessibility. The laser is not something the student has used before, so it would require an admin who is trained to teach the student how to use it. Similarly, it is only accessible during certain hours, so ensuring that scheduling aligns for the student to both be able to use the machine as well as being able to be taught how to use the machine may be an issue. The 3-D printing should not have any issue as it can be run 24/7, and is a student-owned machine. They are already trained in how to use the machine, so issues should be limited.

In the winter there were a few manufacturing issues. For one, the professor that was going to help the student with the laser cutter had some arrangements that lead to him being busy. This pushed the schedule of when the wood was going to be cut from the beginning of the winter term to closer to the end. To work around this, the brain assembly was done first and the 3-D printing was done second. This put the student a little behind schedule but was still able to get everything done on time. Another manufacturing issue that was ran into was issues with the 3-D printing process. The bed was having adhesion issues, so research was done and the student was able to discuss with peers about some possible troubleshooting fixes to get it back up and running. This did cause some prints to be done late, but still before the projected due date. Other than those two setbacks, everything else went smoothly with no real issues.

### v. Discussion of Assembly

Assembly went in the order of 3d print the articulation components, cut the wood components, glue the wood components, assemble the brain, and then final assembly. The 3-d printed components were done first as they were the easiest to finish as the student had their own printer and all the files prepared. Following this, the wood components were cut out. They were laser cut for precision, which allowed the student to cut out the full side assembly rather than glue it together piece by piece. The hope with this was to limit imperfections caused by the gluing process. To eliminate waste, the cross members of the bridge were cut out in the gaps of the bridge. The articulation system components were also laser cut out, however because of the design and saving material, they were not cut in one assembly, but rather each individual piece to then be glued. It will not undergo much weight or stress, so imperfections were no as crucial to this system. The sides could then be glued together with the cross members and the road deck, and the articulation structure could be assembled and mated to the bridge with the articulation pins. Then the brain could be placed on the motor deck with the motor seated in the mount. The cable reel was placed on the motor, and the cable Passover was placed on the dowel during the gluing process. That was the finished and functional assembly(Appendix b figure b01). In terms of operation, it is a fairly simple design. One button on the brain turns the motor on, one button switches direction, and there is a dial that can adjust the speed of the motor depending on how fast the bridge should be lifted. It should be to spec based on the initial benchmarks. All the components fit what was designed with the safety factor in play, and everything was within the budget and manufactured as intended.

# 4. TESTING

## a. Introduction

The bridge underwent 7 different tests to determine whether the bridge passed the requirements. These are the "vehicle transversing the bridge test, articulation showing height test, bridge resting on abutments test, 10 grams allowing for 20lb paper test, support between 18.9 to 20kg load, weight of bridge (articulation components removed), and the max vertical deflection test. Much of the testing was preformed on a 400mm gap with the bridge resting on 60mm wide abutments. This allowed for a simulation of testing of how the bridge would act under "real world conditions". The weight of bridge test will be the only one that will not use the 400mm gap. This test will also involve disassembling portions of the bridge unlike the others that utilize all the components.

Based on the calculations done in the analysis, the bridge will be able to withstand the 20kg load as well as articulate the required 140mm vertically about the middle, and deflect no more than 25mm. Based on the dimensions of the bridge, the vehicle is also predicted to be able to pass, the bridge will be resting on the abutments, and the weight of the bridge will be under 85g. Based on the weight of the bridge alone and the build of the articulation structure, a 20lb piece of paper should be able to be slipped under the opposite end to the lifting mechanism.

## b. Method/Approach

There are various pieces of information that were gathered to determine whether the bridge passed or failed. The bridge was calculated to be able to withstand a load of 20kg, so the test will use a 20kg weight. With the 20lb weight on, the deflection will be measured, and will pass if it in under 25mm between the horizontal axis and the lowest point of deflection. Similarly, the articulation will be tested using the horizontal axis and the bottom middle of the bridge, if it is able to articulate up 140mm, then it will pass. For the vehicle transversing the bridge, the bridge will be set up on the abutments and a 32mm wide x 25mm high block will be pushed across the bridge to ensure it can pass smoothly. To test whether the bridge rests on the abutments, it will be placed on them and if it fits within the width(60mm) and length(400mm) between them, then it will pass. For the sheet of paper test, a 10g weight will be attached to the articulation cable. If it is able to lift the bridge up enough for a piece of standard 20lb printer paper to be slipped between the bridge and the abutment, then it will pass. Finally, the articulation components will be removed from the bridge till it is only the articulation and bridge structures remaining. They will be weighed, and if they are under 85g, then it will pass.

One tool that will be necessary for this is a level to span across the 400mm gap to give a basis for a level horizontal axis. This will be used in the deflection and articulation tests to give a basis to measure against. For the vehicle test, the 32mm x 25mm block is all that is needed. Weights will be needed in both the load test and the paper test, 20kg for the load test and 10g for the paper test. A scale will be needed to measure the weight of the structures.

The tests that were more in depth for this project were the articulation height test, the articulation cycle time, and the load test. The articulation tests were preformed in similar methods, both setting up the bridge, and running the articulation. The differences are that the height test will use a measuring tape to determine the max height the bridge is able to reach, and the articulation cycle time test will use a stop watch to find the tie it takes the bridge to complete one full cycle. Specifics of how these tests were performed can be found in appendix G. For the load test, the Instron was used to determine the max load and max deflection of the bridge. It was mounted in a jig and then allowed to run and compress the bridge to the specified load, giving results for the ability of the bridge to maintain a load as well as the max deflection. Further details can be found in appendix G.

In these three tests there was not much variation from the original plan devised in the spring, however, there were some. For one thing, the original plan was to do the deflection test as one test and the load test as another. As it would both be on the machine under the same loads, it made more sense to combine these tests as the output of the Instron gives both load and deflection. This left room for more in depth looks as the cycle time and the articulation height which are other major requirements for the bridge. Other changes about testing were that the load test was going to originally be preformed with weights hanging from the bridge, but because the intron gives more precise measurements as well as an accurate reading of the deflection it was a better choice for the process. The final change was that for both the articulation tests were that originally, they were planned to be preformed on platforms, but as they did not really need to be elevated it added unnecessary steps, so they were changed to be done on a flat surface.

In terms of issues faced, the only major one was the improper mounting for the articulation structure and the bridge. To resolve this, an extended beam was added to the front of the articulation structure to give the bridge a solid place to mount to for a more controlled lift and lower. Another issue that was faced was the motor was struggling to lift and lower the bridge slowly. It was still able to lift, hold, and lower the bridge, however, it could have been slower and more controlled. This was not fixed as it would cost a bit of money and take time to adjust the design, and as the current system was functioning, it was not something that felt necessary to fix in the current iteration. Future ones a motor with better low end torque would fix this issue or by adding a lower gear ratio to allow the original motor to be used, but slow the lifting on the bridge end.

## c. Test Process

The testing process for the bridge is fairly straight forward, most of which was able to be completed on a desk with the exception of the load test being done on the Instron. As the bridge is small scale, not much space is needed, so as most of the tests deal with the quality of the bridge and how well it is able to hit the requirement, a good portion of them are visible inspections. For the ones that are not like the articulating and weight tests, enough space is needed to raise the bridge high enough to have weights hanging below, as well as have enough space above for the bridge to articulate. This could be on a desk with a stack of books that the bridge and articulation system would rest on. The load test will need to be performed at school with proper PPE as the bridge could be destroyed. Overall, the test process should be straight forward due to the scale and nature of the project.

## d. Deliverables

For deliverables, the student created a document/checklist for the bridge. The checklist section determines whether the bridge fit the requirements. There will also be a section to fill in quantitative info such as how much weight the bridge held, how high the articulation went, etc. Photos will also be taken of the bridge throughout testing, as well as video for the website to give demonstrations of the bridge in action and how it functions.

In the end, there will be photos and videos to demonstrate visually how the bridge preformed and where it may have fallen short, and a document to give qualitative data to depict the bridges performance. These two deliverables should give enough data to create a good report off of along with the documentation written and drawn throughout the year.

The first test done was the articulation test to determine if the bridge is able to articulate a minimum of 140mm vertically about the middle. The predicted value for the articulation height was 140mm which was calculated in analysis 4 using basic geometry to determine where the bridge needed to end up, so how tall to make the articulation structure. It was found that the bridge reached an average height of 142.6 mm. This is over the 140mm minimum as well as over the predicted 140mm, so it did pass the test. Some issues that were encountered when testing was originally the bridge articulation brain used two buttons, one to start and one to change speeds. Reaction time came into effect on this, so to try and make it as easy as possible to achieve good results the system became a one button system that would hold down for the bridge to lift. Once the button was not pressed anymore then the bridge would stop lifting. Another minor issue was that the bridge lifted very quickly due to limitations on the motor. Because it does not have enough torque at lower speeds to lift the bridge, it was only able to lift it when moving at a faster rate than desired. A fix for this would have been to purchase a new motor for the bridge that did have the proper low end torque to lift the bridge, but as it was functional, it was not changed for the testing.

The second test preformed was the articulation cycle time test. This involved setting up the bridge, running a camera to capture the bridge moving, and running the bridge up and down with a 10 second pause at the peak. This was done to fit two requirements, those being the bridge must be able to maintain full articulation for at least 10 seconds (requirement d10) and the bridge cycle time, that being the time up to peak and back down to resting including the 10 second pause must be completed in under 60 seconds (requirement d11). The predicted value for this test was that the bridge would be able to complete a full cycle in 17.4 seconds, which was found in analysis 13 using the circumference equation to determine the circumference of the reel and unit cancelation to go from RPMs of the motor to seconds using the circumference of the reel and the length of cable displaced. After preforming the test, it was found that the bridge was able to maintain full articulation for at least 10 seconds at the peak and that the average full cycle time of the bridge was 15.2 seconds. This is under the required 60 second minimum as well as under the predicted time so the bridge does pass the test. Reasons that the time would be below the predicted value could be that one, it was hard to time exactly 10 seconds at the peak due to the bridge being articulated by buttons, so reaction time did take effect, and two, the motor was not powerful enough to lower the bridge at the rpm that was used and rather resorted to a controlled free fall. For timing the bridge to be at the top for 10 seconds, it was opted to bode on the higher side and go over 10 seconds as that would fit the requirement of at least 10 seconds. To solve these issues, a stronger motor could be used to allow the bridge to lift and lower more in control as well as at the stated RPM in the program or design a way to incorporate a lower gear ration to allow the motor to output more torque onto the rope. To solve the inconsistency of hitting exactly 10 seconds, it could be incorporated into the code that at the press of a button, the bridge would run the full cycle on its own and have the computer time exactly 10 seconds before lowering. As that would take more time and money, and the bridge did pass the requirements and succeed testing, it is perfectly fine for the time being, but could still be incorporated in future iterations.

The final test preformed was the load and deflection test. The setup process involved setting up the bride jig, attaching the load plate, and mounting the bridge to the jig in the Instron and recording the results. The requirements needing to be fit in this test were that the bridge needed to be able to maintain a load of 20kg (Requirement 12) while also deflecting less than 25mm at its lowest point (Requirement 9). The predicted values for the load and deflection tests were 20kg and 6.869mm. The 20kg predicted value was assumed and calculation for the cross-sectional areas of the beams were done using this assumption. The deflection was calculated in analysis 12 using an online calculator. This essentially did a series of beam deflection tests with the result having deflections at various points in the bridge. Following the testing, it was found that the bridge was able to maintain a load of 9.7kg and deflected 4.03mm. This was under the required load and deflection, so it failed the load test and was inconclusive with the deflection test. This was due to the bridge not reaching to 20kg requirement, so it was undetermined whether the bridge would deflect 25mm at that load. What was noticed in testing was that the bridge broke with the grain, due to it being under tension pulling it grains apart. This could be solved by having the grains stack left to right rather than top to bottom so when the bridge is in tension it is not trying to split the grains from each other (weaker bond). Images of the failure can be seen in appendix G3. Another modification that could be done is increasing the cross-sectional area of the beams on the bridge to increase the stress the beam is able to undergo. The hole in the road deck was also not centered causing the bridge to be pulled in a weird direction, so ensuring that the hole is centered in future constructions will allow for more predictable results following the calculations. In the end the bride did fail this test, so future modifications will need to be done to preform the test successfully.

# 5. BUDGET

## a. Parts

Parts that need to be sourced were the balsa wood for the structure, an Arduino for the brain of the articulation system, components for the articulation structure, 3-d printing filament to create articulation components, and fishing line for the articulation cable. The brain for the Arduino and the other miscellaneous electronic components were $95 as they were in a bundle. The balsa wood for the structural members were purchased in ¼" x 4" x 36" bundles for $9, 1/8" x 4" x 36" for $5.50 for the road deck and articulation structure and $10 for the balsa wood dowls for the cable to pass over. The 3-d Printing filament was $30 for 2 spools of 1kg of PLA. Most of the manufacturing was able to be done in house with the 3-d printer, however, cutting the balsa wood required a laser cutter which will be provided by the school. The full parts list can be referenced in appendix D.

## b. Outsourcing

The only outsourcing necessary for the project was using the laser cutter as the student did not have their own to use. As the student would be designing the part and running the machine, the only cost would be their time, which at a standard rate would be between $13 and $20 per hour. In this case, the median can be used at $16.5 per hour for about 2 hours totaling at $33.

## c. Labor

The labor costs fall into the design phase, as well as the assembly, and manufacturing of the components. For the design portion, the labor cost that was used was for an entry level civil engineering position as in the real world, Civil Engineers might be the ones to design a bridge for the city, and as the student is comparable to an entry level position, it would seem to fit. Entry salary is about $65k per year according to indeed. As the student is working for about 3 months at about half the time per week of an engineer, the cost would come to $8.125k for the project. As this was a small scale project, the labor costs can be 1/10$^{th}$ the overall costs of real work coming to $812.5 for design labor. Assembly costs will also be small scale as this was a small project. The entry level construction costs for labor is about $24.04 hourly. Using the same time frame of 3 months for about 4 hours daily, the $5769.6, which when reduced to the same 1/10$^{th}$ would come to $577.0 for labor. Manufacturing costs can use standard rates as they are the same process. 3-d printing results in about $1 per hour in house, which after printing would result in $20.

## d. Estimated Total Project Cost

With the estimated and adjusted labor costs for the scale of the project and the parts used for construction and assembly, the total cost for the project resulted in $1520.50. This was mostly labor costs with materials coming in at $221.21.

## e. Funding Source

All funding for the project was provided by the student. This included all the materials used, as well as the use of the 3-d printer as it was accessible in house.

## f. Winter Updates

**5a(Parts):** Nothing changed to the needed parts from fall quarter. There were some errors in purchasing though. Excess material was purchased in order to be prepared in the event of damage to original to not have to wait on new parts to be ordered and shipped. The original bill was much higher with a greater number of excess materials in the event of manufacturing error, however this was reduced to excess material for 1-2 manufacturing mistakes as this seemed more reasonable. This decreased the price of parts from around $250 to $200.24Realistically costs could have been reduced more if they were not purchased, however, the student wanted to play it safe as time is of the essence. An area that was not accounted for was shipping costs, which over the course of the entire purchasing was only around $14 as most of the materials were purchased in groups to have free shipping. As of yet, no errors in manufacturing have caused any errors that would warrant needing to purchase extra material, as that was also accounted for in the original budget of 200.24, so no changes/modification was needed for winter term. Parts costs can be seen in appendix c table c1

**5b(Outsourcing):** There were no changes in outsourcing. The student used the schools laser cutter as planned, so nothing was changed from fall term.

**5c(Labor):** Labor costs are also consistent from what was planned in fall term. The student has been sticking to the ghantt chart schedule very well, as seen in appendix f. The one area of divergence was in the 3-d printing as it was having issues with prints adhering to the bed, so some troubleshooting needed to be done. The result was an extra 2 hours needed to be added to the time. Not a huge change in the long run, but still to be noted. Other than that everything stayed consistent. Labor costs can be seen in appendix d table d1.

**5d(Estimated Total Project Costs):** After purchasing all the parts, the student was able to adhere to the planned budget of $200.24 with the exception of the unaccounted for $14 for shipping that was not accounted for in the plan, bringing the new total for parts to 214.24. The area of increase was in the labor costs with a little extra time being used for 3-d printing, however, as the student is “self-employed” the costs do not affect the project. Overall the estimates for costs for the project were about right with just shipping forgotten to be accounted for and 2 hours of extra print time.

**5e(Funding Source):** All funding for the project was still paid for by the student through employment opportunities and pulling from savings

## g. Spring Updates

**5a(Parts):** Following testing in the spring, only one modification was needed which was the addition of a small bracket at the front of the articulation structure to mount the bridge. This was completed using left over scrap wood through so no extra cost was used. The result was the budget was unchanged from the winter term.

**5b(Outsourcing):** There were no changes in outsourcing. The additional bracket that was manufactured was completed using a knife as the process did not require the tolerance the laser was able to have. The part was not going to be under intense stress, so using a knife to ge the job done quickly was perfectly suitable. In the end no extra outsourcing was needed, so no change from fall and winter terms.

**5c(Labor):** Labor did not change much from the initial amount following the spring testing phase. A bracket needed to be added to the front, but this took only about an hour with the main process being waiting for the glue to dry. As a result, the values from the spring are still accurate.

**5d(Estimated Total Project Costs):** As there was no extra parts purchased for the testing term, the project was still able to stay at the budget of $200.24 that was adjusted in the winter term.

**5e(Funding Source):** All funding for the project was still paid for by the student through employment opportunities and pulling from savings

**Summary:**

The testing was ordered in a way that would have the one with the highest risk of damaging the bridge at the end. This meant that there was no need to replace or fix things before proceeding to the next test. There was no costs due to errors in testing as nothing broke or needed repairing following the first and seconds tests. After the third test, the bridge did fracture in the middle, however as that was the final test nothing needed replacing so no extra costs were needed. This did not affect the overall budget as no extra parts were needing to be purchased. To prevent errors and future mistakes, the order of the tests was done intentionally. The articulation tests posed little risk to the structural integrity of the bridge, but it was assumed that the load and deflection test would pose risks that could damage the bridge to a point where a new construction would be needed. Preforming the minimal risk tests first prevented the need for a new bridge to be constructed and saved cost in both parts and labor by ordering the tests this way.

# 6. SCHEDULE

## a. Design

In the Fall Quarter was the design phase of the project. This entailed creating an initial design matrix to determine the design that was to be further analyzed. Once chose, calculations could be done. The main calculations were for the stresses on the bridge to determine the compression and tension forces acting on the bridge, which could be used to calculate the cross-sectional area of the beams. This was done for the various components of the bridge to ensure that all points were able to withstand the desired weight. All calculations were done with a safety factor of 1.5. Having this safety factor ensured that components that are not meant to break will not. If the bridge were to break in testing in a time or place it is not supposed to, then it can affect future testing as well, so ensuring that the breaking points were predictable was vital to the success of the project. Design scheduling for the project can be seen in sections 1,2, and 3 of the schedule in Appendix E figure 1.

In winter, only a few design modifications were done. This was all in the 3-D printed parts, as the student was learning the limitations of the machine. One such issue being how small the printer was able to create. As the printer could only go so small, the designs were changed to be slightly larger to allow for the printer to create the part. This pushed back the ideal completion date a few days as revisions to the parts needed to be made. Other than the issues with the 3-D printing size, there were no other design issues that caused scheduling conflicts.

## b. Construction

Using the design completed in the fall, this was worked off to build the bridge. Tasks that needed to be completed before the Testing Phase were gathering the needed materials, including the wood for the bridge, motors and computers for articulation, etc. This also included the manufacturing portion such as 3-d printing some of the smaller articulation components and cutting the wood to bridge parts, and the final assembly of the bridge and articulation structure and components.

In winter term, the goal was to complete the bridge portion as early on as possible, however, this was put to a halt due to material delays. The wood for the bridge got delayed, so the parts could not be laser cut out. Similarly, the wood arrived for the articulation system, however, the wrong material was delivered, so new material was ordered to replace. This delayed the process a few days as well. To attempt to stay as on track as possible, 3-D printing was done first to have parts completed that could be reworked if needed. The brain was moved in scheduling from the end to the earlier stage to have something else complete to be tested if needing rework. Not the ideal order, however, everything got done and is still moving smoothly. In terms of how close the time estimates were to the scheduled/estimated time most all of there were very close. The only issues came in with the 3-d printing as setting on the printer needed to be tweaked causing messed up prints and reprints. Scheduling for winter term can be seen in Appendix E figure 1 in sections 4 and 5 of the schedule.

## c. Testing

After the Construction Phase, the bridge was ready for testing. Requirements for the bridge that were accounted for during calculations were that the bridge needed to be able to complete the slide test, length test, weight test, and the various articulation tests. If the bridge can pass all the tests, then the design was successful.

The first tests that was completed was the articulation height test. This found the height that the bridge was able to reach and how close it was to the 140mm minimum requirement. The second test that was completed was the articulation cycle time test. This aimed at finding the time it takes for the bridge to complete a full cycle including the 10 second pause at the peak. This also tested whether the bridge was able to pause at the peak per the 10 second requirement, and how close the bridge was to the 60 second maximum time limit. The final test was the load and deflection test which was done to find the load the bridge was able to support and the deflection of the bridge under the load. Following the load test the minor requirements were also tested but less in depth.

Some issues with the scheduling were that the bridge did need some modification before being able to test. This pushed the time for testing back a little bit as the bridge was not fully functional. Another issue with the schedule was that the load and deflection test required the Instron, so a time needed to be scheduled for the test to be completed rather than on the student's own time. In terms of changes to the original plan there were none. The plan was to perform the load and deflection test last if it causes the bridge to break. The articulation tests were done first, and the minor tests were preformed after the load test, so it followed the original plan.

While there were some issues with testing, a buffer was in place in the schedule to account for some potential setbacks. In the end the testing was still finished before the final poster was needed for submission, so the process was able to get back on schedule. In the end, the project went fairly smoothly, and as a result, even with the few hiccups, enough extra time was allotted so the project finished very close to the scheduled time.

# 7. PROJECT MANAGEMENT

There are various risks that are associated with this project. In terms of physical risks, the bridge could break, the articulation structure could fall, the motor could stop working, etc. Financially, the student is at risk as the bridge if fully funded by them. This leads to limitations in the extent the bridge resources go which means that there is both a low budget as well as minimal margin for mistakes. As the bridge runs on a computer, there could be a software error, or the file could get corrupted. To combat these risks, initial calculations and analyses will account for real world error as best as possible to eliminate as many of those risks as possible. For the financial risks, the best thing that can be done is budget and be careful when manufacturing, measuring twice and not rushing through the job. Eliminating the software issues would be backing up data, creating copies, and debugging as much as possible to create the most efficient program possible.

## a. Human Resources

One of the human resources was the engineer. They were responsible for the design, construction, and testing of the bridge. Their resume can be seen in appendix H. Necessary skills they possessed was knowledge in fundamental physics, material analysis, and material design. They were also familiar with designing parts in SolidWorks, manufacturing parts, and preforming testing on components.

Another human resource was the CWU faculty. They provided knowledge in engineering fields that the student may have not been familiar with, as well as help in breaking down the processes for the project. Similarly, they had access to machines the student would otherwise have not, so they were able to assist in learning how to run and manufacture with new machinery.

Risks associated with having faculty is availability. School hours are limited, so there is a time constraint to when they are accessible. To resolve this, other parts of the project were planned around their time. This allows for their time to be used effectively and for everything to be completed in the end.

## b. Physical Resources

Physical Resources that were used were a 3-d printer, a laser cutter, a table, and a computer. There is limited risk with the 3-d printer as it is always available for use and can be ran 24 hours of the day. The one area of concern is if a piece of the printer breaks, as it is owned by the student, replacing that part will come out of the student's budget. This would not happen if it were a school owned machine, however it is not. To ensure nothing breaks, regular precautions will be taken, in that standard setup procedures will be taken and the machine will be run in a safe way and as the manufacturer intended.

Risk associated with the laser cutter is that it is a school machine, so availability is limited. To ensure that the risks are not going to affect project flow, other pieces of the project will be scheduled around available hours of the laser cutter. This will allow for everything to get done.

The computer has limited risk as it is a student owned machine. The only major risk associated is files getting corrupted. To combat this, copies will be saved in various places to make sure there is always a backup available to the student.

## c. Soft Resources

Soft Resources that were used were SolidWorks, Arduino, and UltiMaker Cura. All these software's are available to the student 24 hours a day, so there is no risk in the availability. The one risk with all of these is a software crash. To combat possible issues with this, backups will be saved of files in various other locations, and files will be saved frequently to prevent corrupting files and wasting time redesigning.

## d. Financial Resources

The financial resources are all provided by the student as they are the sole doner. They will provide the finances for parts, as well as the 3-d printer, and the computer to work on the software. If the project goes overbudget, the student will be sad, but there is not repercussions.

# 8. DISCUSSION

## a. Design

The design for the bridge did not change much throughout the fall quarter. The Pratt design was selected, and the bridge was built around this style to fit the requirements. That being, the dimensions for the bridge were adjusted to ensure it would satisfy the requirements of future testing. One aspect that did change was the articulation system. Initially the base was going to be 50mm long with a 50mm extending post to keep from tipping over, however, in examining the drawing of this component, it was decided that the base would be 100mm with no extension arms to provide the best stability. Additionally, the motor mount has gone through various changes as well as the build for the motor brain has not yet been finalized, meaning that space necessary for all the components has not yet been found. To fix this, the motor itself will be mounted to the articulation on a PLA mount that will allow for weights to be added. Originally, the full brain build, and motor were going to be mounted, which would allow for no additional weights necessary to keep the bridge from tipping, however, as the brain will no be mounted to the system, weights will be added. This was due to time constraints, as well as design simplicity. The brain for the articulation system will use an Arduino as well as a bread board, which will take up more space than available under the articulation structure. Future revisions may be made to allow the brain to reside under the articulation system, however, the current design places the brain next to the articulation structure, using a motor mount, the motor, and weights to support the structure.

There were very few risks that needed to be overcome, the main one being software issues as the student's home computer runs SolidWorks 2022 and the school computers run SolidWorks 2023. Issues arose where parts were made in both, so assemblies were only able to be completed on the school computers as the 2022 version cannot run 2023 created parts. This risk was overcome by planning out when assemblies would be worked on, and sending all parts between the two computers every day to ensure that there were always copies.

Most of the bridge build was very successful up to this point, all the initial designs fit and work together, as well as follow the requirements for the project. The main unsuccessful component was in the creation of the motor mount. That being what was mentioned earlier with the brain components causing issues with spacing, so adjustments needed to be made, and extra components needed to be added to made the system function. Overall, the structures were a success, but the components for the articulation system were a shortcoming.

## b. Construction

The design stayed very consistent with that created in fall quarter. There were a few changes made however, that being there were pins created to connect the bridge to the articulation system so there was a pivot point to move off of. Second off, the articulation reel and cable Passover were upsized a little as the 3-d printer was having issues with how small the components were. The Passover was upsized to have an outer diameter of 7mm and an inner diameter of 3.5mm. The cable reel was adjusted to fit over the motor pin as the PLA shrunk relative to the required diameter. After enlarging it by about 0.25mm, it fit snug as intended. This solved the sizing issue the printer was having. Modifications to the bridge just involved adding a 1/8” hole to the bottom beam at the end to account for the usage of the connecting pin. The rest of the bridge stayed consistent with the design from fall quarter.

There are new risks that need to be accounted for, mainly in the manufacturing processes. With 3-d printing, if the bed or extruder are set wrong, the print can come out wrong leading to structural issues or causing the print to come detached from the bed leading to filament spewing around causing waste. This was combatted by adjusting the components to their proper setting before printing and ensuring that they are still set properly before printing again. If the prints were still not sticking, then a thin layer of glue stick was added to the plate to ensure good adhesion. There are also some risks associated with the laser cutter. If run to slow, then it can burn the wood, and if run to fast it might not penetrate the wood fully. Making sure that the settings on the laser are set properly will ensure a clean and safe cut. Unknowingly to the student but another risk that was associated with the printer was trying to coordinate times with the professor who runs the printer. Due to some outside factors, cutting got very delayed, which was resolved in the end and parts were manufactured. Gluing can also have some risk involved, being that if the part is not set properly when gluing, then it can cause the bridge to sit wrong. In that event, the parts would need to be cut and sanded off, which could lead to damaging the side pieces. If they are damaged, then they would need to be completely remanufactured. To fight this issue, it would be smart to work slowly and carefully as to ensure it is done the first time around. Bracing would help to keep the parts aligned as well.

In terms of the success of the manufacturing process, almost every process was successful. The manufacturing of the balsa wood on the laser cutter went smoothly after learning how to use the machine and getting things scheduled with the professor, and the gluing process was taken slowly and did not have any issues. One area that did lead to some trouble was in the manufacturing of the 3-D printed components. The issue that came up was that the printed parts were not sticking to the bed, so they would run through the first few layers, then get snagged and ripped off the bed. Multiple routes were taken to try and solve this issue, releveling the bed, applying glue sticks to the bed, adjusting the z offset, and ensuring the filament was seated properly. In the end, the issue was solved by tightening the belts on the bed and the extruder as there was some play in them that would have been causing shaking while printing. Also adding glue added an extra adhesion to keep the prints on, and to ensure that they stayed on, an adhesive layer was added to the sliced parts in the software to maximize the surface area of the part on the bed. Overall, most of the processes went very smoothly, and the issues that arose in the manufacturing processes were quickly resolved.

## c. Testing

For spring term most everything stayed the same in terms of the bridge design. The only modification was the addition of a new mounting structure for the articulation pins that push them out in front of the original articulation structure to allow for proper mounting of the pins as well as room for the bridge to articulate. The reason for this modification was because the original mounting method was going to be to narrow, so this was done to allow for the pins to clear the width of the articulation structure. This was installed in the same method as the rest of the bridge construction, using wood glue. For quickness of manufacturing though the pieces were not laser but, but done with an knife. This is because getting an opportunity to run the laser would have taken a lot of scheduling and as the part is not under extreme load the precision did not need to be to tight. Other than that the original design has been maintained. There were some changes to the testing itself, as the they needed to be a bit more detailed. The tests that were preformed to evaluate the bridge were an articulation test to see whether or not the bridge was able to reach 140mm, a timed test of how long it takes the bridge to run a full cycle, and the load test on the bridge to determine both the max load the bridge could handle as well as the deflection at 20kg and max deflection. These were in depth tests, but there were also some minor tests that were preformed to determine if the bridge fit the requirements.

There were a few issues that were ran into during the testing phase. For the articulation test, the prior mounting system to connect the bridge to the articulation structure was no connection, so adding the mounting bar at the front and connecting the pins to it allowed for the bridge to have a controlled lift up and down. Another issue that was ran into was that the bridge did not have a fail safe to stop the motor from running and over lifting the bridge. Originally, a two button press system was used, one press would kick the motor into a faster rom and another press would shift the speed into slower speed. The issue with this was that it was very heavily reliant on reaction time and how fast the student could press a button. To fix a part of this issue rather than pressing a button to switch into high speed, the button just needs to be held down and the motor will be in high speed, and when released it will switch back to low speed. Now it is not a reaction time of a press, but just lifting a finger off the button. This did solve most of the issues with over lifting, but a sensor that just shuts the bridge off at a certain height would have been ideal with more time.

Overall, the bridge did pass all the tests. It was a successful project, however there are some modifications that would be done in future iterations. The main issues that were faced was that the bridge lifted and lowered very fast. This is due to restrictions in the motor as it lifts and lowers very quickly. This is due to the motor have poor low end torque, so as lower rpm, it does not have the torque required to lift the bridge. In order to successfully lift the bridge the rpm needs to be relatively high, so in order to fix this issue a new motor would need to be purchased to slow down the raising and lowering. Since the bridge was functional in the current setup this was not an issue that felt necessary to resolve, but for future variants, it would be ideal to have a more controlled lift both raising and lowering. Another issue was with the articulation system, specifically the fail safes. One issue is that the bridge does not know its own limits, so as long as the button is pressed down, the motor will continue to run until the battery dies. Ideally, there would be a sensor that would detect the max height of the bridge and once it has reached that point shut the motor down to the lower speed to maintain bridge height. This would both eliminate potential damage caused by over lifting, but allow for more precise results in the lifting mech. Other than some issues with the articulation, the overall project went very successfully with little to no hiccups.

Following the first update to the discussion section (8), the test that was preformed was the articulation cycle time test. The aim of this test was to find the time it would take for the bridge to perform a full cycle up and down including a 10 second pause at the peak, as well as whether or not it was able to pause at the peak for 10 seconds and complete the full cycle in under 60 seconds. The deliverables for this test are the cycle time tested, and the percent off of the required 60 seconds the bridge was able to reach. Another necessary deliverable is whether or not the bridge was able to remain at the peak for 10 seconds. There were no major issues in preforming this test. The only issue that was found was that timing and running the bridge at the same time were very difficult. To resolve this issue, the bridge cycle was video recorded so that it could be timed after the cycle was completed allowing the student to focus on one thing at a time. Another fix for this would be to update the bridge to cycle on its own instead of running off multiple buttons and requiring human interaction throughout the entire process. This would require incorporating sensors for fail safes, so for future builds, it would be ideal to use this method. Other than having to video the process to get accurate times, the process went very smoothly with no issues faced.

# 9. CONCLUSION

## a. Design

The project that is being tested is the articulating balsa wood bridge. The function of the bridge is to allow for passage over normally impassable terrain. Important analysis for this project is determining the force acting on the bridge system, determining the cross sectional of the beams to account for these forces, and determining the requirements for the articulation system to function (in terms of the components). Engineering methods that were used to determine this analysis were statics, mechanics of materials, material design, geometry, and basic electricity. These allowed for the bridge to succeed in that it meets the minimum requirements for the project. It is able to hold the desired load without breaking or deflecting over a certain value and articulate up and down while constraining to size, weight, and material limitations. With the various analysis that has been completed and the decisions that have been made about materials, the bridge is ready to be manufactured and tested. The base has been set for it to be able to meet the necessary requirements.

## b. Construction

The design of the bridge consisted of a Pratt truss setup with a standing triangle articulation structure, allowing a motor to be mounted to the base to have a cable pass over a top beam and attaching the top middle of the bridge to then pull it up. The articulation system was created using an Arduino and a motor placed at the base of the system, with the motor in a weighted structure. When one button on the system was pushed it would turn on the motor, the second button would switch directions of the motor, and the dial adjusted speeds at which the motor would rotate.

There were not many modifications that needed to be done to the initial design. The only modifications needed were upsizing the diameters of the 3-d printed components as the PLA was creating smaller holes than the program was calling for, and the addition of articulation pins to mount the bridge to the articulation structure.

Overall, the manufacturing process went very smoothly. The outcome was a bridge that fits all the necessary requirements stated in 1d. It is set in a good spot to begin testing in the spring.

## c. Testing

Following the testing phase, the bridge preformed well, passing 2 of the 3 tests. Results can be seen in the testing reports(Section G), but the articulation height and cycle time tests were both passed, meeting all the requirements. It was able to articulate vertically about the middle 142.6mm which is greater than the required and predicted 140mm. The cycle time test was found to be 15.2 seconds which is less than the predicted 17.4 seconds and less than the required 60 seconds so it did pass. The load and deflection test were not as successful as the bridge was only able to carry a load of 9.7kg which is much less than the required 20kg. As it did not reach the 20 kg mark, the deflection test results were inconclusive. Issues that may have lead to these shortcomings were the orientation of the grains as they were pulling apart the grains rather than with the grain(stronger bond), causing the bridge to be weaker. Also, the calculations were done with general balsa numbers, and as this wood was very light, it may have been weaker than the one used to preform the calculations. In future iterations, using the same wood, greater cross-sectional areas should be used to compensate for the low tensile strength of the wood as well as orienting the grains to have the stronger bond in tensions rather than trying to split the grains. Alternatively, another method that could be used is choosing a stronger balsa wood to use. The higher density and increased tensile strength would allow the original design to be used, while creating a stronger structure. Overall, the bridge did well, but there was still plenty of room for improvement in future iterations.

# 10. ACKNOWLEDGEMENTS

The completion of this project could not be done without the assistance of the mentors at Central Washington University, as well as their provision of machinery that would otherwise have not been accessible. Fellow classmates also played a large role in the success of the project in being able to bounce unbiased idea off of to ensure that the project stayed on the right path. None of the following would have been possible without the support of others.

# References

- Truss Deflection Calculator: https://valdivia.staff.jade-hs.de/fachwerk_en.html

# APPENDIX A - Analysis

## Appendix A01 – Design Drawing + Force Calculation(Pratt)

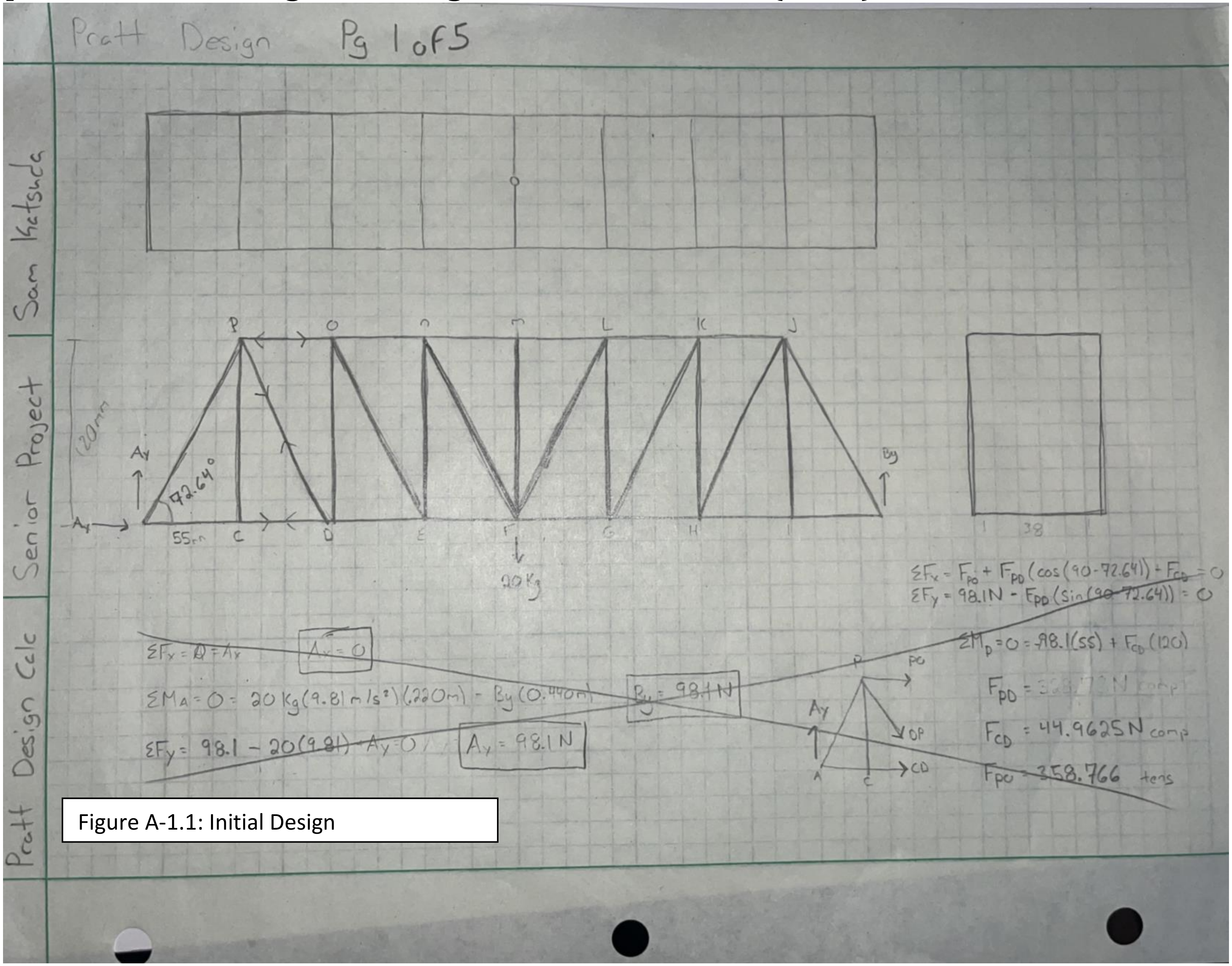
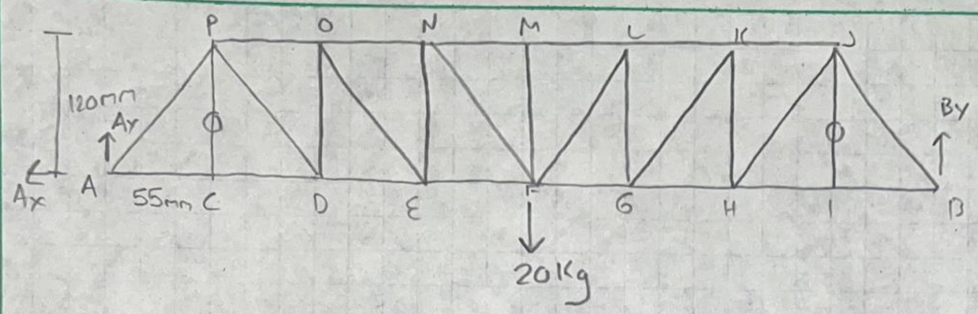



Figure A-1.1: Initial Design

Pratt Design Calc | Senior Project | Sam Katsube




PC = 0 Force Member
JI = 0 Force Member

$\sqrt{120^2 + 55^2} = r \quad r = 132$

Given: Image

Find: Reaction Forces, Tension and compressive Forces at each Joint

Assume: Uniform Material, Rigid Body, Symmetrical Design

Method: FBD, Equilibrium, Method of Joints

Equivilance:

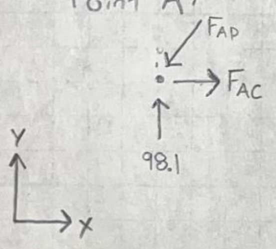
$\Sigma F_x = 0 = A_x$ $\boxed{A_x = 0}$

$\Sigma M_A = 0 = (20kg \cdot 9.81 m/s^2 \cdot 0.22m) - B_y(0.44m)$ $\boxed{B_y = 98.1N}$

$\Sigma F_y = 98.1 - 20(9.81) + A_y = 0$ $\boxed{A_y = 98.1N}$

Method of Joints:

Point A:



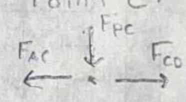

$\Sigma F_y = 98.1 - F_{AP}(\sin(\frac{120}{132})) = 0$

$\boxed{F_{AP} = 124.34N \text{ comp}}$

$\Sigma F_x = -F_{PA}(\cos(\frac{55}{132})) + F_{AC} = 0$

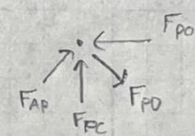
$\boxed{F_{AC} = 135.97N \text{ tens}}$

Point C:




$\boxed{F_{AC} = F_{CD} = 135.97N \text{ tens}}$

Point P:




$\Sigma F_y = F_{AP}(\sin\frac{120}{132}) - F_{PD}(\sin\frac{120}{132}) = 0$

$\boxed{F_{PD} = 124.34N \text{ tens}}$

$\Sigma F_x = -F_{PO} + F_{PA}(\cos\frac{55}{132}) + F_{PD}(\cos\frac{55}{132}) = 0$

$\boxed{F_{PO} = 227.57N \text{ comp}}$

Figure A-1.2: Reaction Forces and Method of Joints

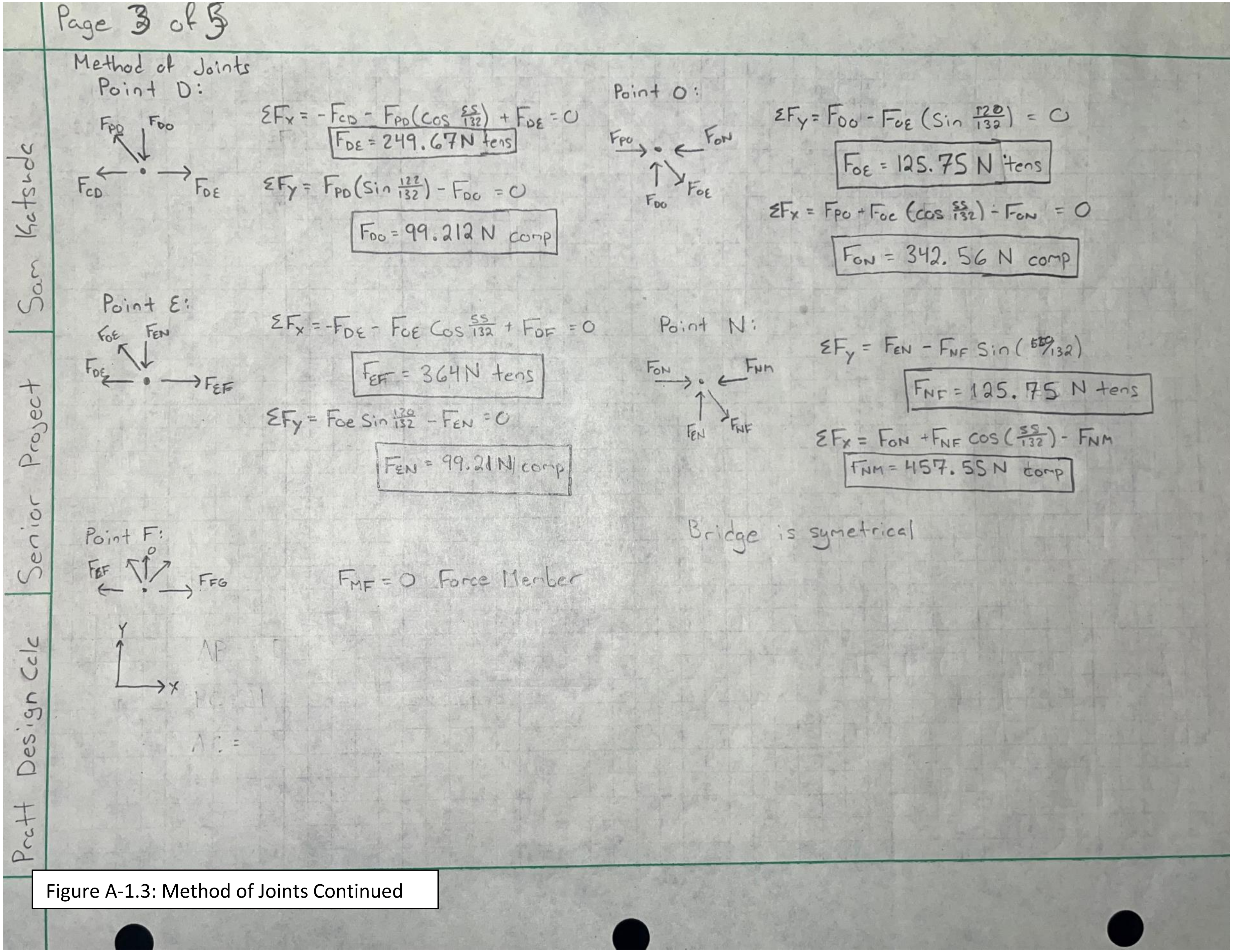
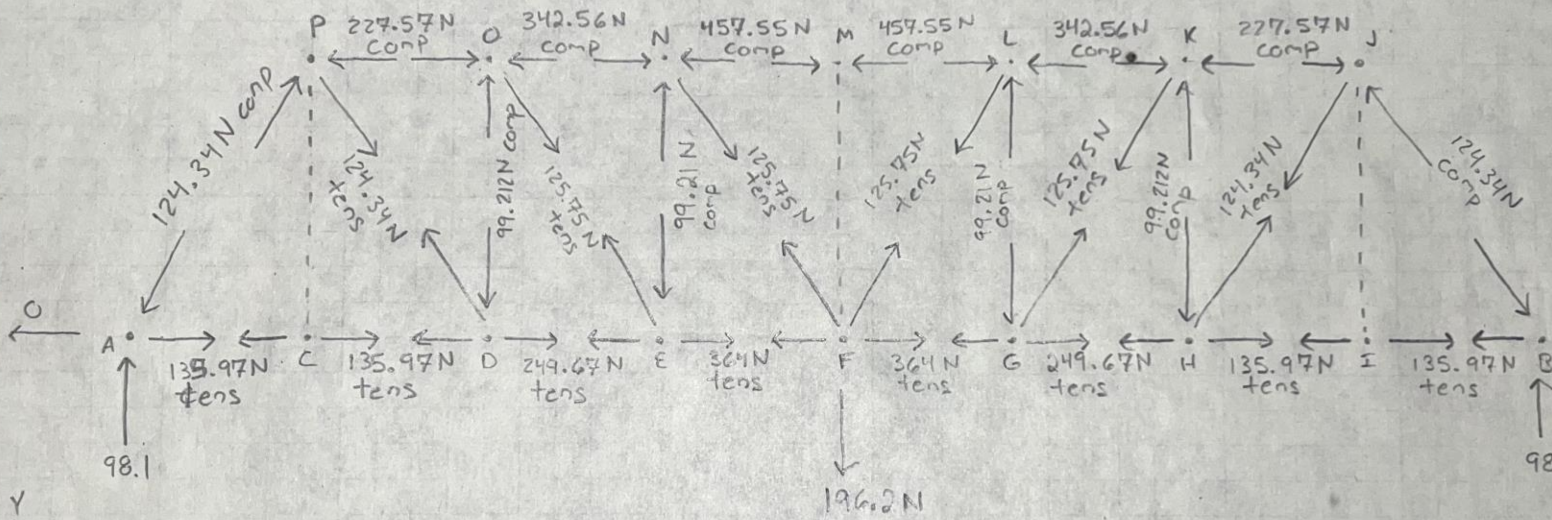



Figure A-1.3: Method of Joints Continued

Method of Joints




Ultimate Tensile Strength: 14 MPA = 14N/mm² = $\sigma_{max} = \frac{P_{max}}{A_o}$

Youngs Modulus: 3GPa = 3000 N/mm²

Compressive Strength: 7MPa = 7N/mm²: $F = \frac{P}{A}$

$$\text{Deflection} = \Sigma \frac{n_F N_F L_F}{E_F A_F}$$

n = axial force in Member F due to virt[ual] unit load

N = axial load in member, due to externally applied load

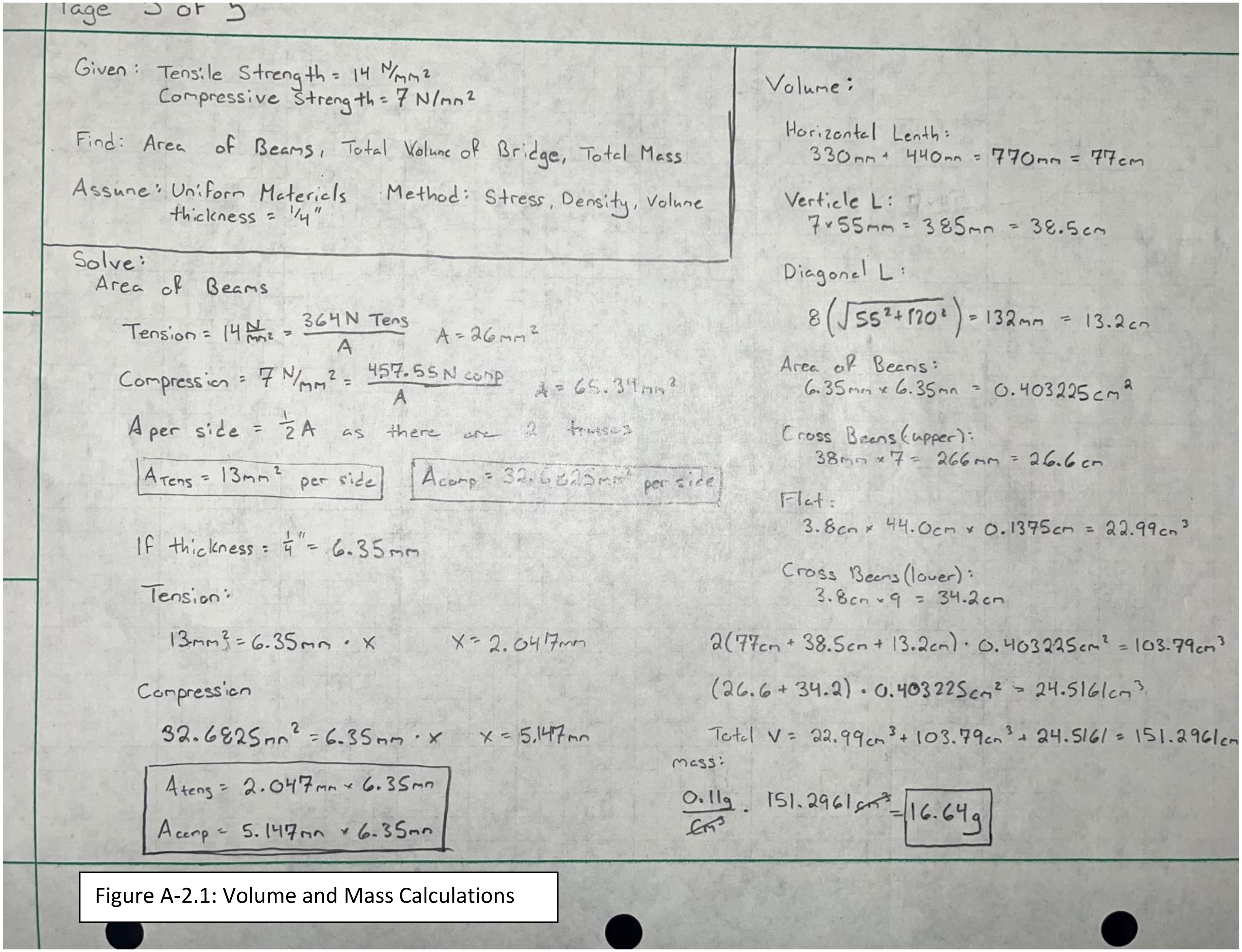
L = length of member

E = Modulus of elasticity

A = Area of member

Figure A-1.4: Final Force Calc Front View

# Appendix A02 – Volume and Mass of Bridge



Page 3 of 3

Given: Tensile Strength = 14 N/mm²
Compressive Strength = 7 N/mm²

Find: Area of Beams, Total Volume of Bridge, Total Mass

Assume: Uniform Materials, thickness = 1/4"
Method: Stress, Density, Volume

Solve:
Area of Beams

$\text{Tension} = 14\ \frac{N}{mm^2} = \frac{364\,N\ \text{Tens}}{A}$  $A = 26\,mm^2$

$\text{Compression} = 7\ N/mm^2 = \frac{457.55\,N\ \text{comp}}{A}$  $A = 65.34\,mm^2$

A per side = $\frac{1}{2}A$ as there are 2 trusses

$A_{Tens} = 13\,mm^2$ per side  $A_{comp} = 32.6825\,mm^2$ per side

If thickness = $\frac{1}{4}'' = 6.35\,mm$

Tension:

$13\,mm^2 = 6.35\,mm \cdot x$  $x = 2.047\,mm$

Compression

$32.6825\,mm^2 = 6.35\,mm \cdot x$  $x = 5.147\,mm$

$A_{tens} = 2.047\,mm \times 6.35\,mm$
$A_{comp} = 5.147\,mm \times 6.35\,mm$

Volume:

Horizontal Lenth:
$330\,mm + 440\,mm = 770\,mm = 77\,cm$

Verticle L:
$7 \times 55\,mm = 385\,mm = 38.5\,cm$

Diagonal L:
$8\left(\sqrt{55^2 + 120^2}\right) = 132\,mm = 13.2\,cm$

Area of Beams:
$6.35\,mm \times 6.35\,mm = 0.403225\,cm^2$

Cross Beams (upper):
$38\,mm \times 7 = 266\,mm = 26.6\,cm$

Flat:
$3.8\,cm \times 44.0\,cm \times 0.1375\,cm = 22.99\,cm^3$

Cross Beams (lower):
$3.8\,cm \times 9 = 34.2\,cm$

$2(77\,cm + 38.5\,cm + 13.2\,cm) \cdot 0.403225\,cm^2 = 103.79\,cm^3$

$(26.6 + 34.2) \cdot 0.403225\,cm^2 = 24.5161\,cm^3$

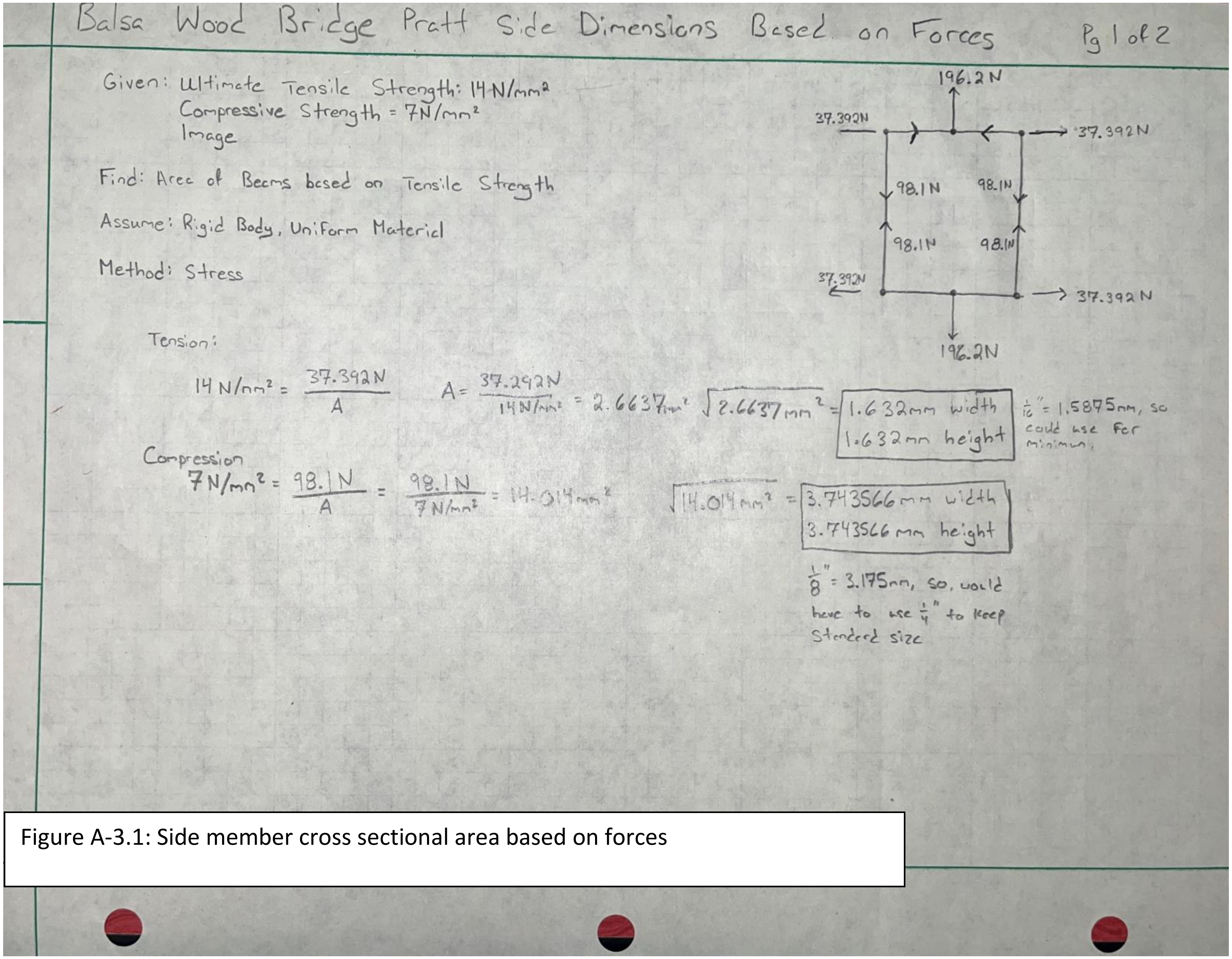
Total $V = 22.99\,cm^3 + 103.79\,cm^3 + 24.5161 = 151.2961\,cm^3$

mass:

$\frac{0.11\,g}{cm^3} \cdot 151.2961\,cm^3 = 16.64\,g$

Figure A-2.1: Volume and Mass Calculations

# Appendix A03 – Force and Minimum Dimensions of Side



Balsa Wood Bridge Pratt Side Dimensions Based on Forces   Pg 1 of 2

Given: Ultimate Tensile Strength: 14 N/mm²
Compressive Strength = 7N/mm²
Image

Find: Area of Beams based on Tensile Strength

Assume: Rigid Body, Uniform Material

Method: Stress



Tension:

$14 \text{ N/mm}^2 = \frac{37.392\text{N}}{A}$   $A = \frac{37.392\text{N}}{14\text{ N/mm}^2} = 2.6637\text{mm}^2$   $\sqrt{2.6637\text{mm}^2} =$ 1.632mm width, 1.632mm height

$\frac{1}{16}'' = 1.5875$mm, so could use for minimum.

Compression

$7 \text{ N/mm}^2 = \frac{98.1\text{N}}{A} = \frac{98.1\text{N}}{7\text{ N/mm}^2} = 14.014\text{mm}^2$   $\sqrt{14.014\text{mm}^2} =$ 3.743566mm width, 3.743566mm height

$\frac{1}{8}'' = 3.175$mm, so, would have to use $\frac{1}{4}''$ to keep standard size

Figure A-3.1: Side member cross sectional area based on forces

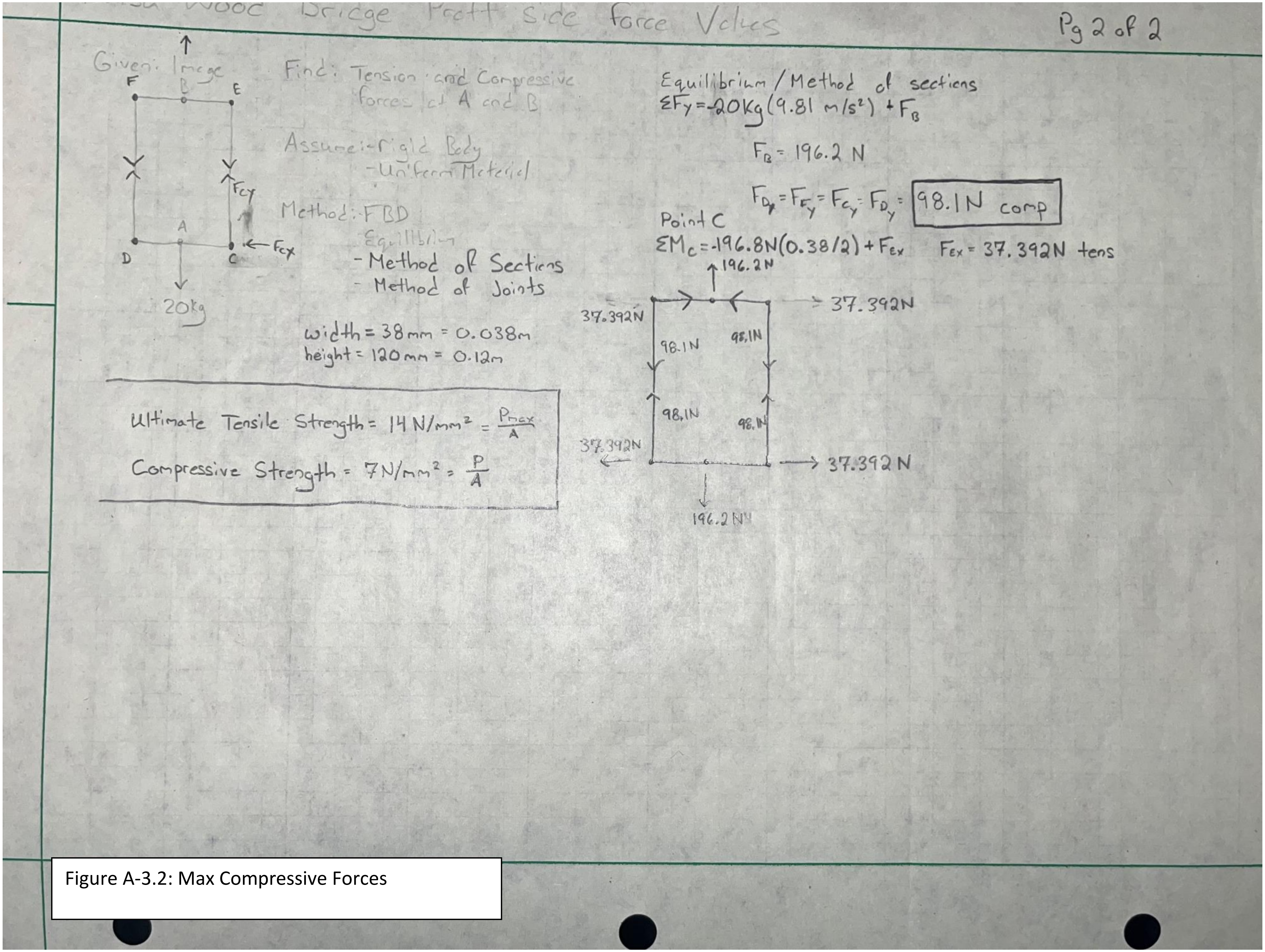



Figure A-3.2: Max Compressive Forces

# Appendix A04 – Articulation Structure Cable Positioning

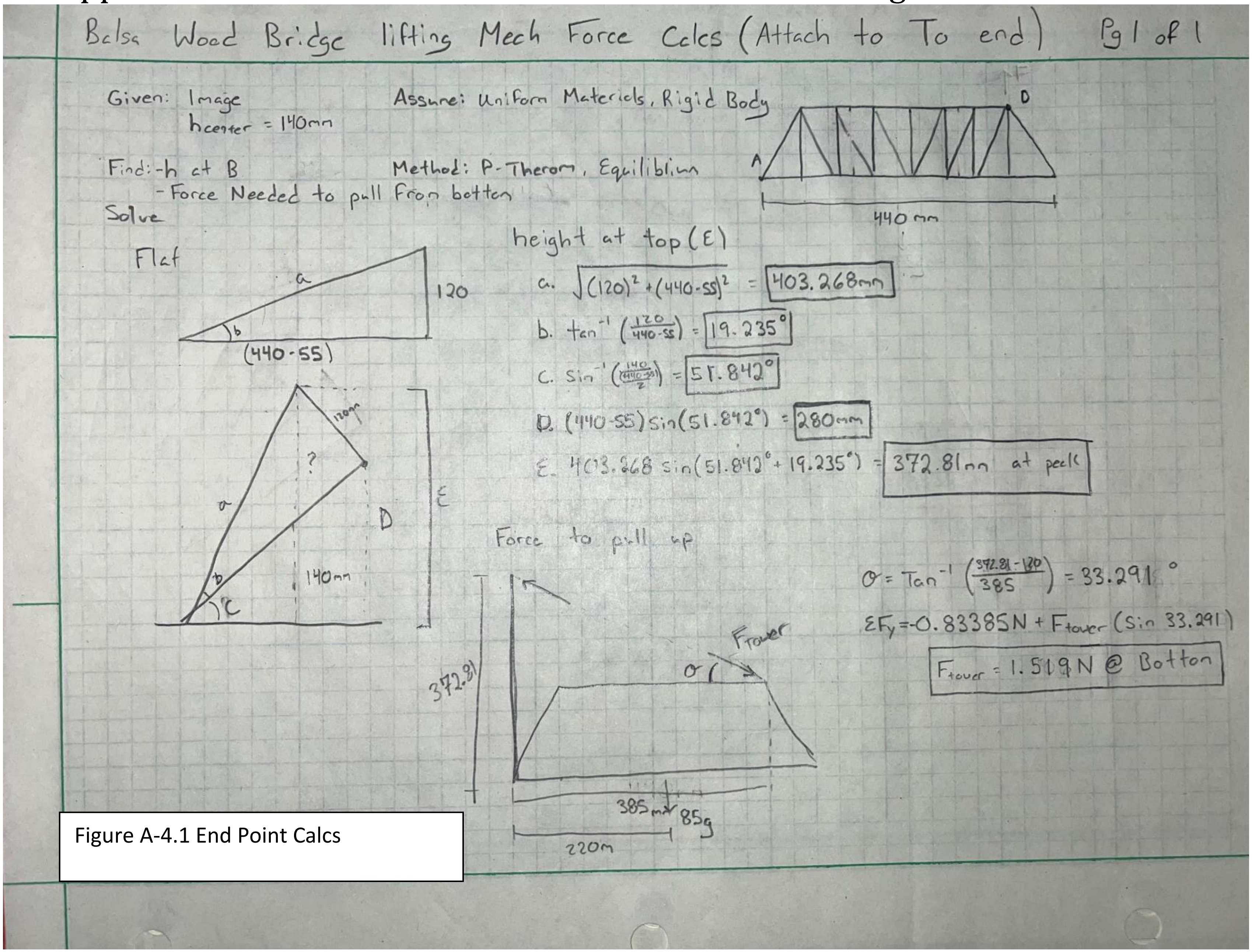



Figure A-4.1 End Point Calcs

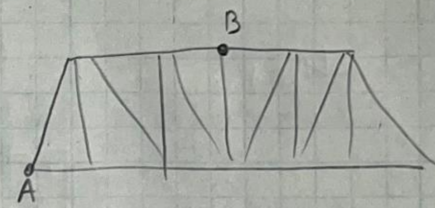
# Balsa Wood Bridge Lifting Mech Force Calcs (Attached to middle) Pg 1of1

Given: h Center = 140mm Image

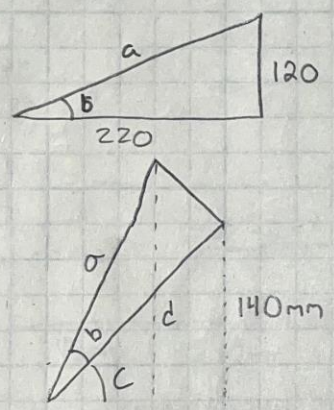
Find: - h at point B
- Force needed to pull (From Bottom ...)

Assume: Uniform Materials Rigid Body

Method: P-Theorem, Equilibrium




Solve:

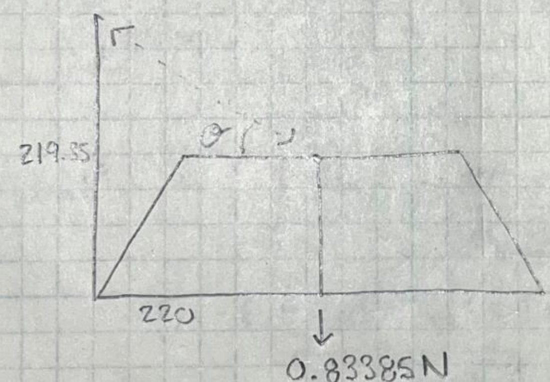



a. $\sqrt{220^2 + 120^2} = 250.6$ mm

b. $Tan^{-1}\left(\frac{120}{220}\right) = 28.61°$

c. $Tan^{-1}\left(\frac{140}{220}\right) = 32.47°$

d. $250.6 \cdot \sin(28.61 + 32.47) = 219.35$ mm




$\sigma = Tan^{-1}\left(\frac{219.35 - 120}{220}\right) = 24.304°$

$\Sigma F_y = -0.83385N + F_{Tover}(\sin 24.304)$

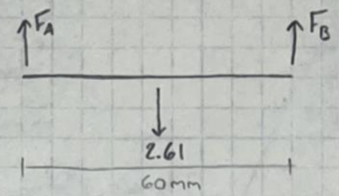
$F_{Tover} = 2.020N$

Figure A-4.2 Middle Point Calcs

# Appendix A05 – Articulation Forces

Balsa Wood Bridge Articulation Structure Forces (Front) Pg 1 of 1

Given: Diagram



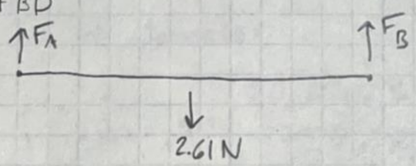

Find: Reaction Forces

Assume: Rigid Body

Method: FBD, Sum of Forces, Sum of Moment, beam bending

Solve:

FBD




$$\Sigma M_A = 0 = (2.61N)(30mm) + F_B(60mm)$$

$$\boxed{F_B = 1.305N \quad F_A = F_B}$$

Figure 5.1: Forces on Articulation Cross Beam

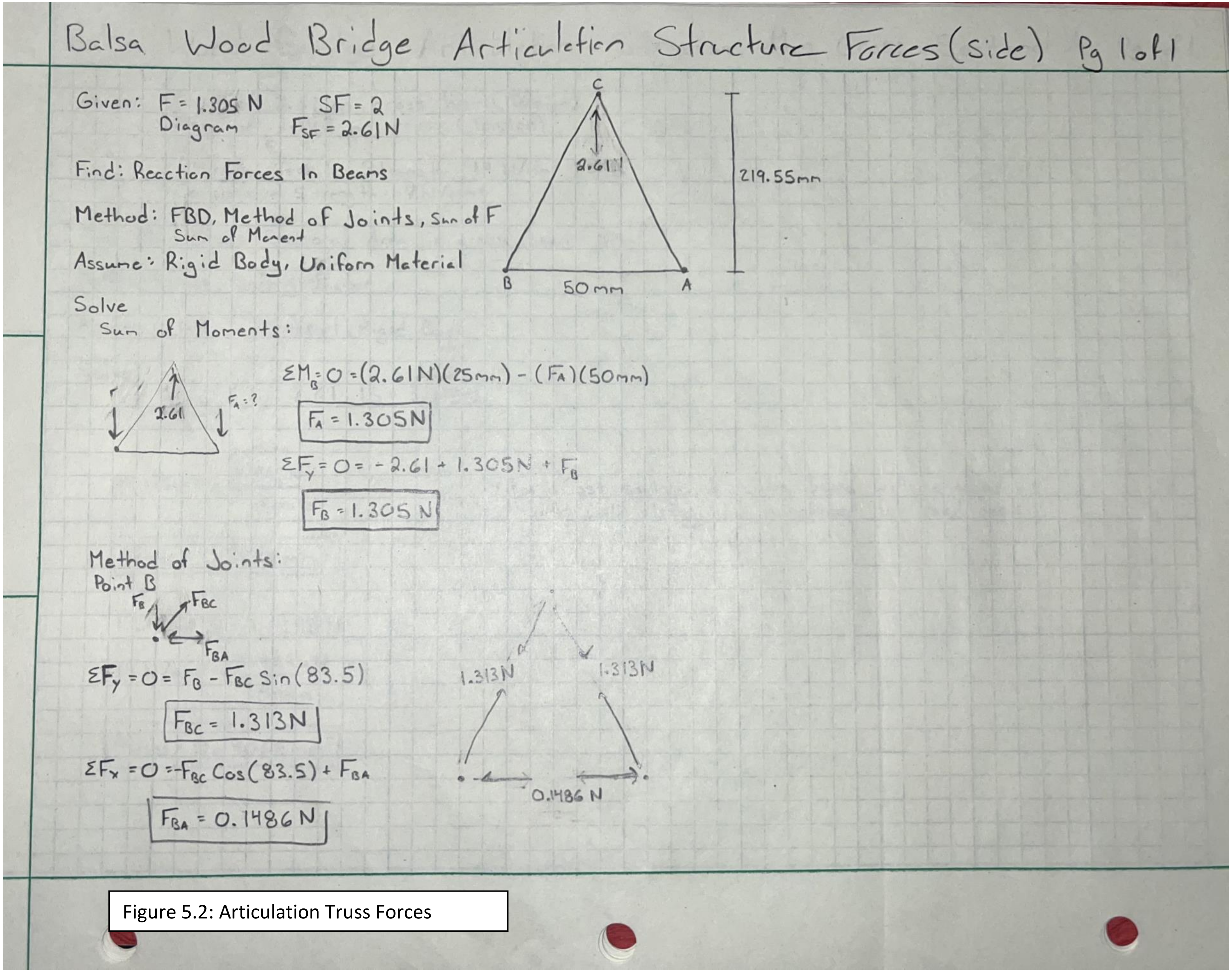



Figure 5.2: Articulation Truss Forces

# Appendix A06 – Articulation Cross-Sectional Area + Weight

Balsa Wood Bridge Articulation Structure Min Cross Sectional A Pg 1 of 1

Given: Max F of 2.61 on cross beam (Tension)
Max F of 1.313 on truss (Tension)
S.F. = 1.5
Ultimate Tensile Strength = 14 N/mm²
Compressive Strength = 7 N/mm²

Find: Min Cross Sectional Area in cross beam + Truss

Method: Stress, Safety Factor

Assume: Uniform Material, Rigid Body

Solve:

$$\sigma = \frac{F}{A}$$

$$2.61 \cdot 1.5 = 3.915N$$

$$14\ N/mm^2 = \frac{3.915N}{A_{cross}}$$

* For Cost savings, 1/8" square beams will be used as board will already be purchased for road deck

$$\boxed{A_{cross} = 0.2796\ mm^2}$$

$$1.313 \cdot 1.5 = 1.9695N$$

$$14\ N/mm^2 = \frac{1.9695N}{A_{Truss}}$$

$$\boxed{A_{Truss} = 0.14068\ mm^2}$$

Figure 6.1: Articulation Structure Cross-Sectional Area

# Balsa Wood Bridge Articulation Structure Weight



Given: 1/8" Square Cross Sectional Area = 3.175mm

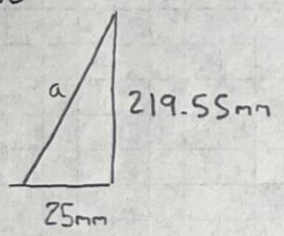
Lower L = 100mm
Beam height = 219.55mm
2 Trusses
Cross bean = 60mm
Density = 0.11g/cm³

Find: Mass of Articulation Structure

Method: Density, P-Theron

Assume: Homogeneous Structure, No Defects

Solve:




$a = \sqrt{219.55mm^2 + 25^2 mm} = 220.97mm$

Length = $(4 \times 220.97) + (2 \times 100) + (60 \times 3) = 1263.88mm = 126.388cm$

Cross-Sectional Area = $0.3175cm \times 0.3175cm = 0.100806 cm^2$

Volume = $126.388cm \times 0.10086 cm^2 = 12.7407cm^3$

mass = $\frac{0.11g}{cm^3} \cdot 12.7407cm^3 = \boxed{1.40g}$

Figure 6.2: Articulation Structure Weight

# Appendix A07 – Joint Analysis

## Balsa Wood Bridge Joint Analysis

Pg 1 of 1

Balsa Wood Strength:
Tensile strength: 14 MPa

Compression Strength = 7 MPa

Wood Glue Strength: (Soft wood parallel to grain)
Tensile Strength: 70 MPa

Compression Strength: 30 MPa

* Prepped Surface

Given: Bridge joint connection

Find: What Materials to use for joint connection

Assume: Pins, glue, and puzzle is the only methods that fit requirements

Method:

Solve:

- Puzzling bridge components is complicated to manufacture, so wont use that
- Pin method requires holes to be drilled, so wont use that

* Glue creates strong bonds and is easy to manufacture

Figure 7.1: Joint Analysis

# Appendix A08 – Motor Power

Motor Power  Pg 1 of 1

Sam Katsuda — Senior Project

Given: 2.61 N tension in cable

Find: What Power Motor is needed

Assume:

Method: P-Theron

Solve:

1 Nm/s = 1 W

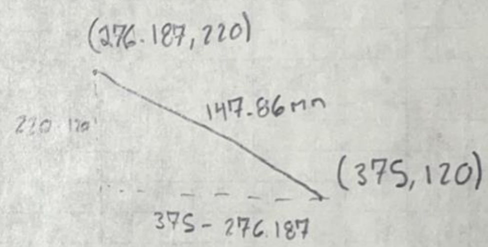
Force = 2.61 N

Distance: Length of cable lifting bridge

Time: 10 seconds to lift

W = Force · displacement

$P = \frac{W}{Time}$




Start position (375, 120)

New position (X, 220)    New Position (121.187, 220)

F = 2.61 N

D = 147.86mm

t = 10sec

$\frac{(2.61\,N)(0.14786\,m)}{10s} = 0.0386\,\frac{Nm}{s}$

**0.0386 watts**

$28.61° + 32.47° = 61.08$

$250.599\cos(61.08°) = 121.187 + 100 + 55$

Figure 8.1: Motor Power Part 1

# Motor For Structure



Given:

Necessary power = 0.0386 watts

Arduino Motor: 6v DC
3.2A max, 2.6 A (Stall Current)

Find: max power of arduino motor for if it can lift bridge

Assume: - Motor Mounted in static
- No Flex in motor mount

Method: Basic Electricity Equations

Solve:

$$P = VI$$

$$P = (6v)(3.2A) = \boxed{19.2 \text{ watts}}$$

$$P = (6v)(2.6A) = \boxed{15.6 \text{ watts}}$$

$$\boxed{0.0386 \text{ watts} \ll 15.6 \text{ watts}}$$

Figure 8.2: Motor Power Part 2

# Appendix A09- Motor Mount

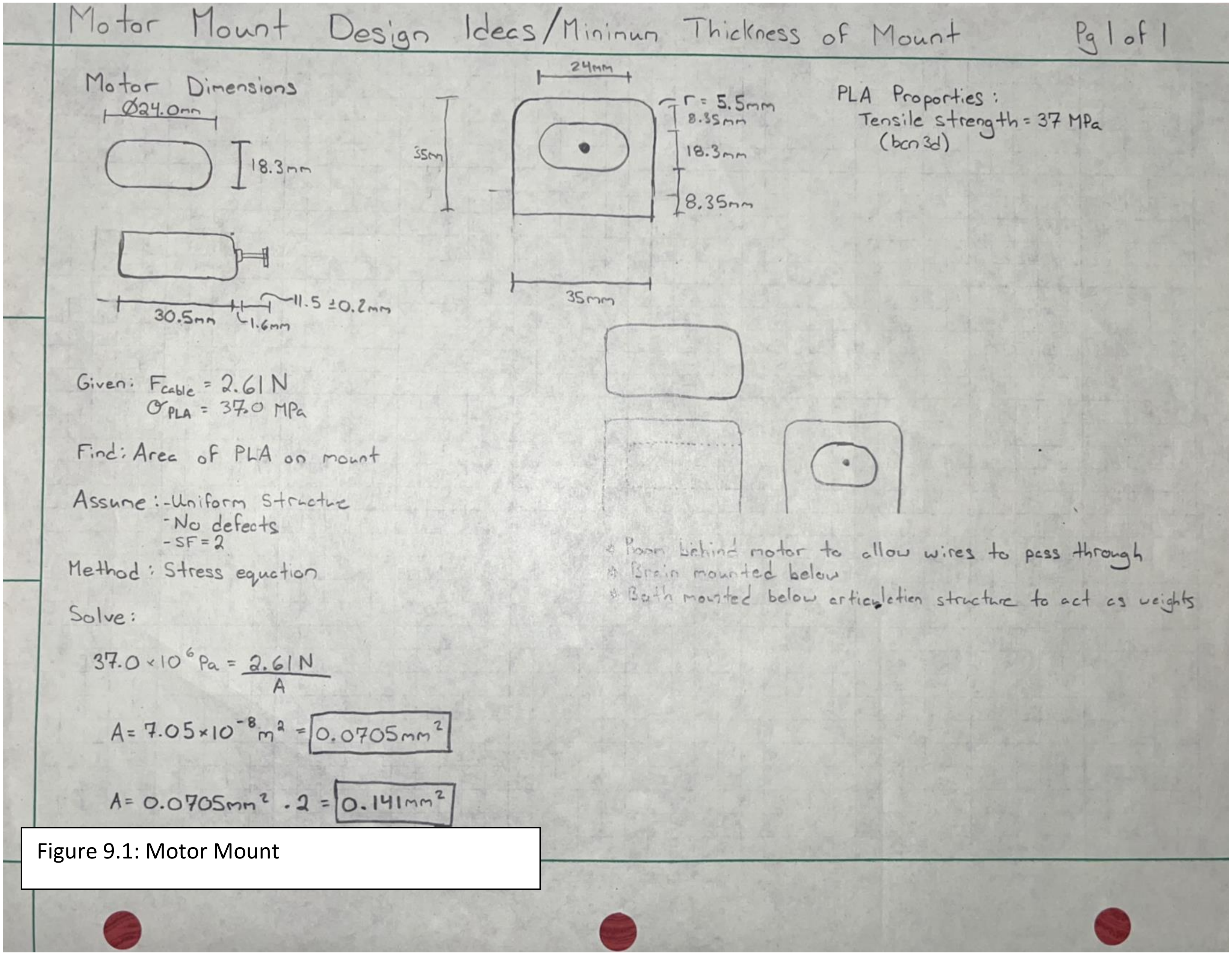



Figure 9.1: Motor Mount

# Appendix A10- Spool Dimensions

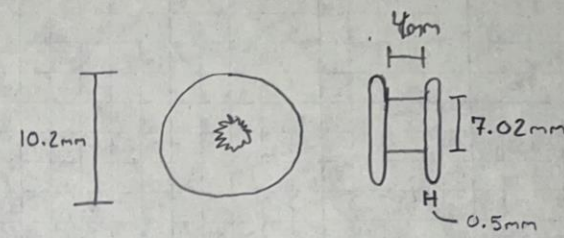
Articulating Balsa Wood Bridge: Radius of Spool / Dimensions     Pg 1 of 1

Given: Spool for Fishing Line, Length of line = 147.86mm

Find: Diameter + Width of spool for fishing line

Assume: Diameter of fishing line = 0.5mm

Method: Circumfrance / Length of Cylinder




Solve

Length = 147.86     Line Diameter = 0.5mm

Circumfrance = $D\pi = (7.02mm)\pi = 22.054mm$

Inner Gear diameter = 6.02mm

$EQ_1 = D\pi = 22.054mm$

Width of Spool = 4mm (Decided based on gear width)

$EQ_2 = \frac{147.86}{D\pi}$ = Number of spools. $\frac{[illegible]}{0.5}$ = 8 wraps of cable per width

if # spools > # $\frac{\text{wraps}}{\text{width}}$, 2nd layer is needed

$\frac{147.86}{22.057} = 6.704 < 8$ wraps per width

lip height = 1.5mm for safety factor of 3 cable widths

Figure 10.1: Spool Dimensions

# Appendix A11- Weight to Prevent Tipping

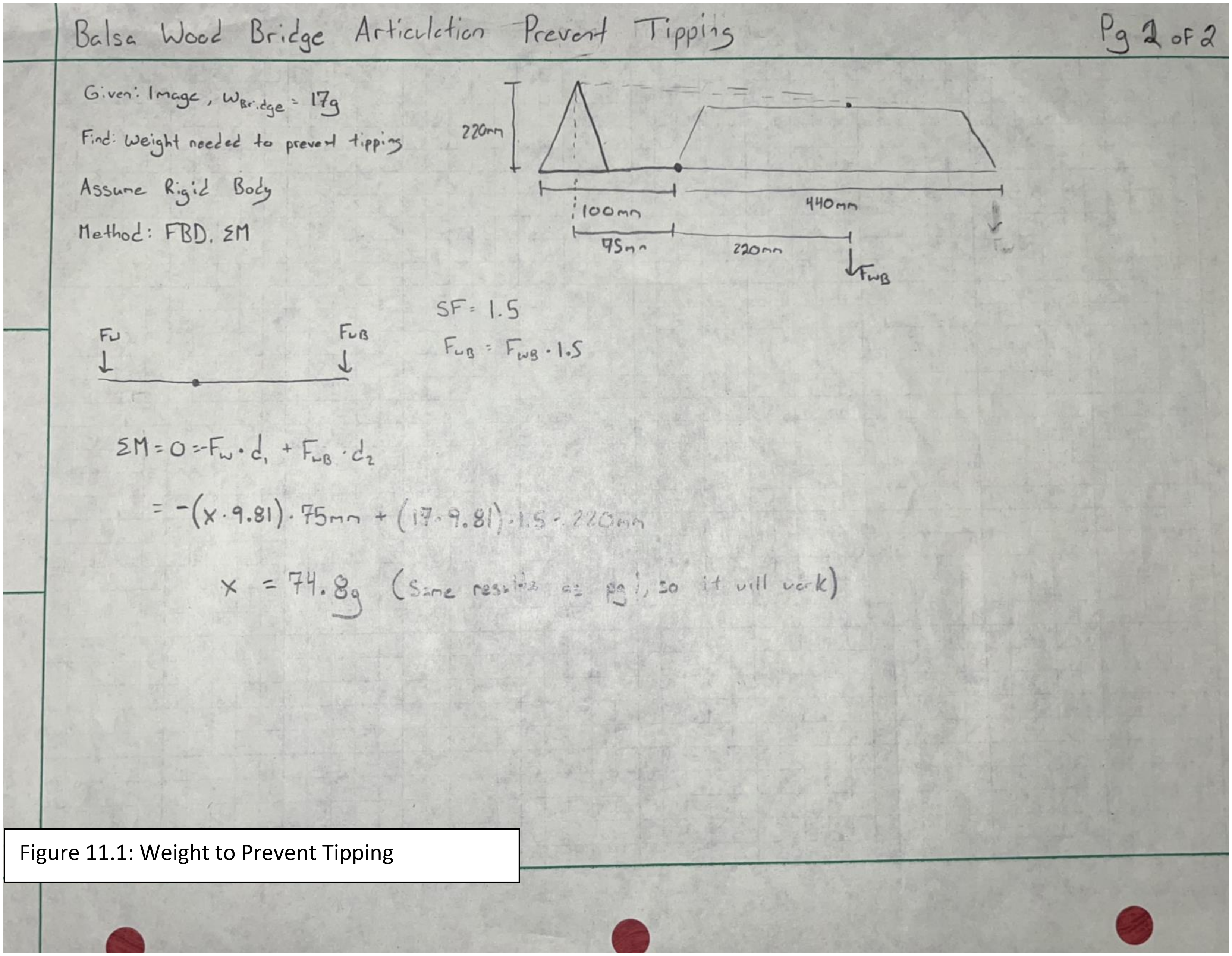



Figure 11.1: Weight to Prevent Tipping

# Appendix A12- Vertical Deflection

Balsa Wood Bridge Verticle Deflection

Given: $A = 6.35mm^2$ Bridge Design
$L = 440mm$

Find: Max Deflection

Assume: $E = 3.12$ GPa for low density balsa Wood

Method: Deflection of Joints

$$\text{Deflection} = \frac{(\Sigma NnL)}{AE}$$

*Using online calc, max deflection was found to be 6.869mm which is less then 25mm, so it will fit the requirement

Figure 12.1: Vertical Deflection Green Sheet

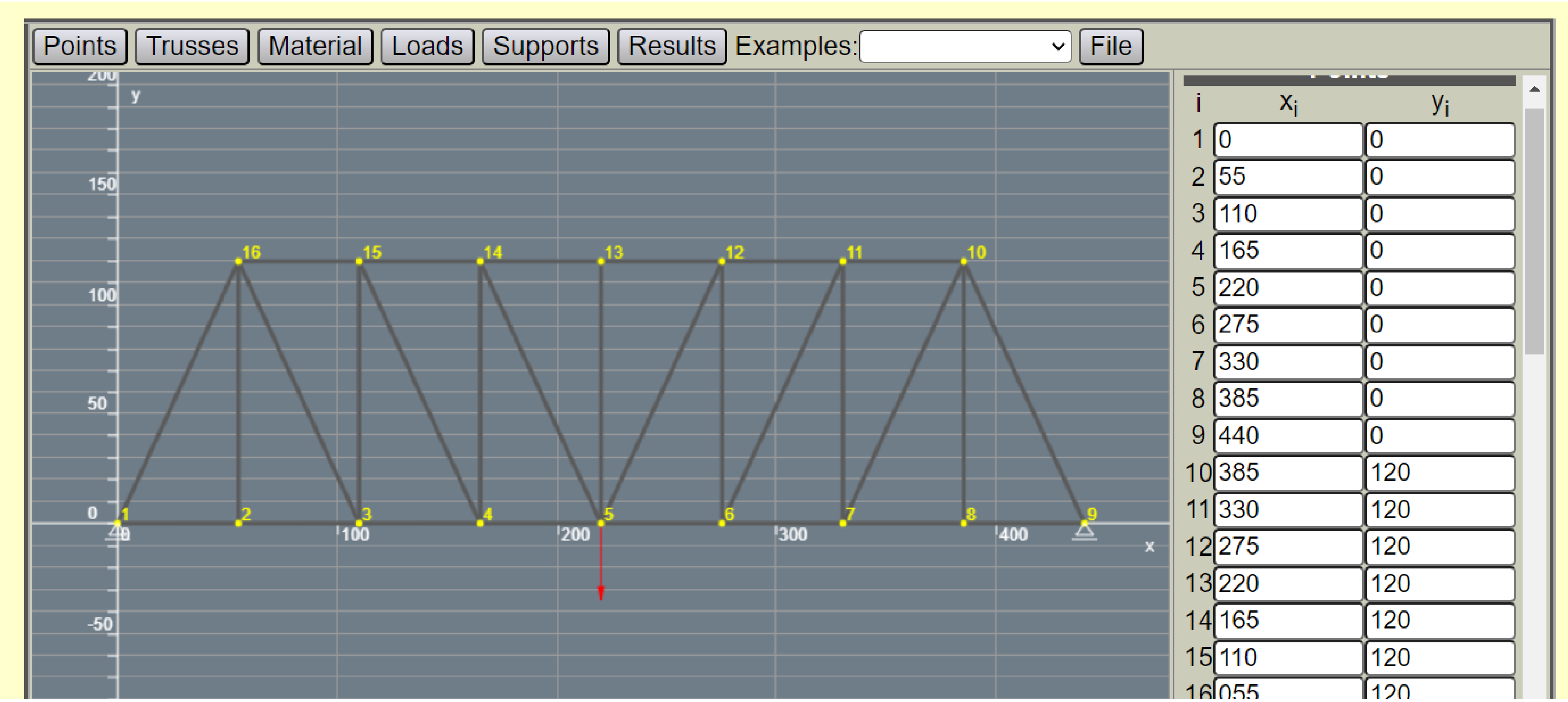



Figure 12.2: Points(Joints) on Truss(mm)

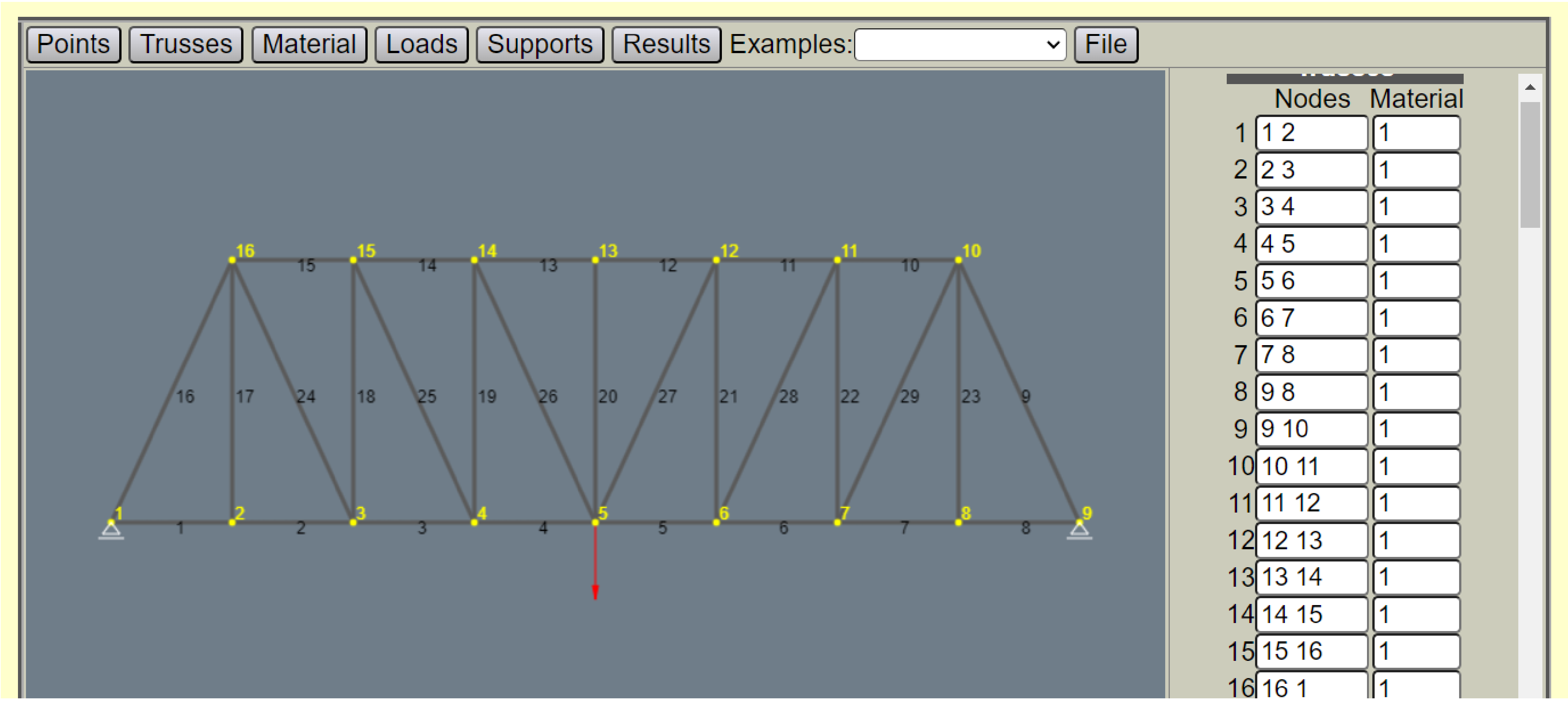



Figure 12.3: Connecting Joints

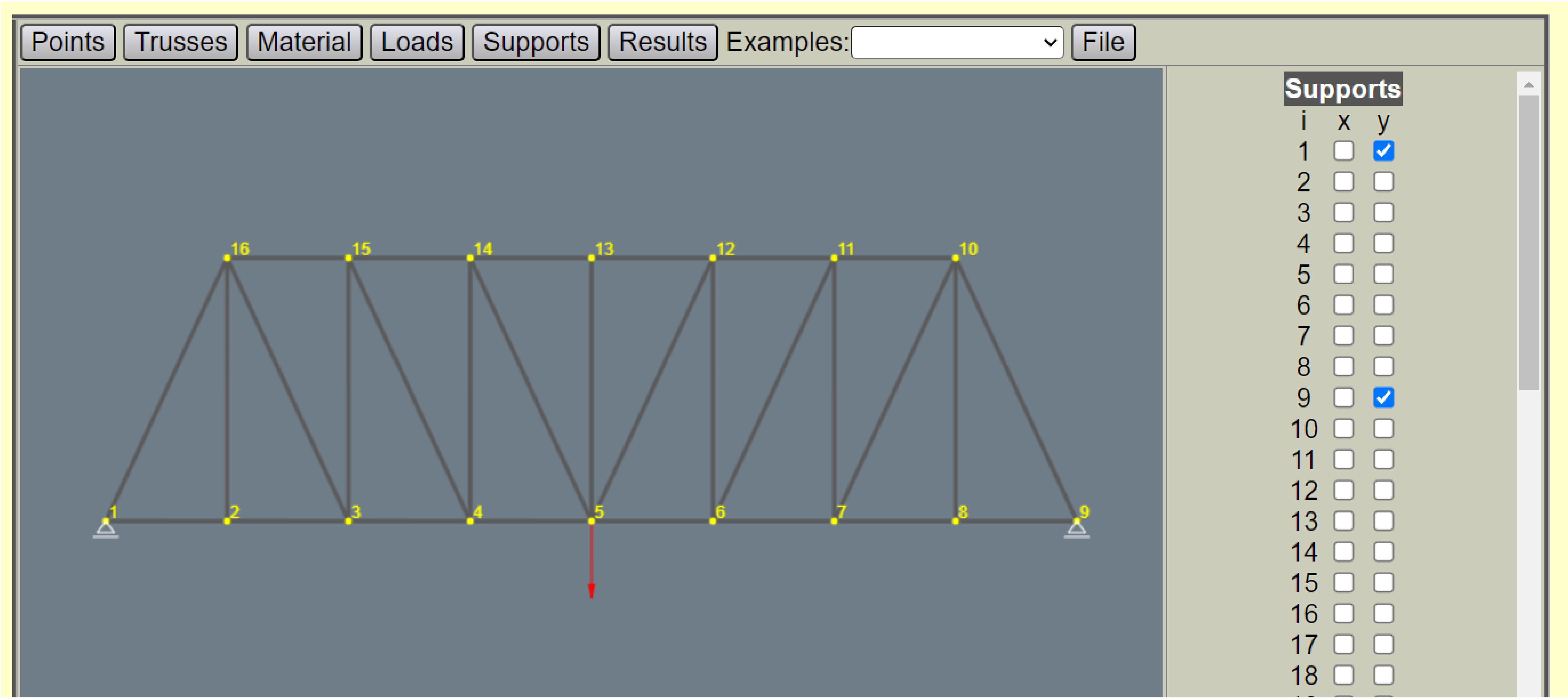



Figure 12.4: Support Locations

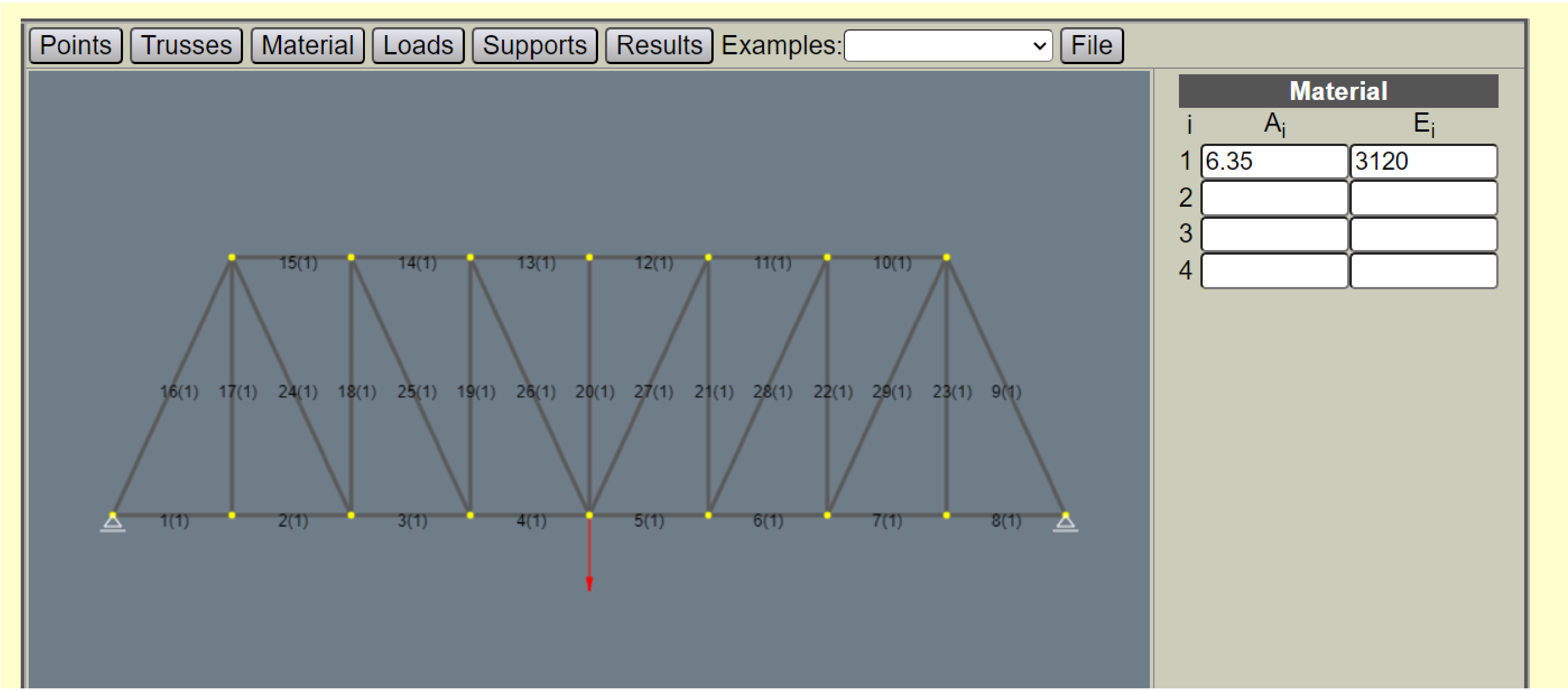



Figure 12.5: Material Properties (Youngs Modulus and Cross-Sectional Area)

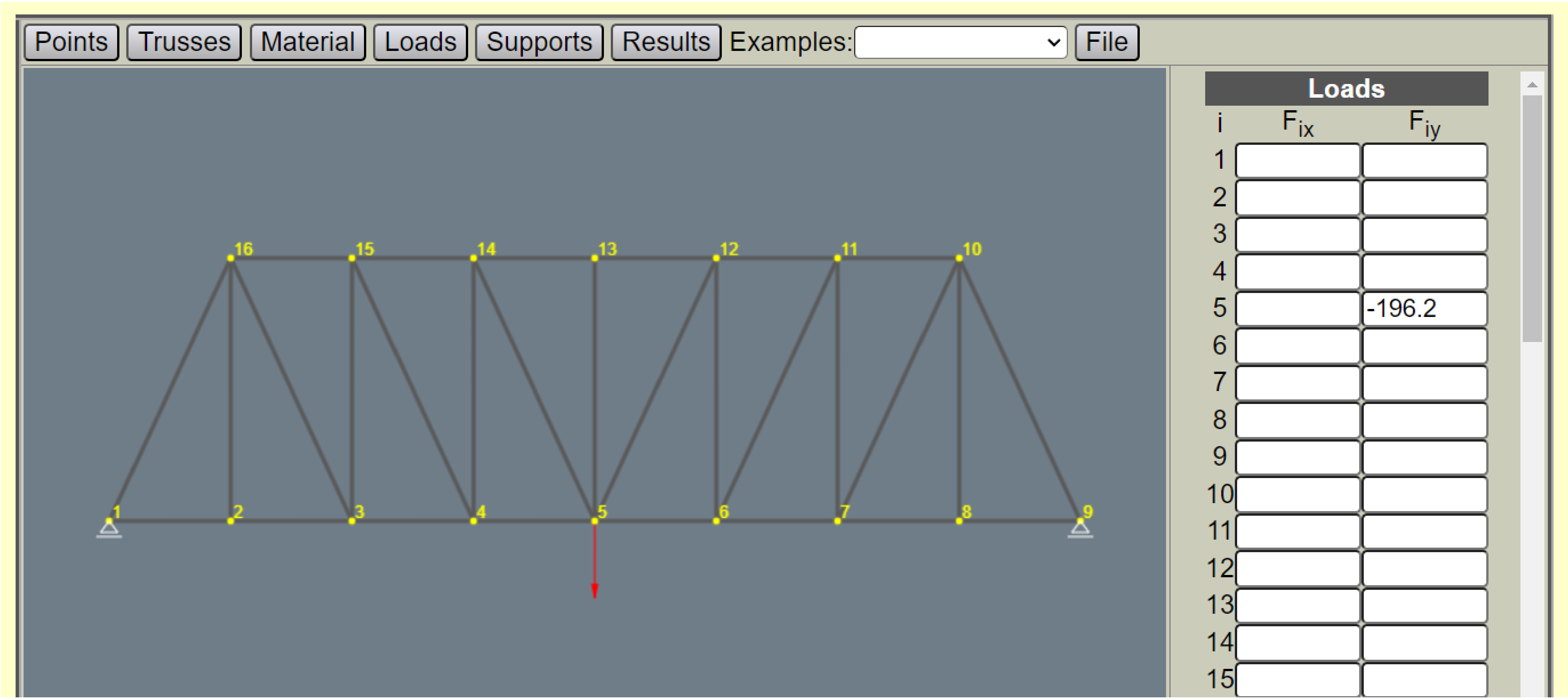



Figure 12.6: Force Acting on Bridge Due to Weight (N)

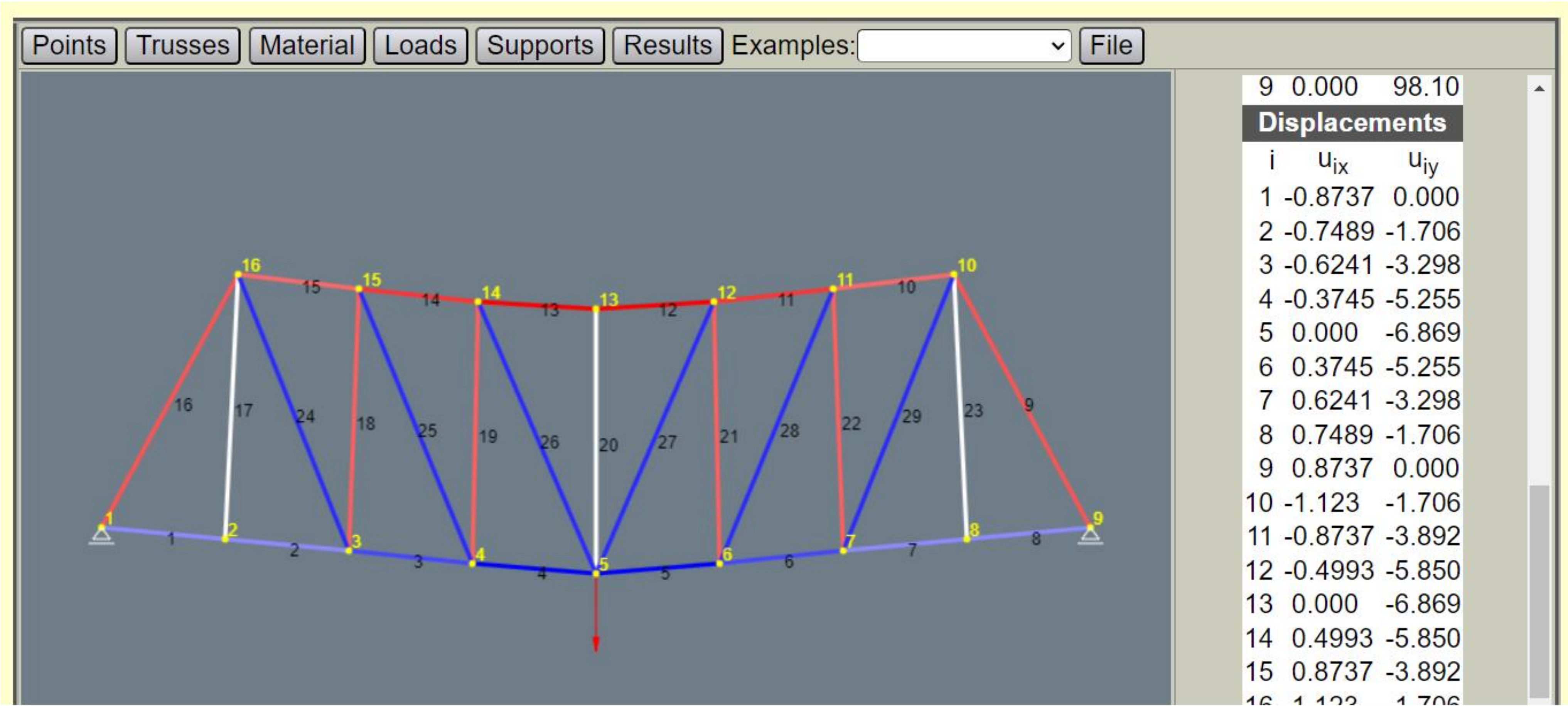



Figure 12.7: Vertical Displacement on Bridge

# Appendix A13- Articulation Cycle Time

Articulation Bridge | MET 489C | Sam Katsuda

Articulation Cycle Time

Given: $\Delta L$ string = 147.86 mm (analysis 8)

RPM = 165 rpm (Per the programmed assigned value)

Reel Diameter = 10mm    10 sec wait @ vertical

Find: Speed to Fully Articulate

Assume: Constant RPM, Constant Diameter, No resistance

Method: Circumferece, unit cancellation

Solve:

$$C = \pi d = 10\pi$$

$$RPM = \frac{\text{rotations}}{\text{minute}} = \frac{165 \text{ Rotations}}{\text{minute}} \qquad \frac{10\pi \text{ mm}}{\text{rotation}}$$

$$\frac{\text{minutes}}{165 \text{ rotation}} \cdot \frac{\text{rotation}}{10\pi \text{ mm}} \cdot \frac{60 \text{ sec}}{\text{min}} \cdot 147.86 \text{ mm} = 1.711 \text{ sec up}$$

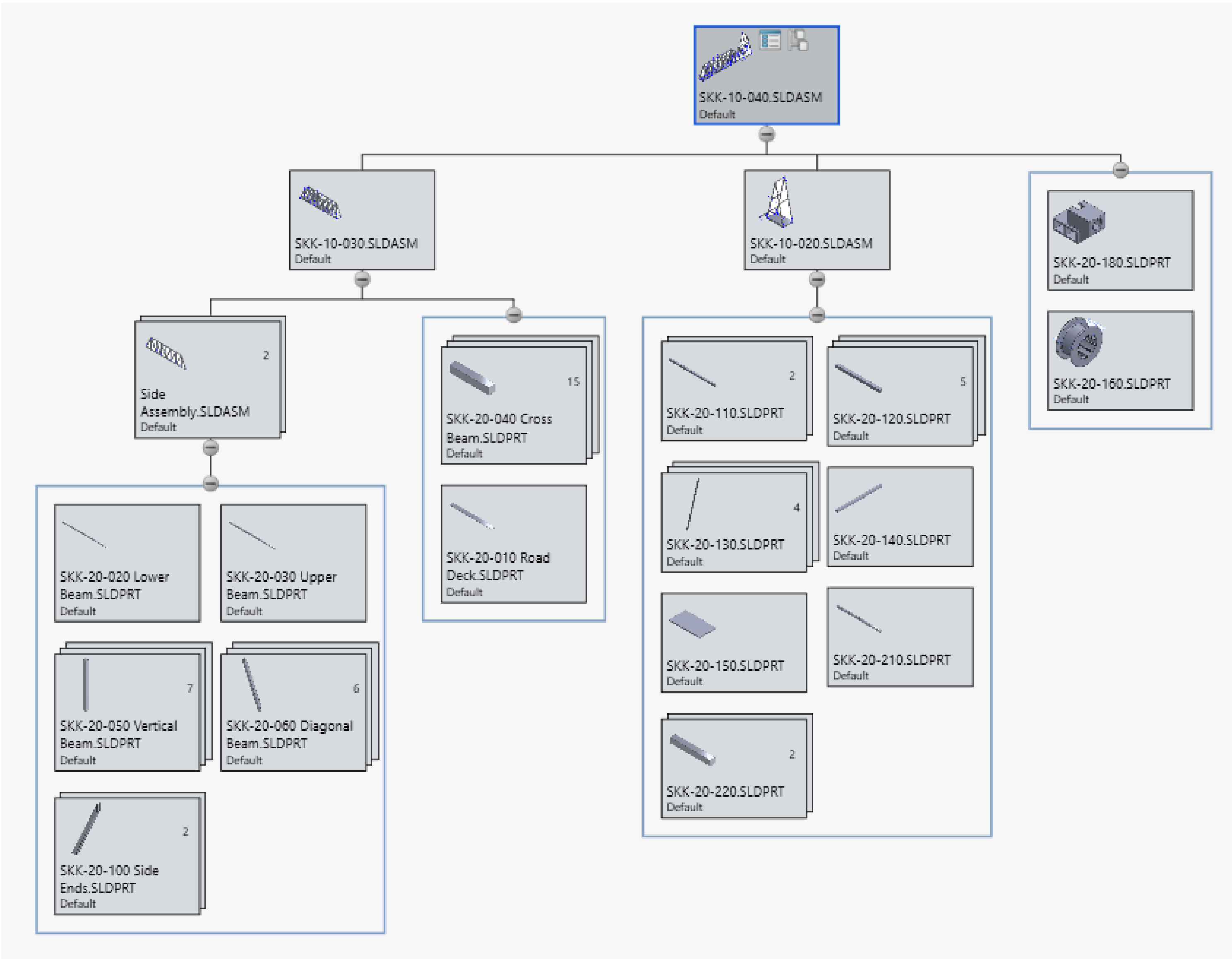
$$\frac{\text{minutes}}{50 \text{ rotations}} \cdot \frac{\text{rotations}}{10\pi \text{ mm}} \cdot \frac{60 \text{ sec}}{\text{min}} \cdot 147.86 \text{ mm} = 5.6478 \text{ sec down}$$

Total Cycle time = 1.711 + 5.6478 + 10 = **17.3588 sec**

Figure 13.1: Cycle Time Calculations

# APPENDIX B - Drawings

## Appendix B01 – Drawing Tree



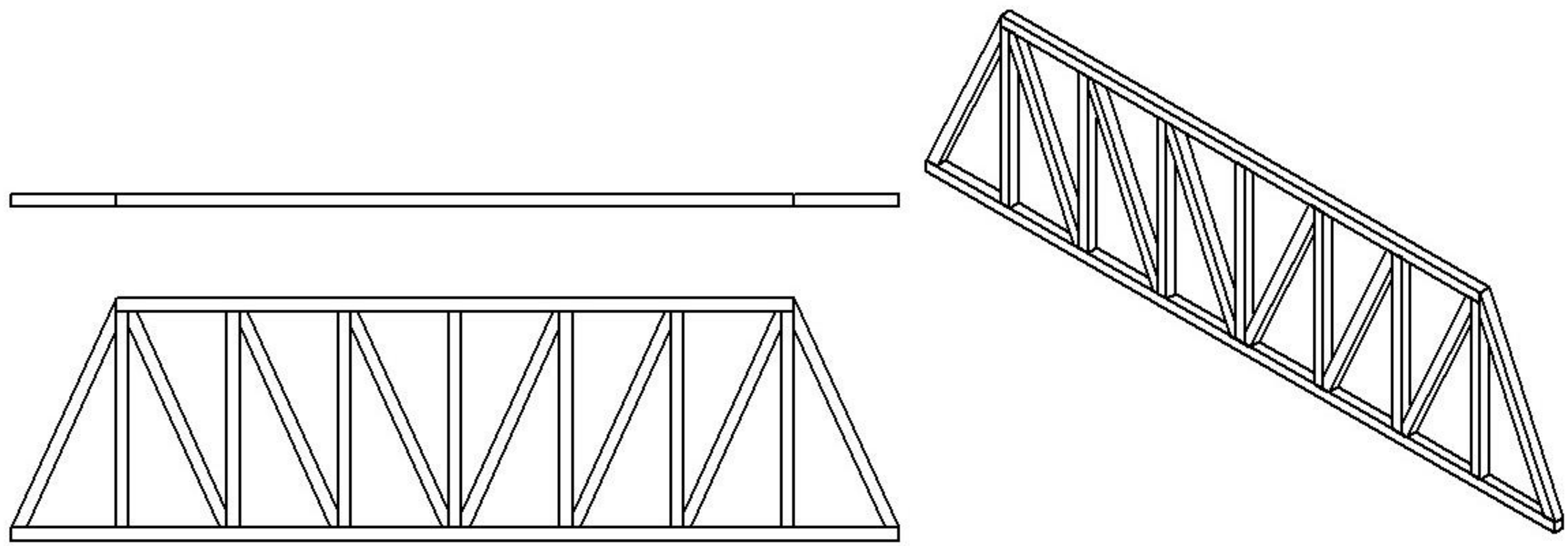
# Appendix B02 – Drawing Index

| DWG Number and filename | Description | DateCreated | ByWhom |
|---|---|---|---|
| SKK-10-010 | Side Assembly | 11/15/2023 | Sam Katsuda |
| SKK-10-020 | Articulation Structure | 11/15/2023 | Sam Katsuda |
| SKK-10-030 | Bridge Assembly | 11/15/2023 | Sam Katsuda |
| SKK-10-040 | Final Assembly | 11/27/2023 | Sam Katsuda |

| DWG Number and filename | Description | DateCreated | ByWhom |
|---|---|---|---|
| SKK-20-010 | Road Deck | 10/23/2023 | Sam Katsuda |
| SKK-20-020 | Lower Beam | 10/23/2023 | Sam Katsuda |
| SKK-20-030 | Upper Beam | 10/23/2023 | Sam Katsuda |
| SKK-20-040 | Cross Beam | 10/23/2023 | Sam Katsuda |
| SKK-20-050 | Vert Beam | 10/23/2023 | Sam Katsuda |
| SKK-20-060 | Diagonal Beam | 10/23/2023 | Sam Katsuda |
| SKK-20-070 | Articulation Base | 11/7/2023 | Sam Katsuda |
| SKK-20-080 | Articulation Verticals | 11/7/2023 | Sam Katsuda |
| SKK-20-090 | Articulation Cross Beams | 11/7/2023 | Sam Katsuda |
| SKK-20-100 | Side Ends | 11/13/2023 | Sam Katsuda |
| SKK-20-110 | Articulation Bottom Beam Rev | 11/13/2023 | Sam Katsuda |
| SKK-20-120 | Articulation Cross Beams Rev | 11/13/2023 | Sam Katsuda |
| SKK-20-130 | Articulation Verticals Rev | 11/13/2023 | Sam Katsuda |
| SKK-20-140 | Articulation Reel Beam | 11/13/2023 | Sam Katsuda |
| SKK-20-150 | Articulation Motor Plaform | 11/13/2023 | Sam Katsuda |
| SKK-20-160 | Cable Reel | 11/18/2023 | Sam Katsuda |
| SKK-20-170 | Cable Passover | 11/18/2023 | Sam Katsuda |
| SKK-20-180 | Motor Mount | 11/27/2023 | Sam Katsuda |
| SKK-20-190 | Articulation Pin Right | 1/12/2024 | Sam Katsuda |
| SKK-20-200 | Articulation Pin Left | 1/12/2024 | Sam Katsuda |
| SKK-20-210 | Articulation Pin Mount | 4/6/2024 | Sam Katsuda |
| SKK-20-220 | Articulation Pin Mount Extension | 4/6/2024 | Sam Katsuda |

# Appendix B03 – <SKK-10-010 – Side Assembly

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | SKK-20-020 | Lower Beam | 1 |
| 2 | SKK-20-030 | Upper Beam | 1 |
| 3 | SKK-20-050 | Vertical Beam | 7 |
| 4 | SKK-20-060 | Diagonal Beam | 6 |
| 5 | SKK-20-100 | Side Ends | 2 |



UNLESS OTHERWISE SPECIFIED:

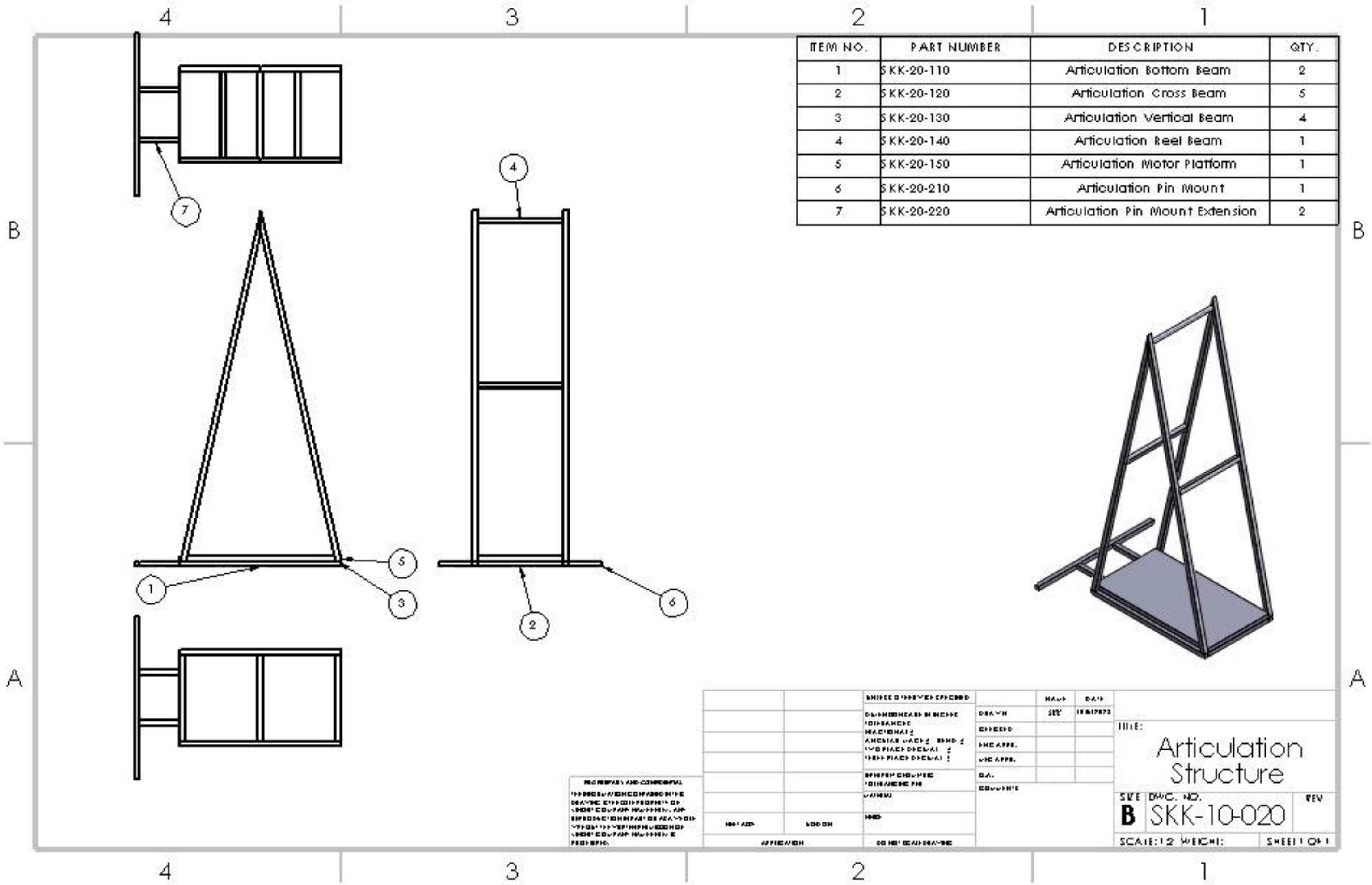
DRAWN SKK

TITLE: Side Assembly

SIZE B DWG. NO. SKK-10-010 REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

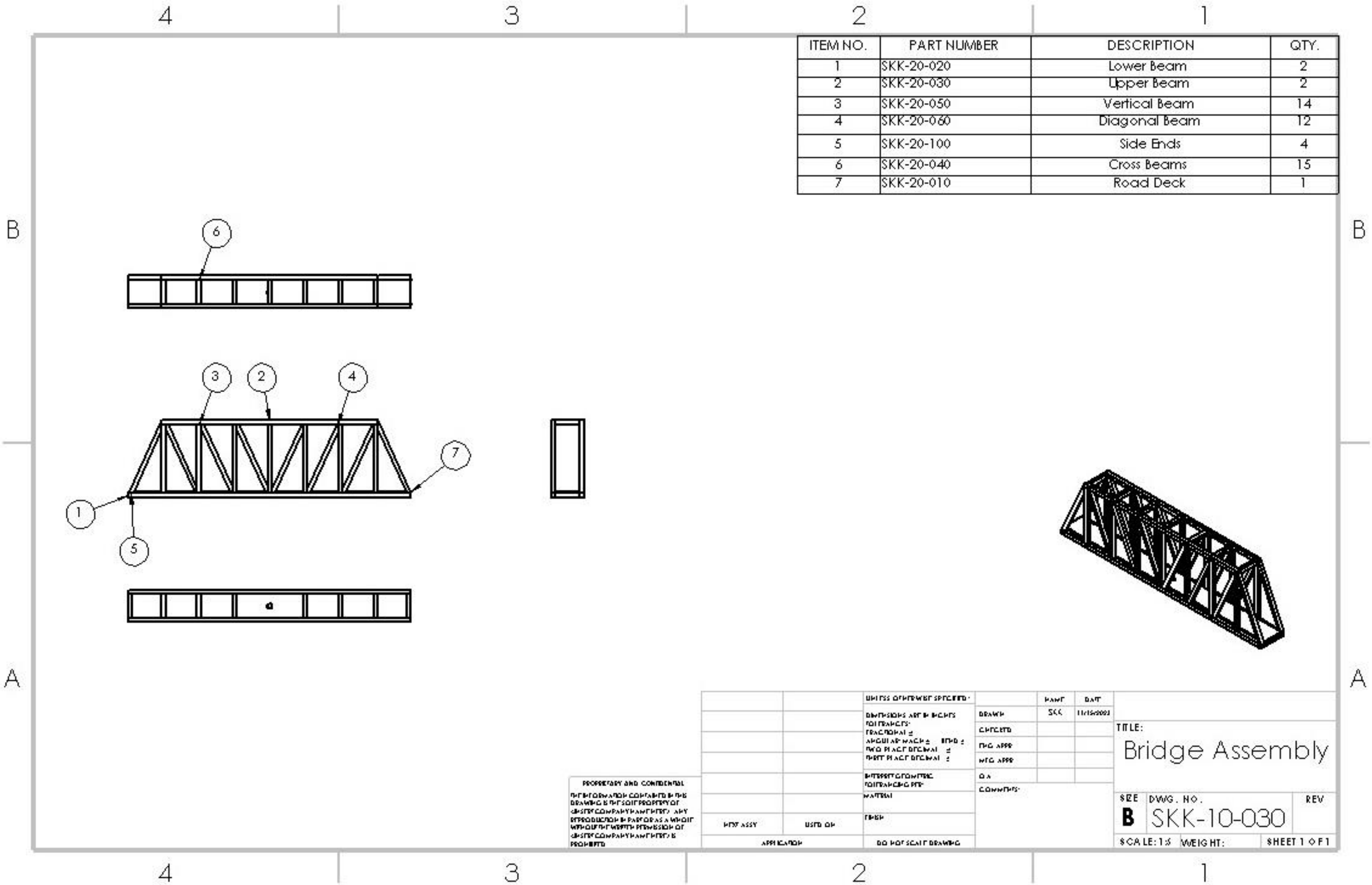
# Appendix B04 – <SKK-10-020 – Articulation Structure



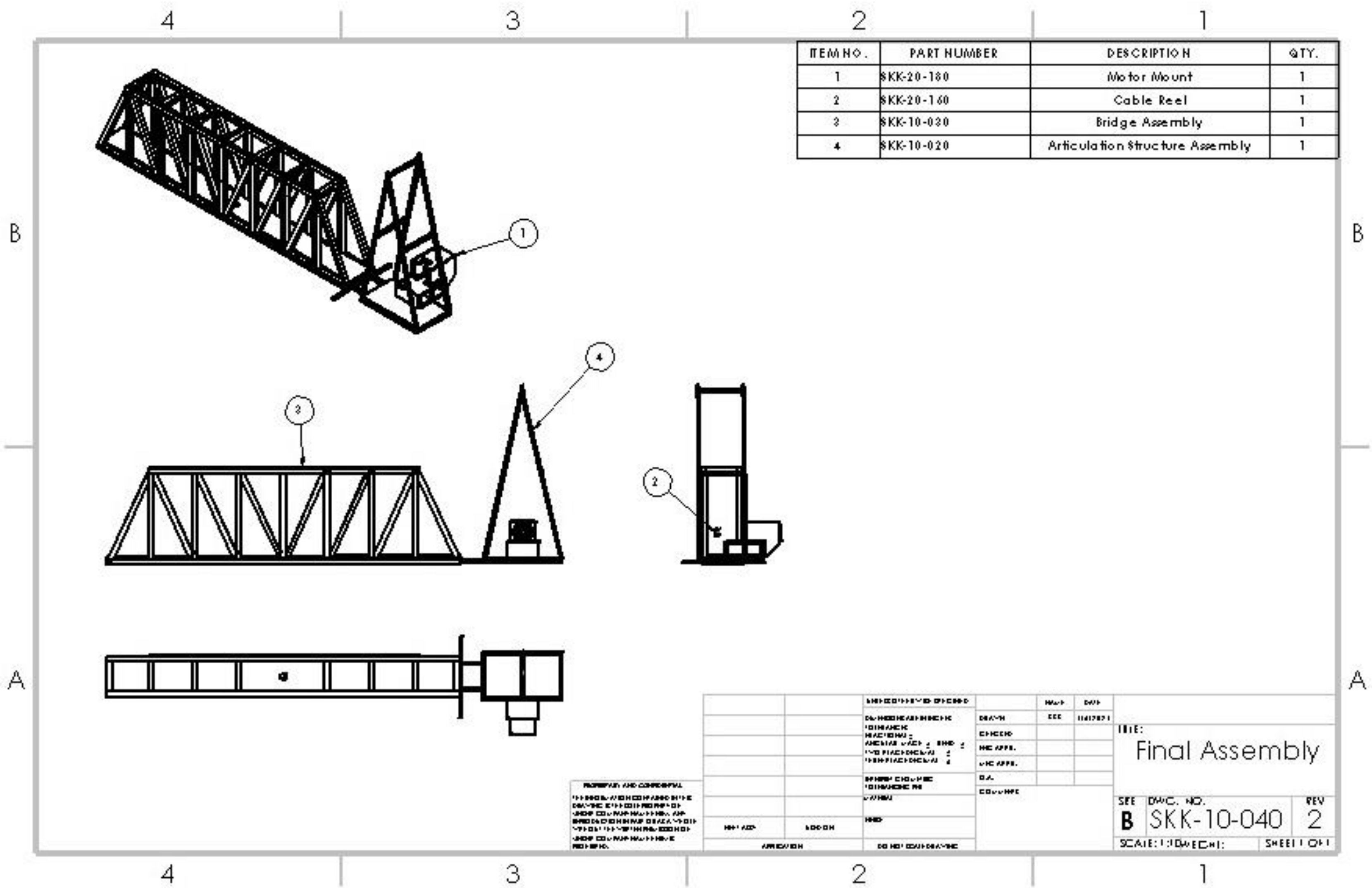

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | SKK-20-110 | Articulation Bottom Beam | 2 |
| 2 | SKK-20-120 | Articulation Cross Beam | 5 |
| 3 | SKK-20-130 | Articulation Vertical Beam | 4 |
| 4 | SKK-20-140 | Articulation Reel Beam | 1 |
| 5 | SKK-20-150 | Articulation Motor Platform | 1 |
| 6 | SKK-20-210 | Articulation Pin Mount | 1 |
| 7 | SKK-20-220 | Articulation Pin Mount Extension | 2 |

# Appendix B05 – <SKK-10-030 – Bridge Assembly

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | SKK-20-020 | Lower Beam | 2 |
| 2 | SKK-20-030 | Upper Beam | 2 |
| 3 | SKK-20-050 | Vertical Beam | 14 |
| 4 | SKK-20-060 | Diagonal Beam | 12 |
| 5 | SKK-20-100 | Side Ends | 4 |
| 6 | SKK-20-040 | Cross Beams | 15 |
| 7 | SKK-20-010 | Road Deck | 1 |

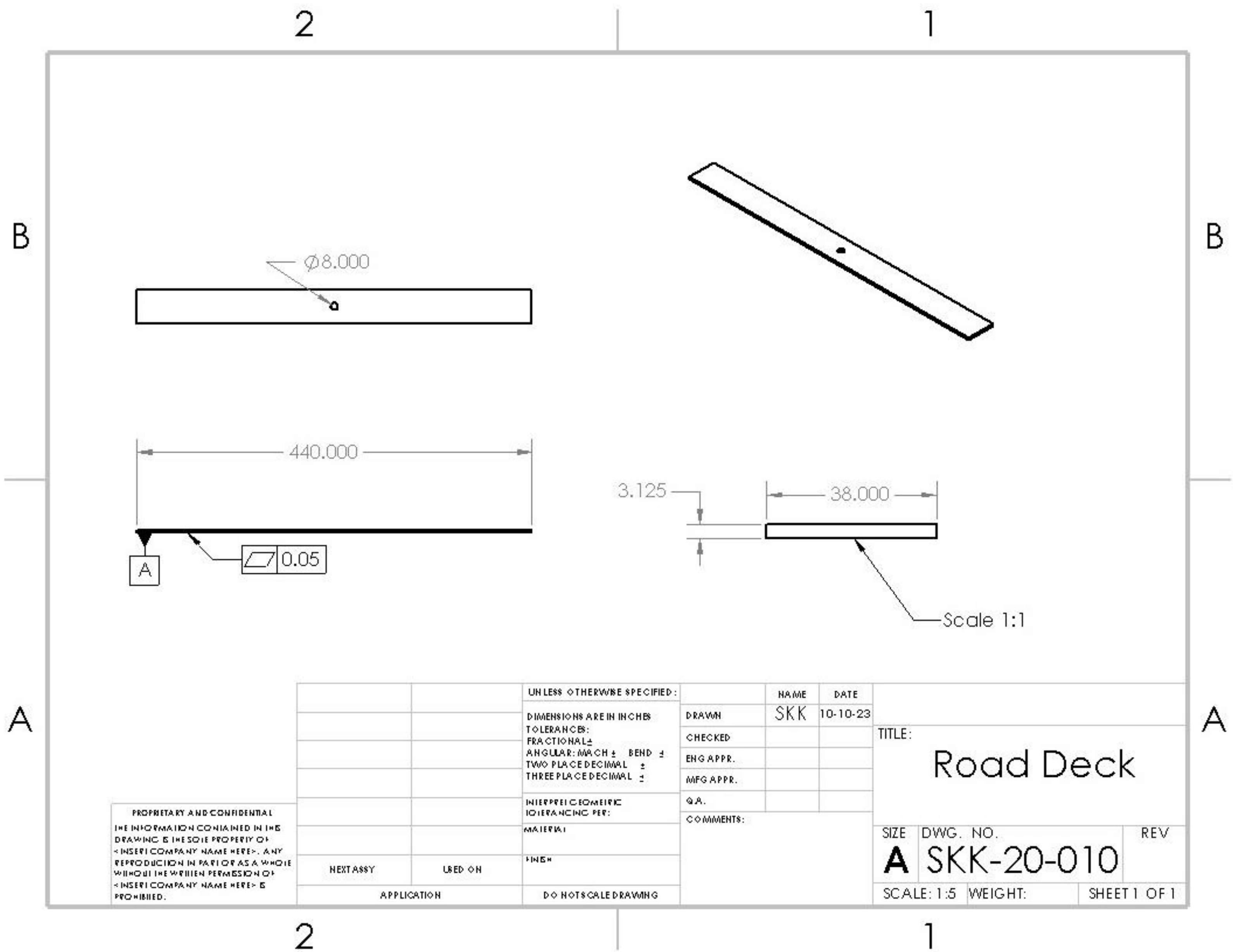


# Appendix B06 – <SKK-10-040 – Final Assembly

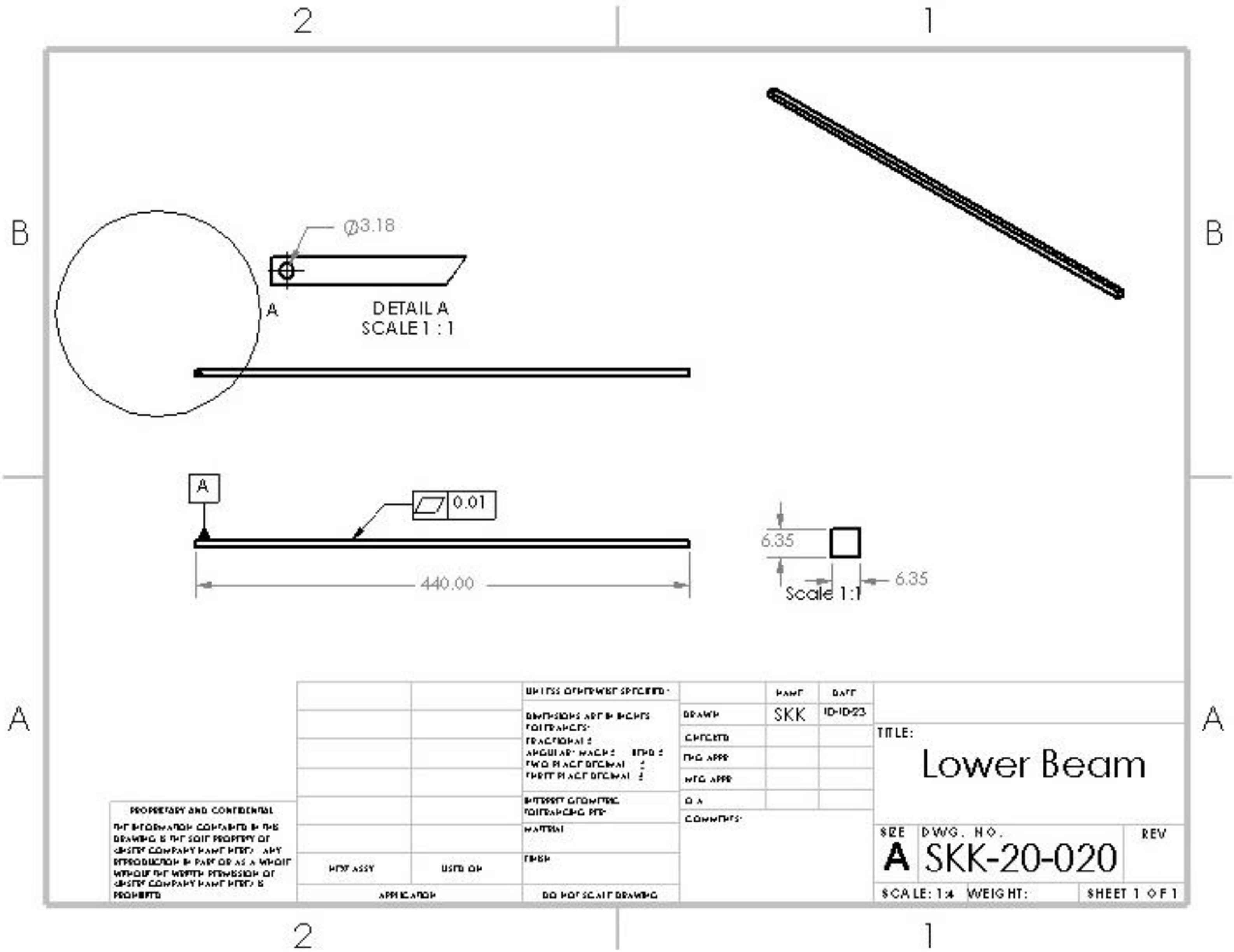



| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | SKK-20-180 | Motor Mount | 1 |
| 2 | SKK-20-160 | Cable Reel | 1 |
| 3 | SKK-10-030 | Bridge Assembly | 1 |
| 4 | SKK-10-020 | Articulation Structure Assembly | 1 |

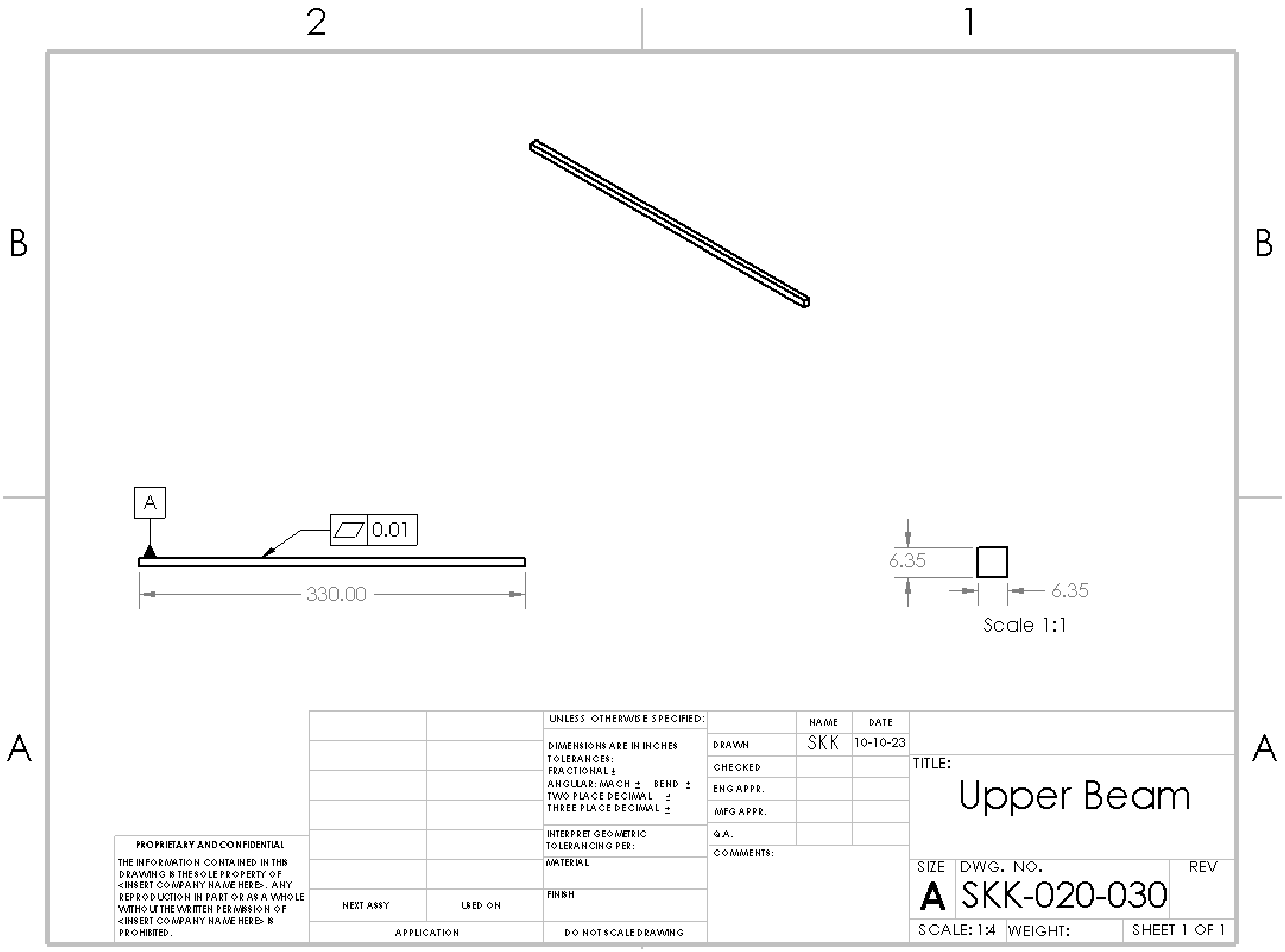
## Appendix B07 – <SKK-20-010 – Road Deck



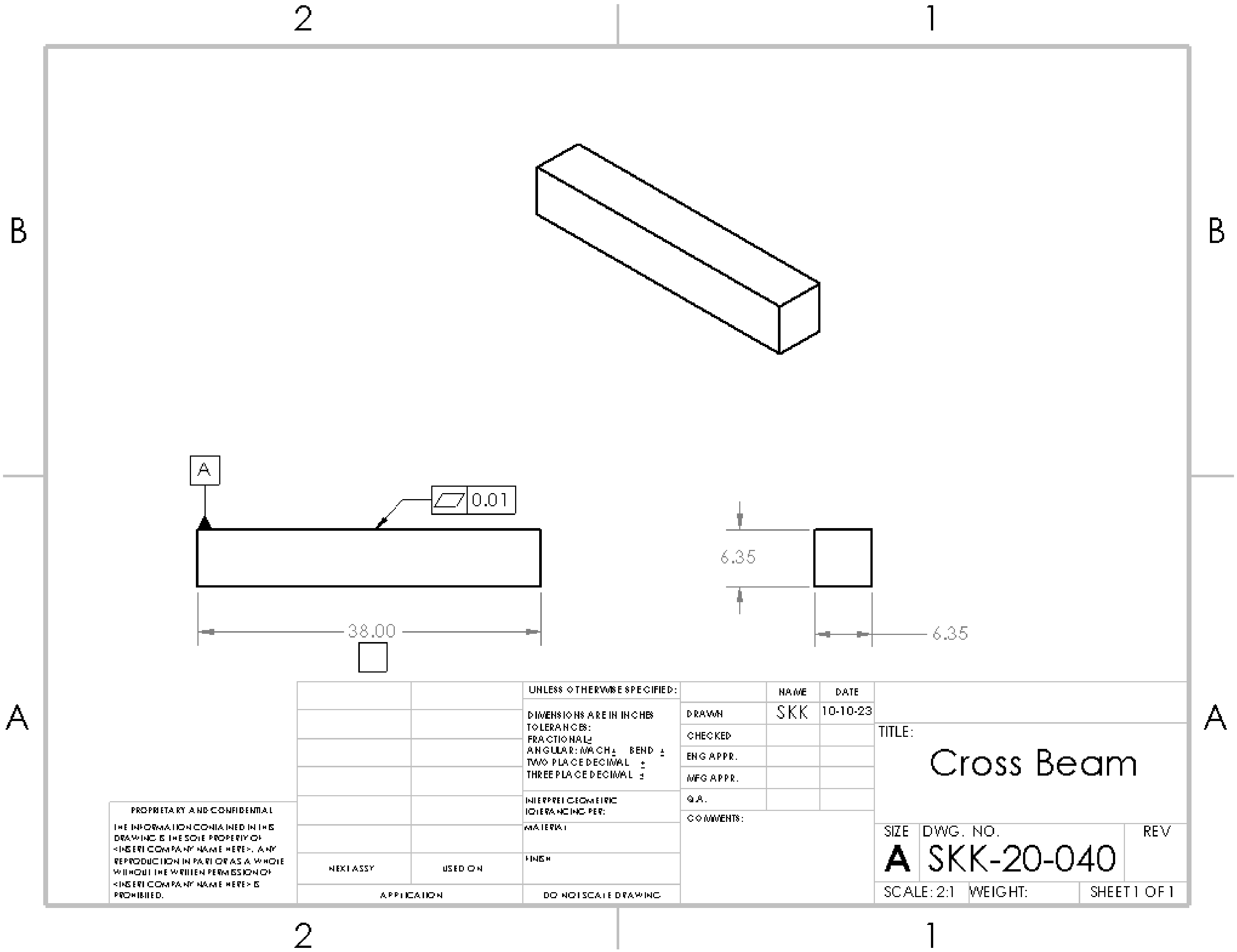
# Appendix B08 – <SKK-20-020 – Lower Beam



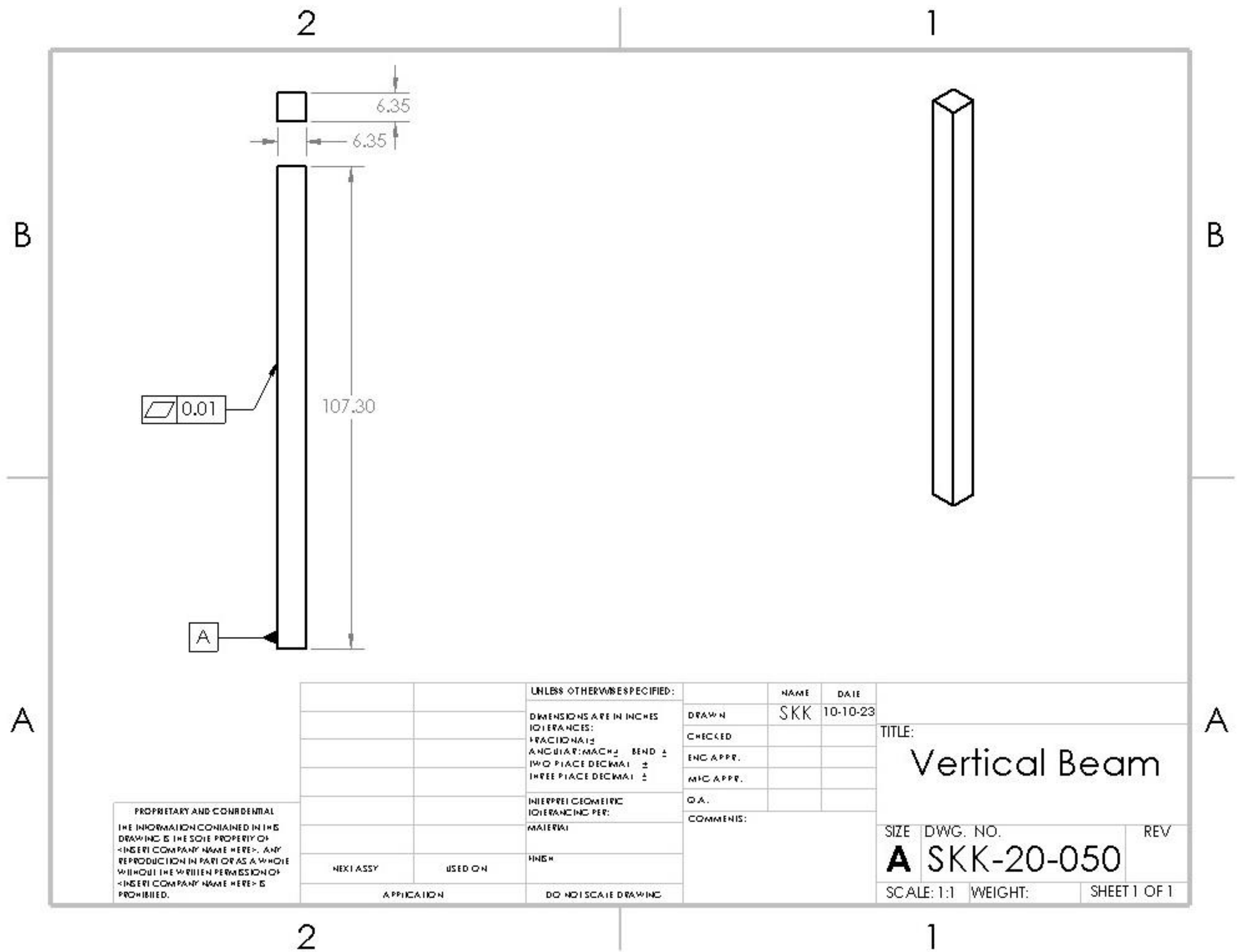
# Appendix B09 – <SKK-20-030 – Upper Beam



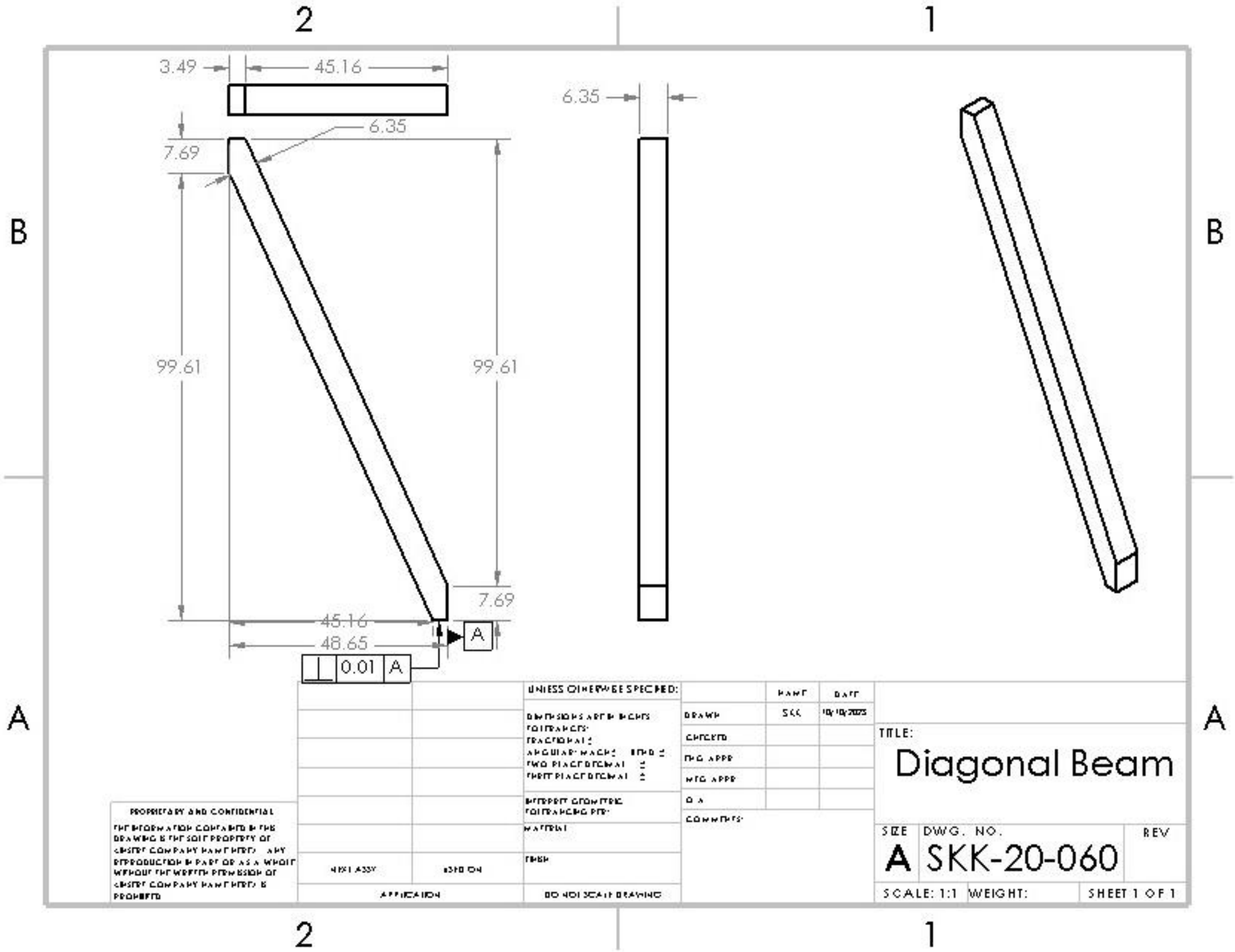
# Appendix B10 – <SKK-20-040 – Cross Beam



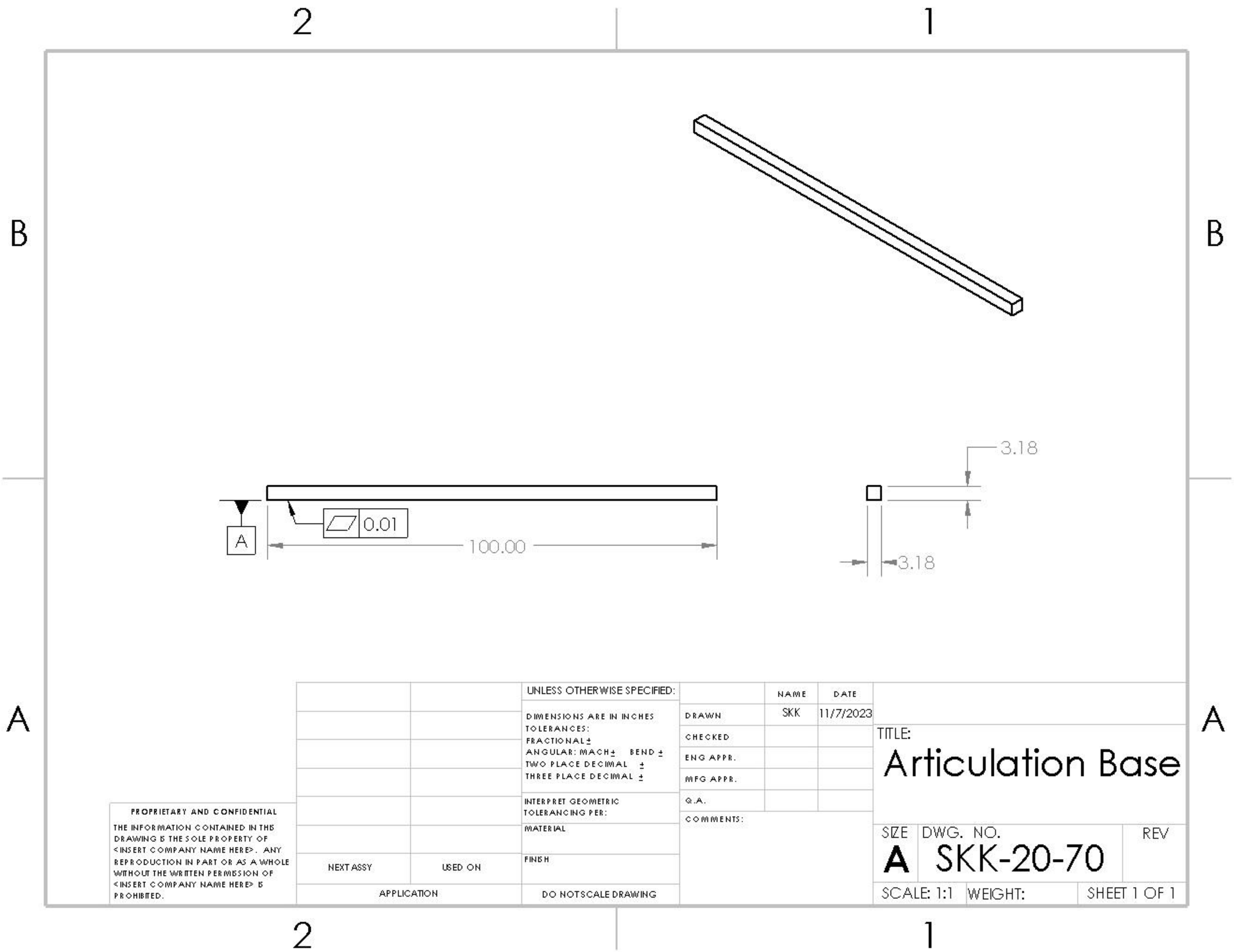
# Appendix B11 – <SKK-20-050> - Vertical Beam



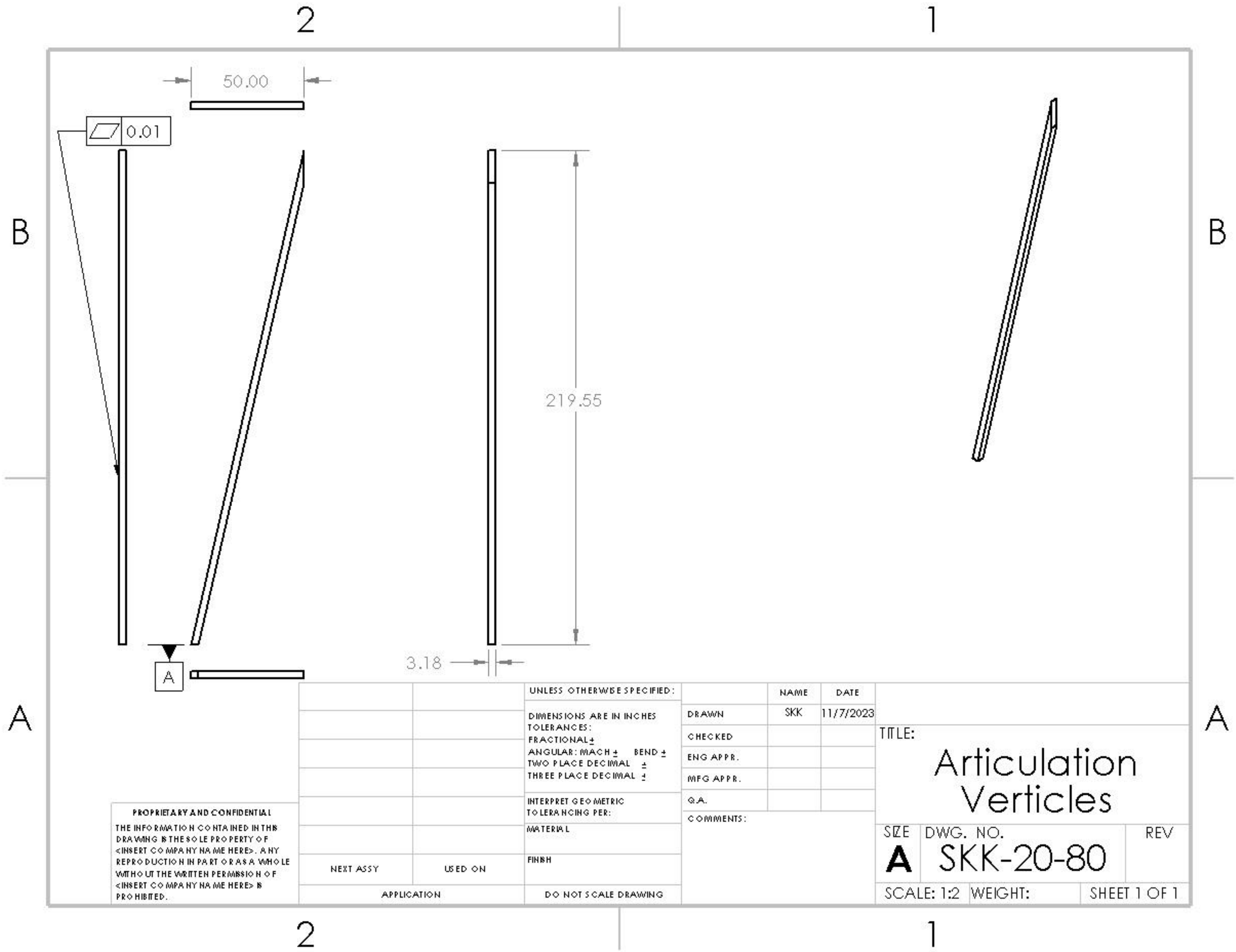
Appendix B12 – <SKK-20-060>  - Diagonal Beam



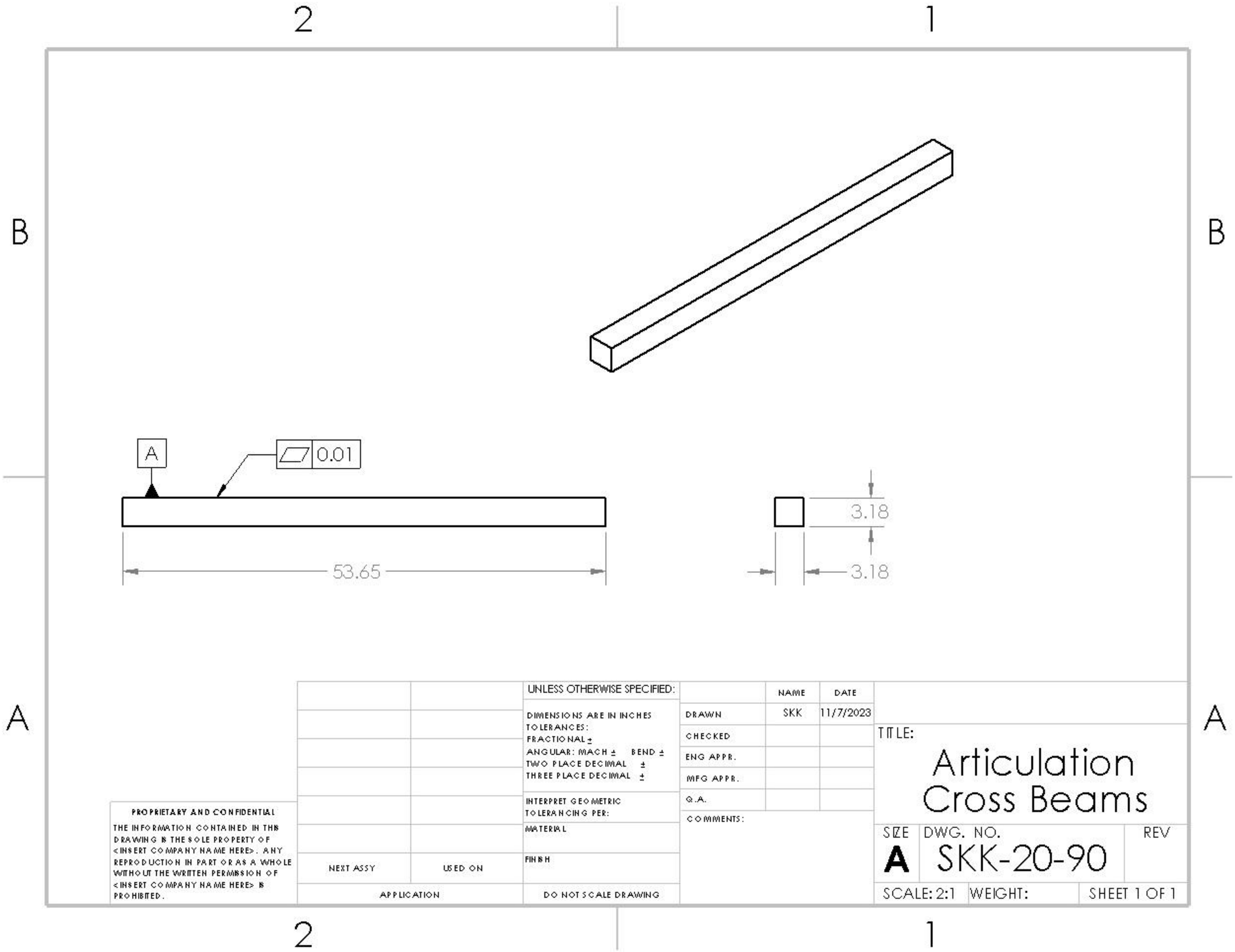
# Appendix B13 – <SKK-20-070> - Articulation Base



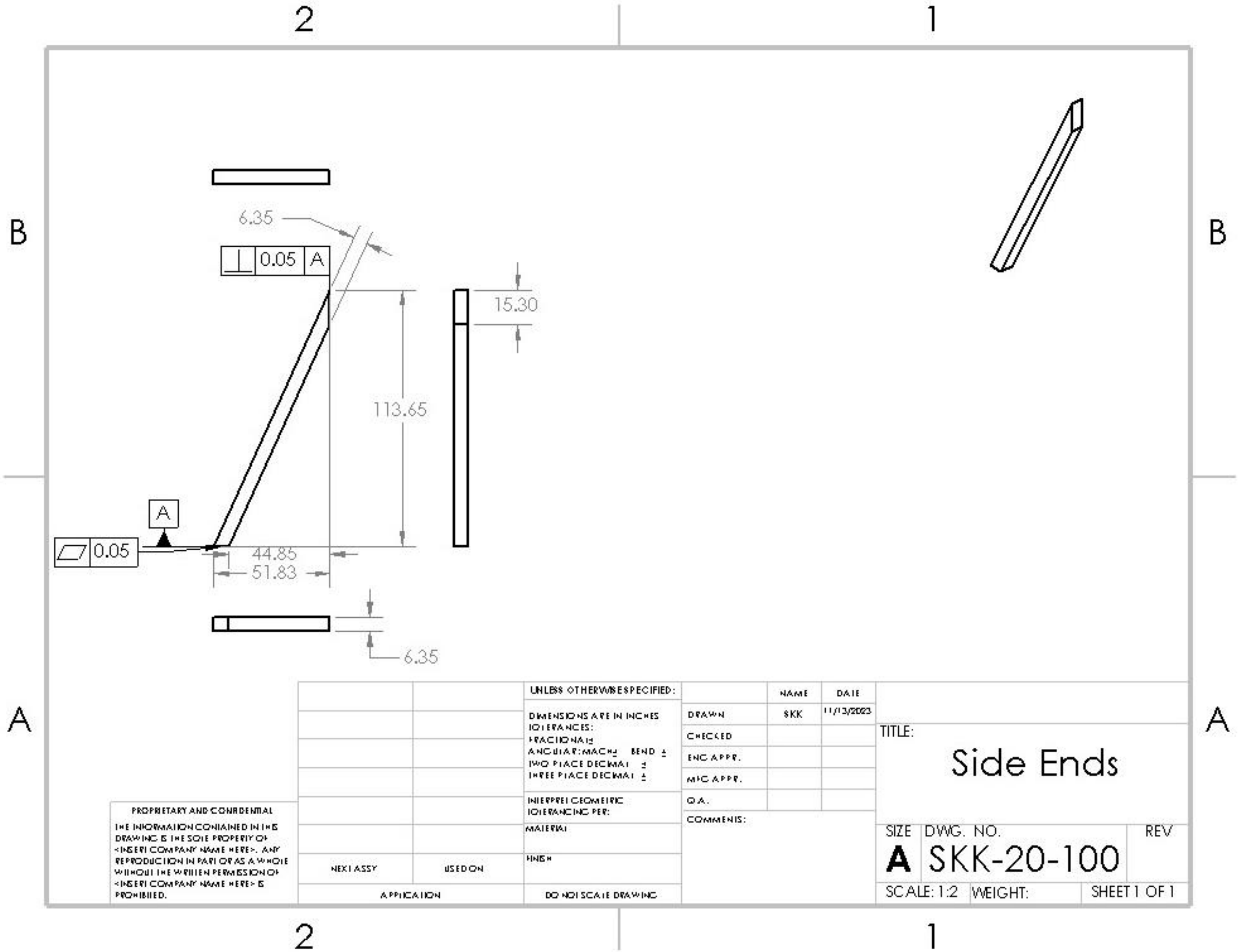
# Appendix B14 – <SKK-20-080> - Articulation Verticals



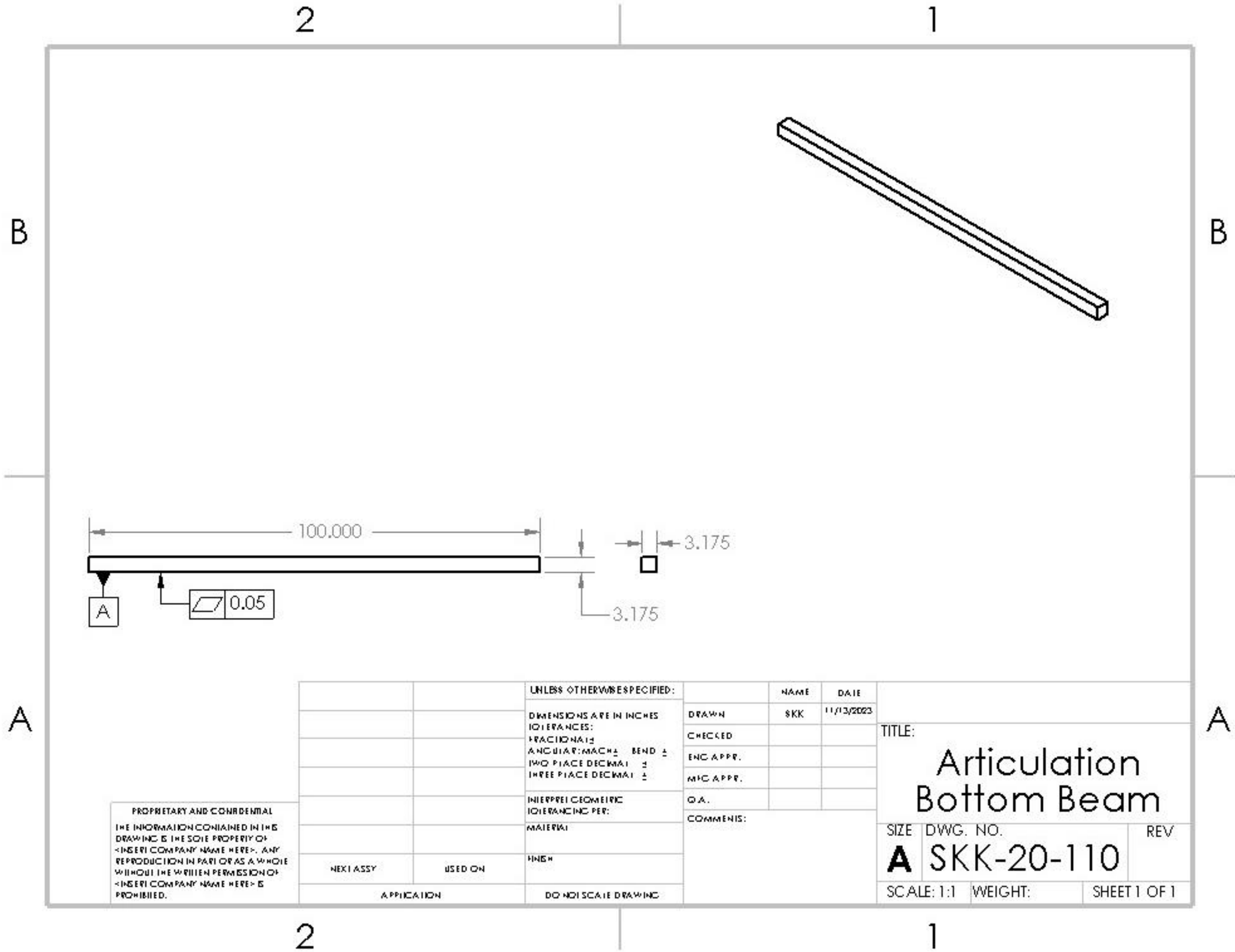
# Appendix B15 – <SKK-20-090>  - Articulation Cross Beams



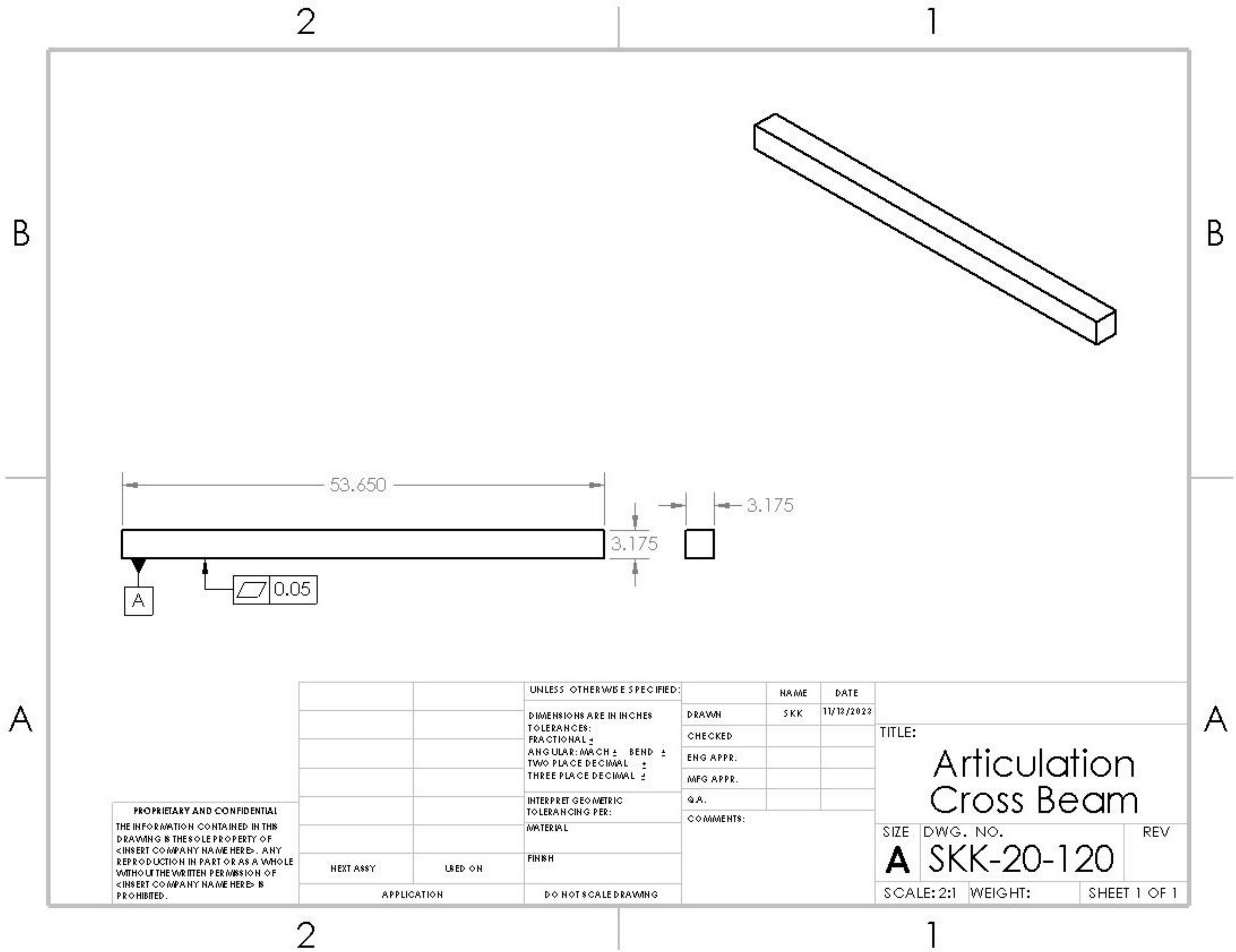
# Appendix B16 – <SKK-20-100> - Side Ends



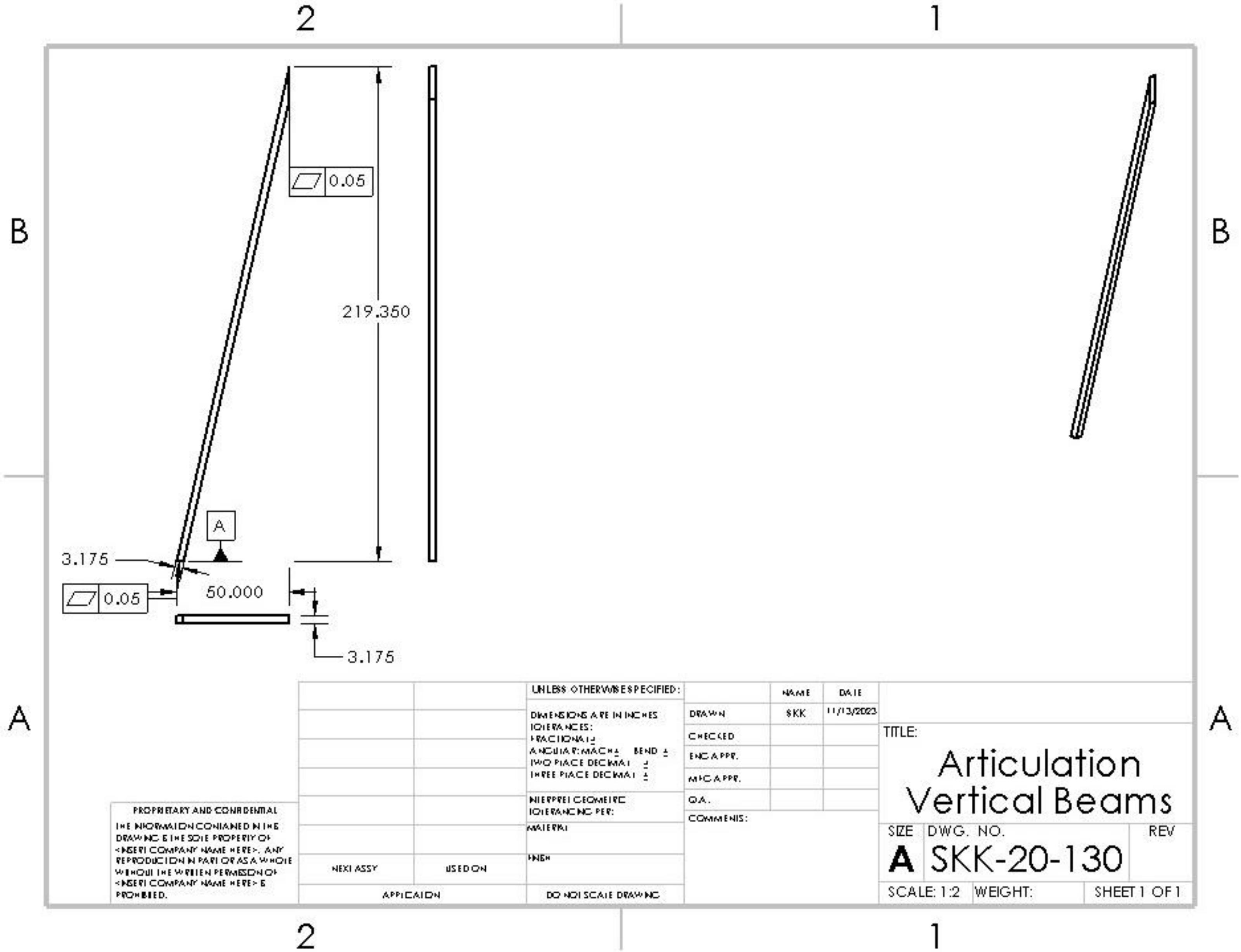
# Appendix B17 – < SKK-20-110>  - Articulation Bottom Beam



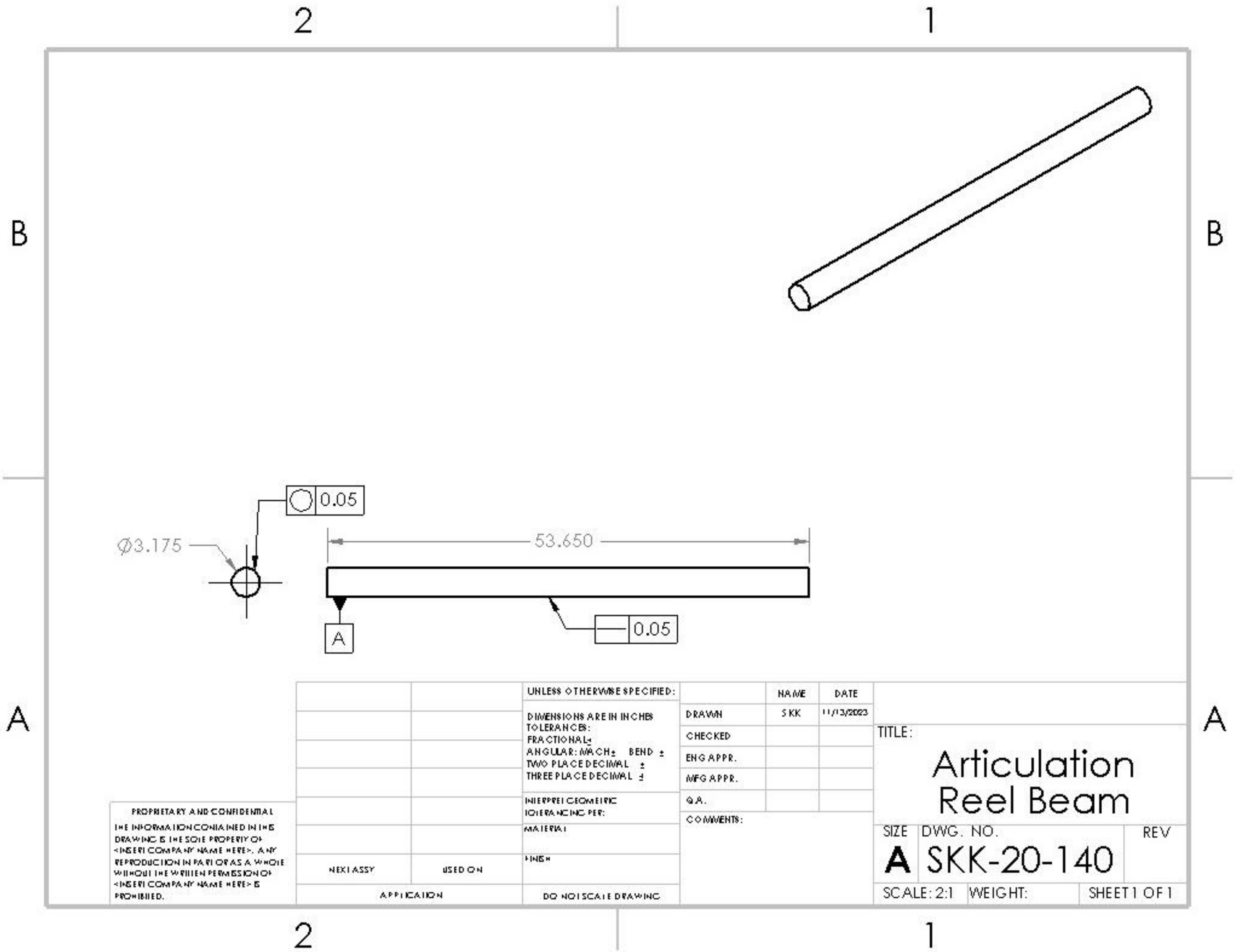
# Appendix B18 – < SKK-20-120> - Articulation Cross Beam



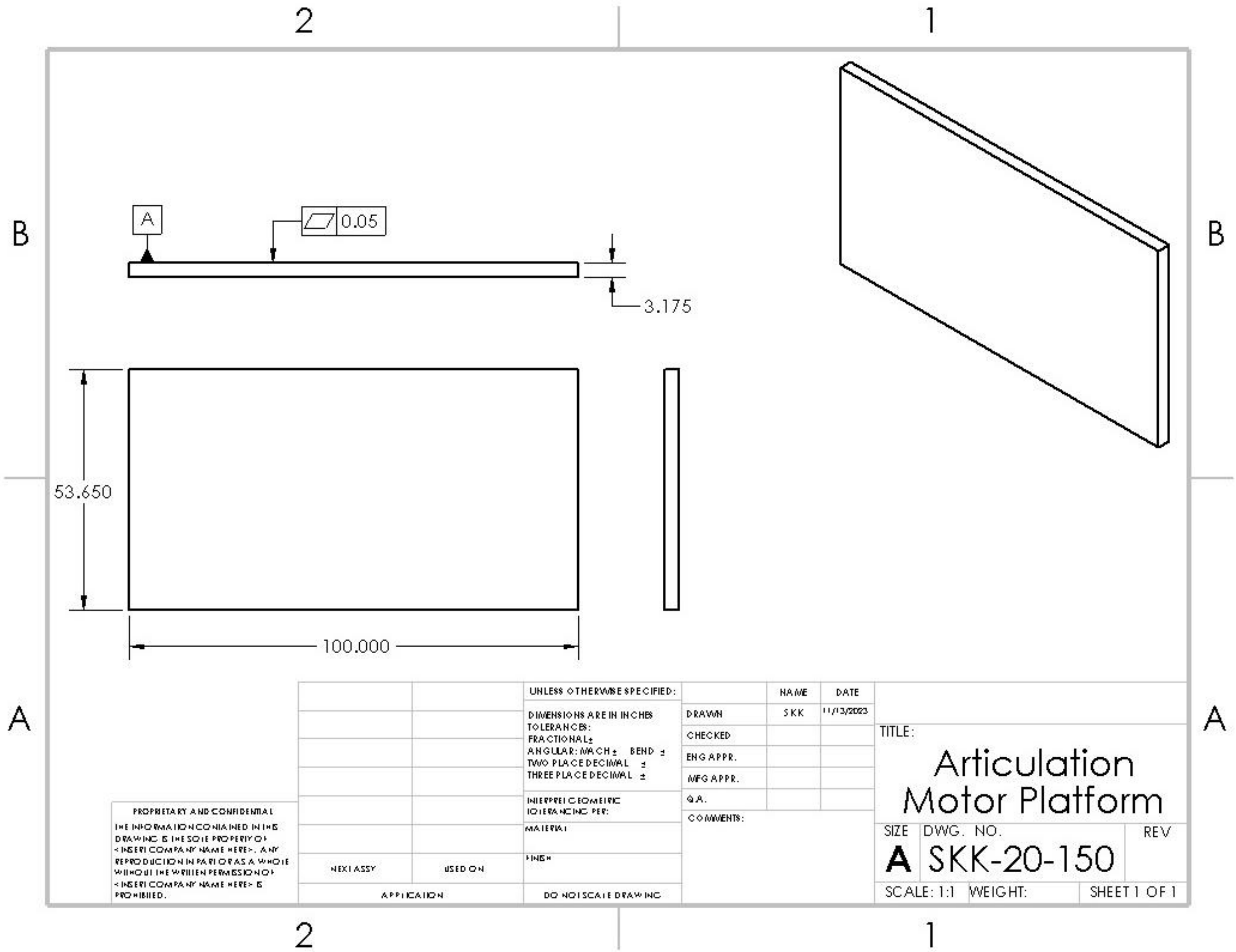
# Appendix B19 – < SKK-20-130>  - Articulation Vertical Beam



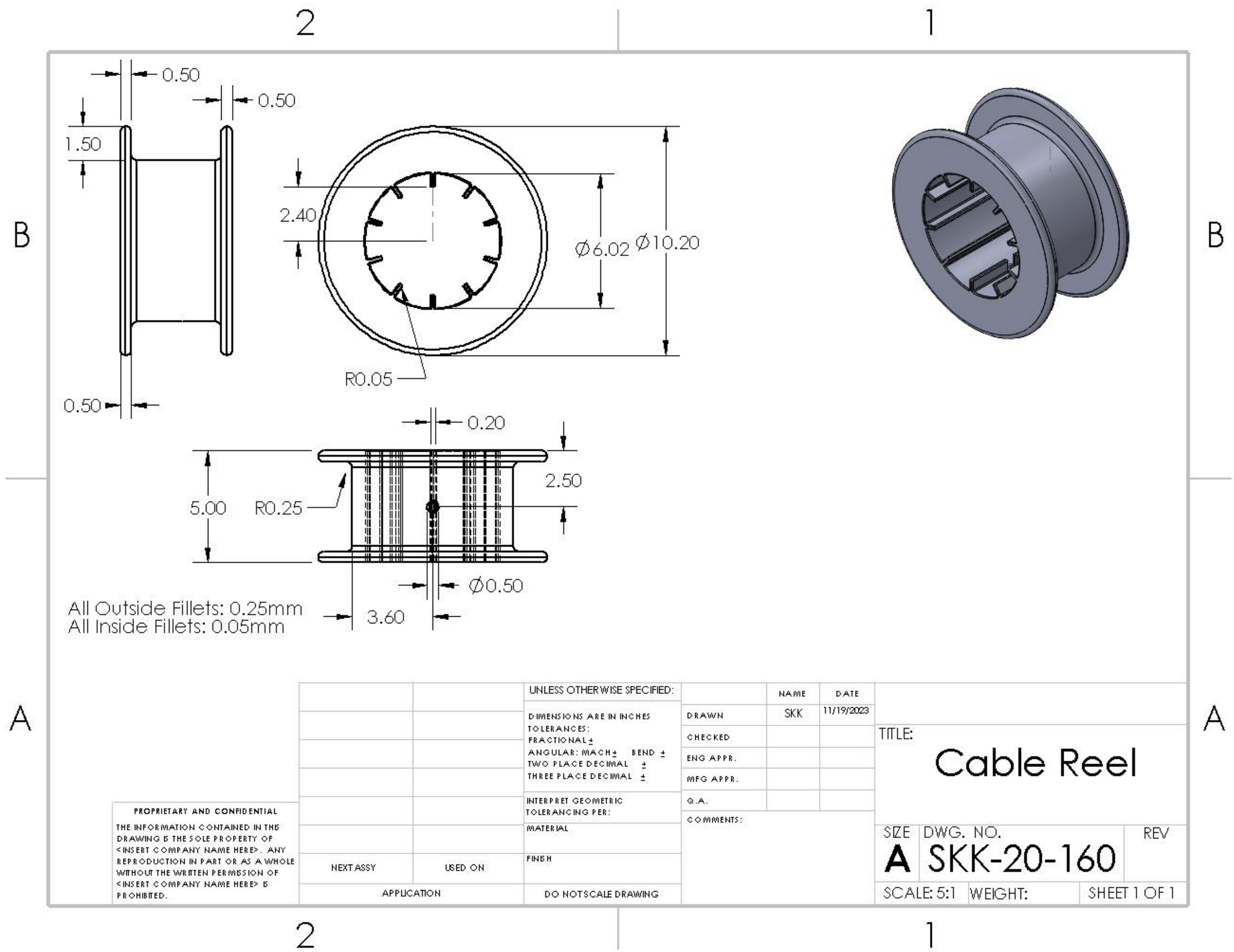
# Appendix B20 – < SKK-20-140> - Articulation Reel Beam



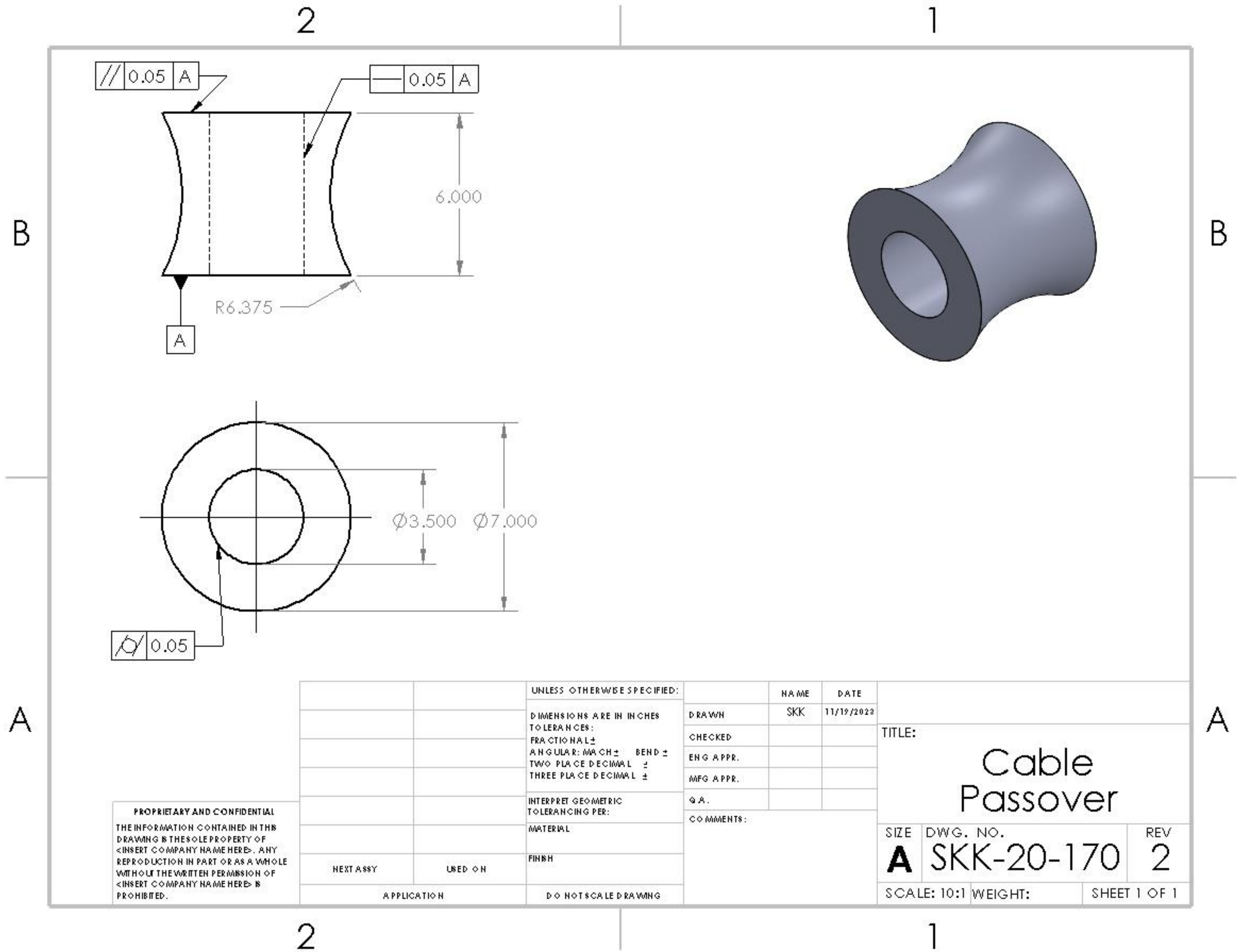
# Appendix B21 – <SKK-20-150> - Articulation Motor Platform



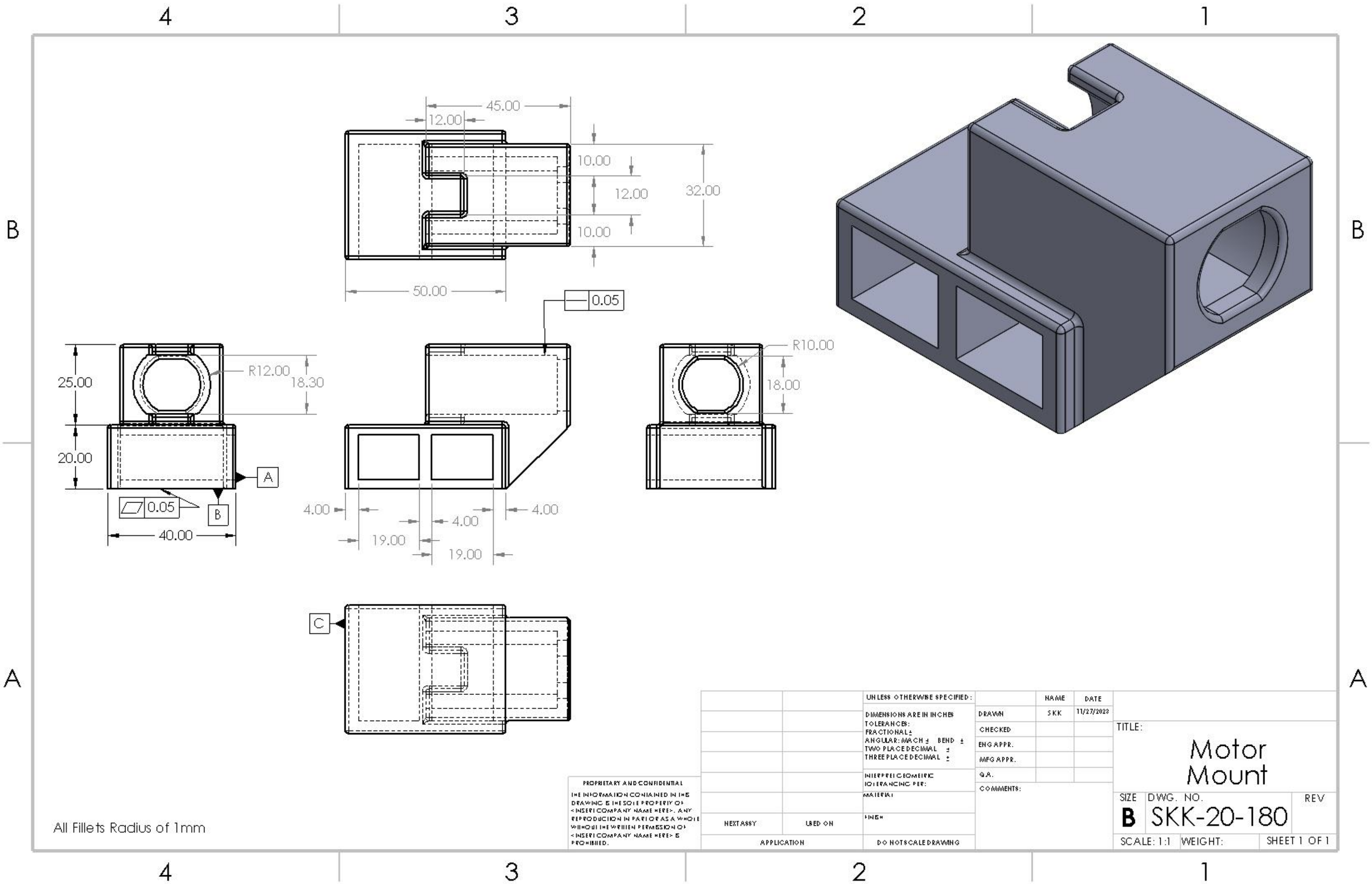
# Appendix B22 – <SKK-20-160> - Cable Reel



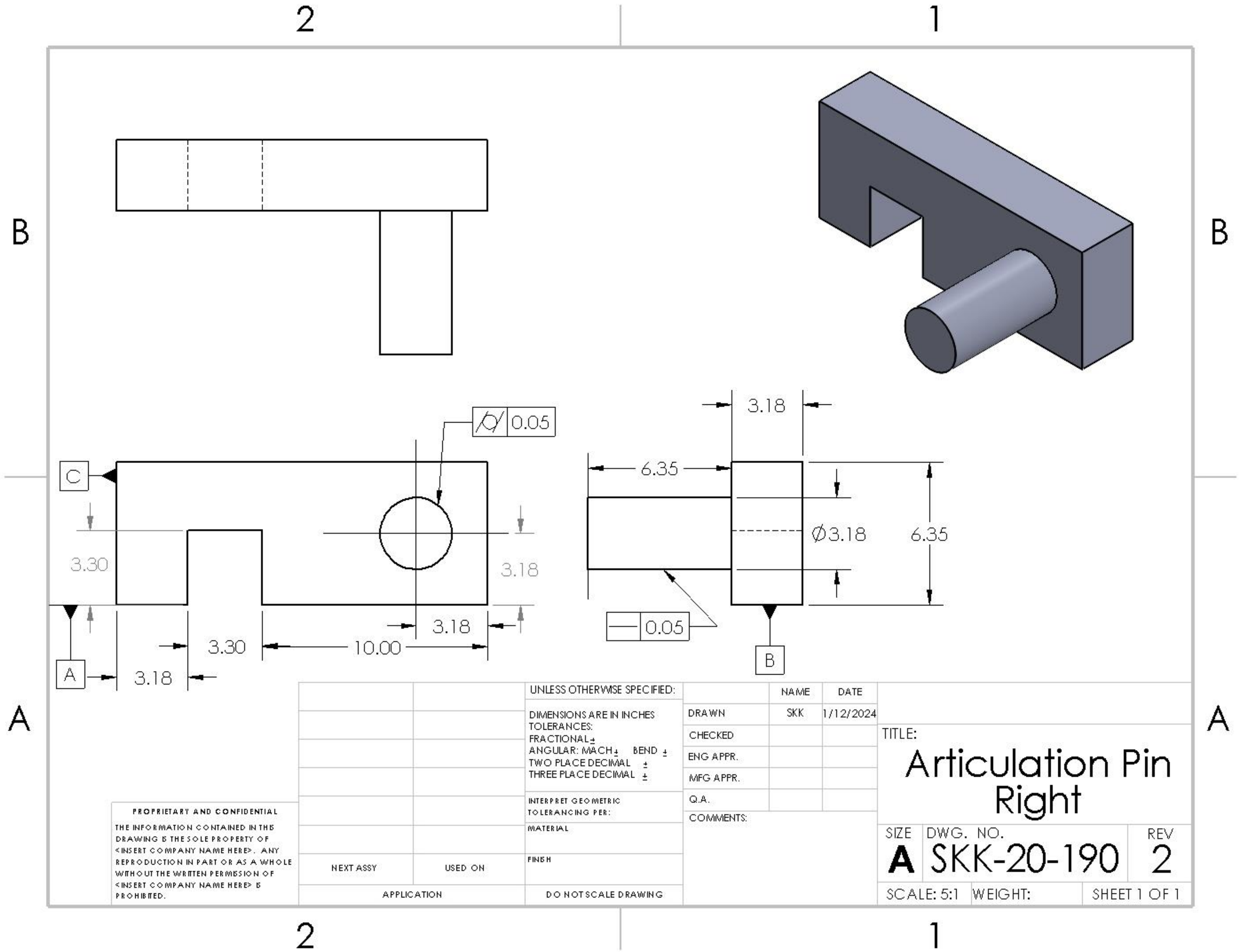
# Appendix B23 – <SKK-20-170>  - Cable Passover



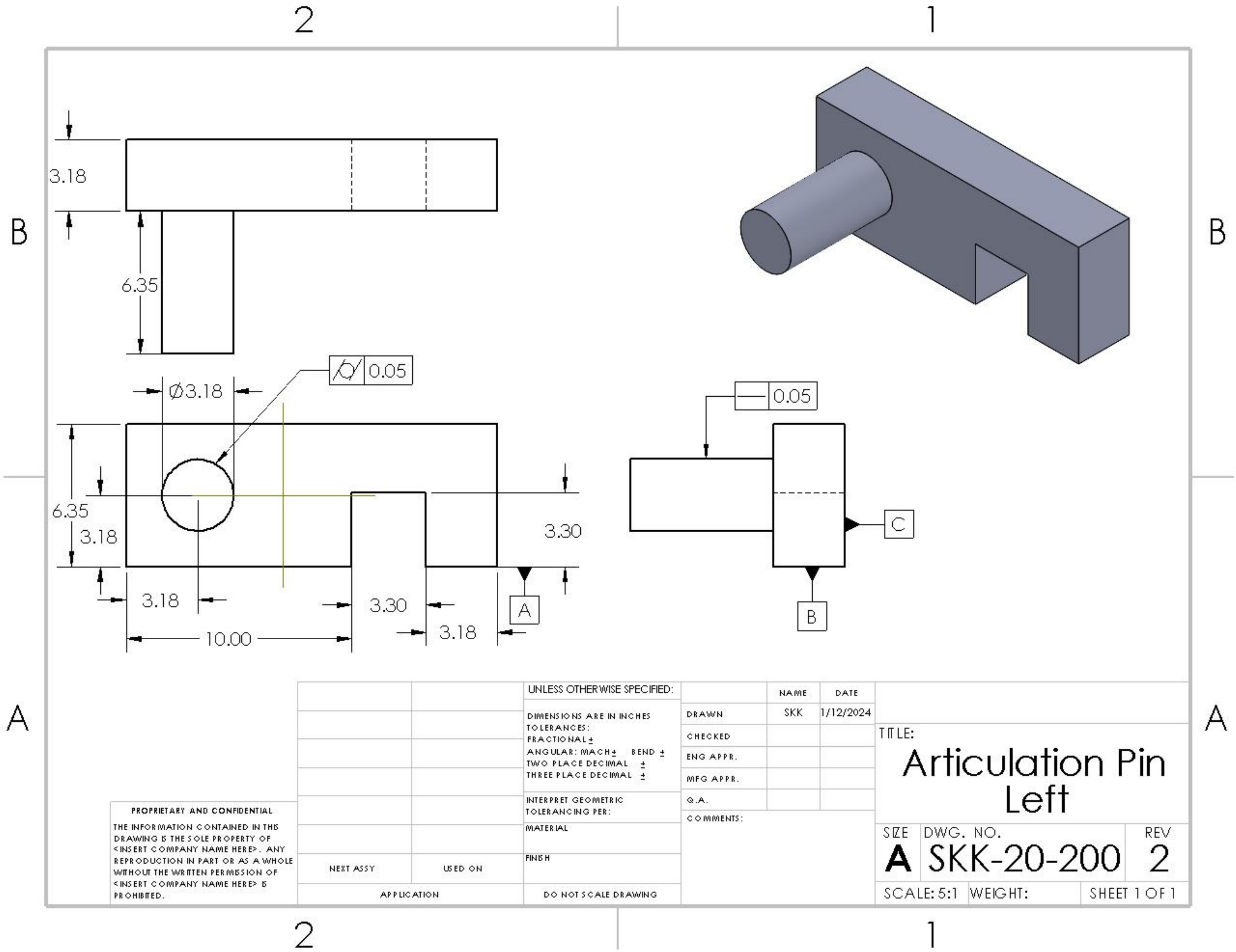
Appendix B24 – <SKK-20-180>  - Motor Mount



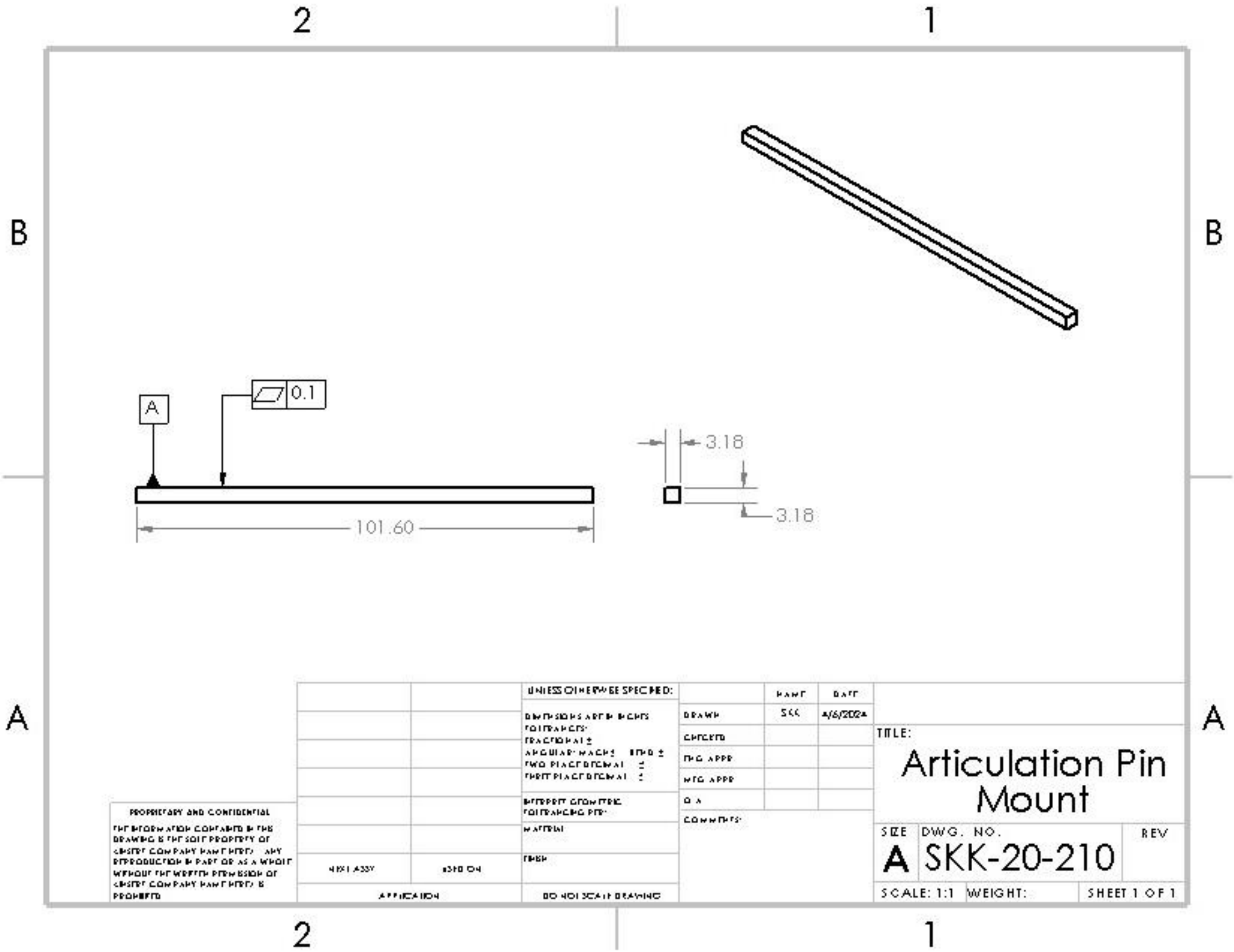
## Appendix B25 – <SKK-20-190>  - Articulation Pin Right



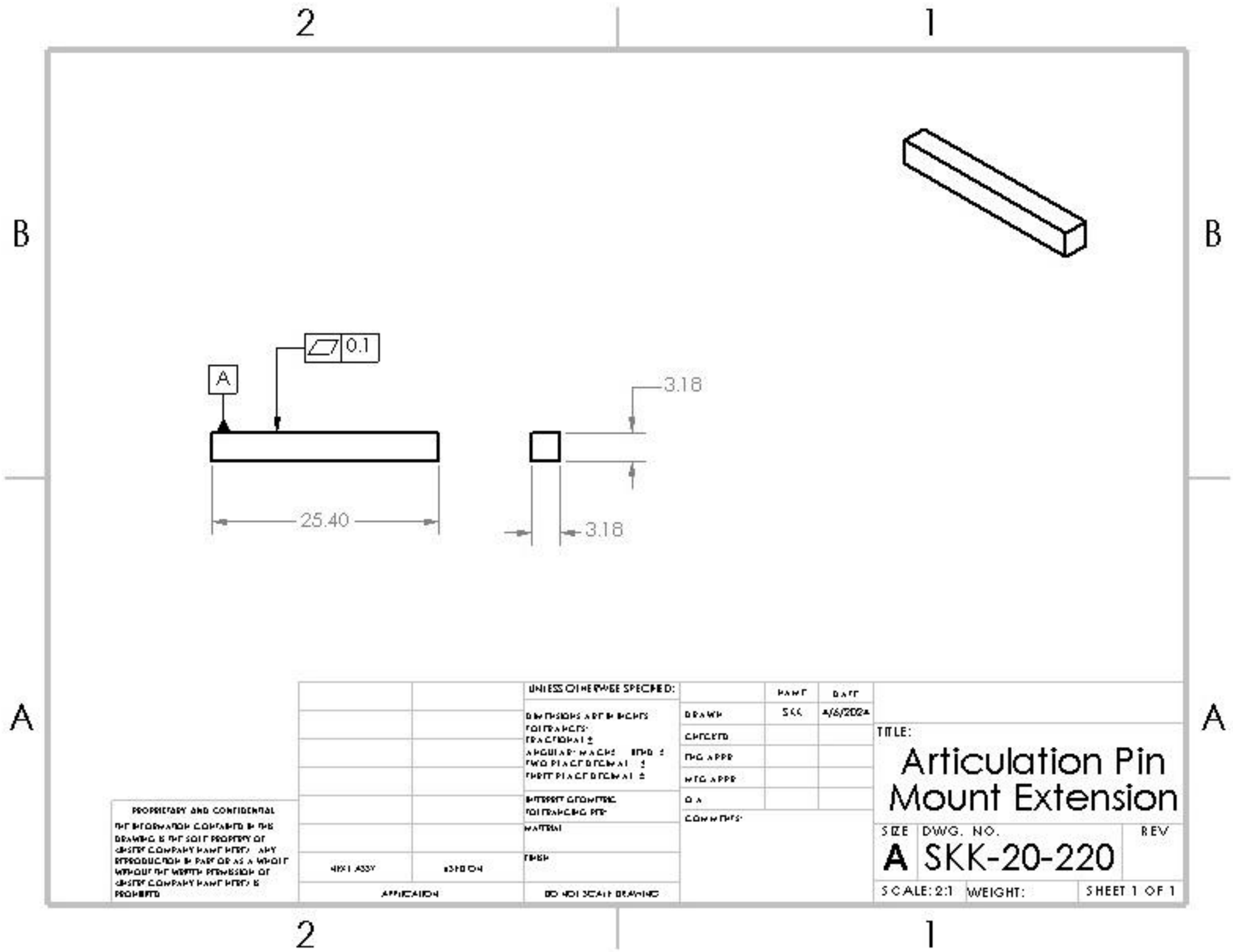
# Appendix B26 – <SKK-20-200> - Articulation Pin Left



Appendix B27 – <SKK-20-210>  - Articulation Pin Mount



# Appendix B28 – <SKK-20-220>  - Articulation Pin Mount Extension



# APPENDIX C – Parts List and Costs

Table C1: Parts List

| Part # | Qty | Part Description | Source | Cost | Disposition |
|---|---|---|---|---|---|
| SKK-55-010 | 1 | Arduino Starter Kit | Amazon | $95 | 10/17/2023 |
| SKK-55-020 | 1 | 1/8” Balsa Wood Dowels | Amazon | $9.99 | 1/12/2024 |
| SKK-55-030 | 2 | 1kg PLA Spools | Creality | $15 per<br>$30 Total | 10/23/2023 |
| SKK-55-040 | 1 | 18oz Gorilla Wood Glue | Amazon | $10.97 | 1/5/2024 |
| SKK-55-050 | 1 | Spool 70lb Fishing Line | Amazon | $8.99 | 1/12/2024 |
| SKK-55-060 | 2 | 1/8” x 6” x 36” Balsa Sheet | Hobby Lobby | $6.99 per<br>$13.98 Total | 1/18/2024 |
| SKK-55-070 | 1 | 1/4” x 6” x 36” Balsa Sheet(2 pack) | Amazon | $31.31 per | 1/5/2024 |
| Totals | | | | $200.24 | |

# APPENDIX D – Budget

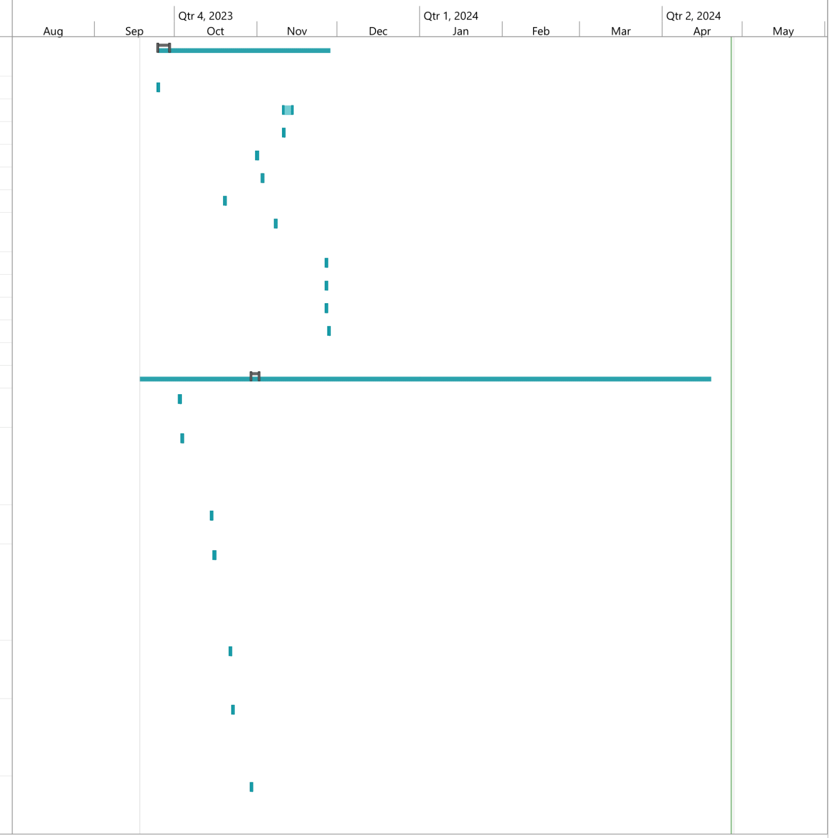
Table D1: Project Budget

| Item | QTY | Description | Costs |
|---|---|---|---|
| Design Labor Costs | Salary 3 Months | Cost of labor to design the bridge and articulation system | $812.5 |
| Construction Labor Costs | Hourly 3 months | Costs of assembly of the bridge | $577.0 |
| Cost of Materials | Full Bill (Appendix C) | Cost of the materials for the bridge | $200.24+$14(shipping)= $214.24 |
| Totals | | | $1603.74 |

# APPENDIX E - Schedule

Figure E1. Project Gantt Chart.

| ID | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|
| 1 | | **1** | **Proposal/Report Writing** | **33 hrs** | **33 hrs** | **Mon 9/25/23** | **Fri 9/29/23** | |
| 2 | | 1a | Intro | 3 hrs | 2 hrs | Mon 9/25/23 | Mon 9/25/23 | |
| 3 | | 1b | Analysis | 24 hrs | 18 hrs | Sat 11/11/23 | Tue 11/14/23 | |
| 4 | | 1c | Methods | 3 hrs | 3 hrs | Sat 11/11/23 | Sat 11/11/23 | |
| 5 | | 1d | Testing | 3 hrs | 3 hrs | Wed 11/1/23 | Wed 11/1/23 | |
| 6 | | 1e | Budget | 3 hrs | 3 hrs | Fri 11/3/23 | Fri 11/3/23 | |
| 7 | | 1f | Schedule | 3 hrs | 3 hrs | Fri 10/20/23 | Fri 10/20/23 | |
| 8 | | 1g | Project Management | 3 hrs | 3 hrs | Wed 11/8/23 | Wed 11/8/23 | |
| 9 | | 1h | Discussion | 3 hrs | 3 hrs | Mon 11/27/2 | Mon 11/27/2 | |
| 10 | | 1i | Conclusion | 3 hrs | 3 hrs | Mon 11/27/2 | Mon 11/27/2 | |
| 11 | | 1j | Drawings | 3 hrs | 3 hrs | Mon 11/27/2 | Mon 11/27/2 | |
| 12 | | 1k | Appendix | 3 hrs | 3 hrs | Tue 11/28/23 | Tue 11/28/23 | |
| 13 | | | | | | | | |
| 14 | | **2** | **Analysis** | **24 hrs** | **24 hrs?** | **Mon 10/30/2** | **Wed 11/1/23** | |
| 15 | | 2a | Analysis 1: Bridge Truss Calculations | 4 hrs | 4 hrs | Tue 10/3/23 | Tue 10/3/23 | |
| 16 | | 2b | Analysis 2: Dimensions of Beam + Weight of Bridge | 2 hrs | 2 hrs | Wed 10/4/23 | Wed 10/4/23 | |
| 17 | | 2c | Analysis 3: Front Forces/Dimensions | 1 hr | 1 hr | Sun 10/15/23 | Sun 10/15/23 | |
| 18 | | 2d | Analysis 4: Articulation Cable Position and Structure Dimensions | 3 hrs | 3 hrs | Mon 10/16/23 | Mon 10/16/23 | |
| 19 | | 2e | Analysis 5: Articulation Forces | 2 hrs | 2 hrs | Sun 10/22/23 | Sun 10/22/23 | |
| 20 | | 2f | Analysis 6: Articulation Cross Sectional Area + Weight | 1 hr | 1 hr | Mon 10/23/23 | Mon 10/23/23 | |
| 21 | | 2g | Analysis 7: Joint Connection Material | 1 hr | 1 hr | Mon 10/30/23 | Mon 10/30/23 | |

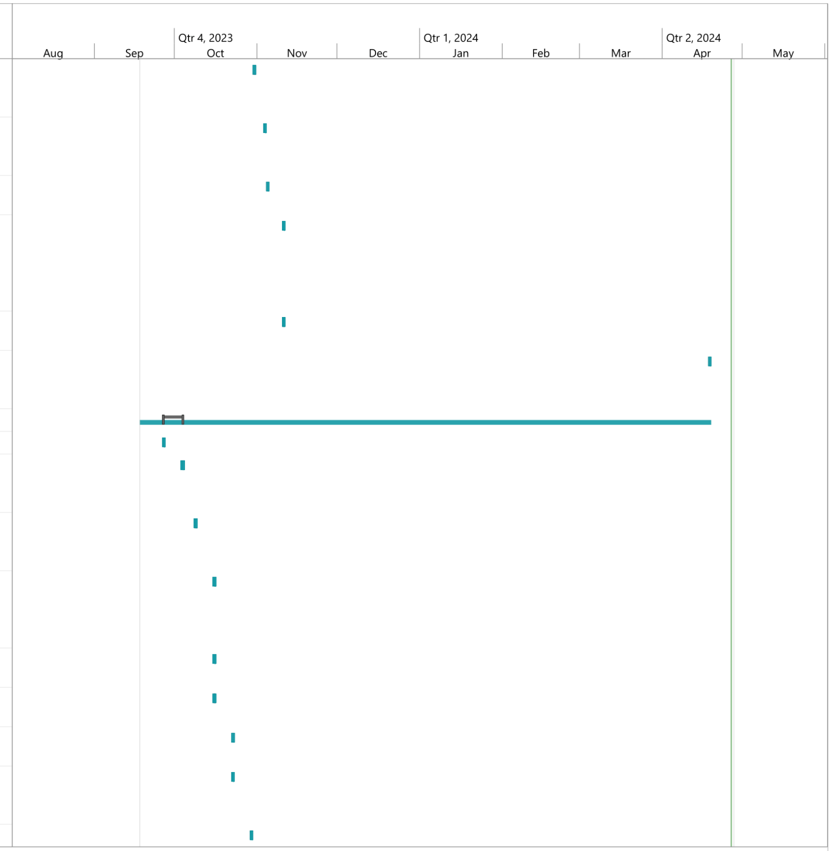



Project: Sam Katsuda Senior Pr
Date: Sat 4/27/24

| | | | | |
|---|---|---|---|---|
| Task | Project Summary | Manual Task | Start-only | Deadline |
| Split | Inactive Task | Duration-only | Finish-only | Progress |
| Milestone | Inactive Milestone | Manual Summary Rollup | External Tasks | Manual Progress |
| Summary | Inactive Summary | Manual Summary | External Milestone | |

Page 1

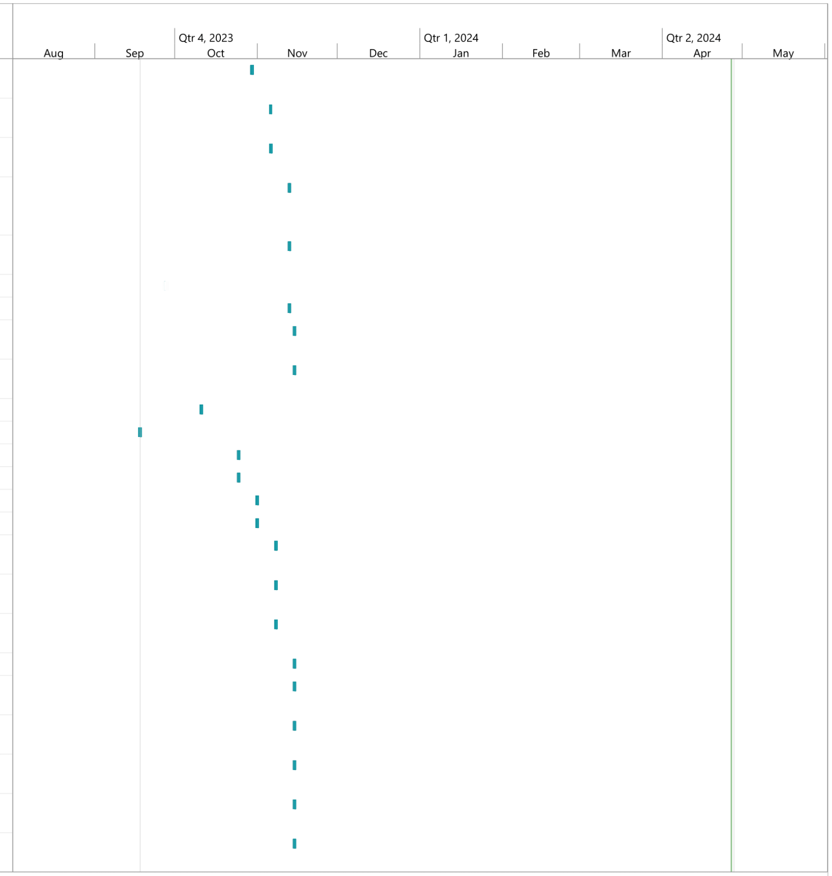
| ID | | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 22 | | | 2h | Analysis 8: Motor Power Calculations | 2 hrs | 2 hrs | Tue 10/31/23 | Tue 10/31/23 | |
| 23 | | | 2i | Analysis 9: Motor Housing/Mounting Design | 3 hrs | 3 hrs | Sat 11/4/23 | Sat 11/4/23 | |
| 24 | | | 2j | Analysis 10: Cable Reel Dimensions | 1 hr | 2 hrs | Sun 11/5/23 | Sun 11/5/23 | |
| 25 | | | 2k | Analysis 11: Weight on Base Structure to Keep Articulation Structure Upright | 3 hrs | 3 hrs | Sat 11/11/23 | Sat 11/11/23 | |
| 26 | | | 2l | Analysis 12: Bridge Deflection | 1 hr | 1 hr | Sat 11/11/23 | Sat 11/11/23 | |
| 27 | | | 2m | Analysis 13: Articulation Cysle Time | 1 hr | 1 hr | Fri 4/19/24 | Fri 4/19/24 | |
| 28 | | | **3** | **Documentation** | **42.5 hrs** | **42.5 hrs** | **Wed 9/27/23** | **Wed 10/4/23** | |
| 29 | | | 3a | Initial Sketch | 1 hr | 1 hr | Wed 9/27/23 | Wed 9/27/23 | |
| 30 | | | 3b | Force/Method of Joints Green sheets | 5 hrs | 5 hrs | Wed 10/4/23 | Wed 10/4/23 | |
| 31 | | | 3c | Cross Sectional Area and Weight Calcs | 3 hrs | 3 hrs | Mon 10/9/23 | Mon 10/9/23 | |
| 32 | | | 3d | Front View force and Cross Sectional Area Calcs | 3 hrs | 3 hrs | Mon 10/16/23 | Mon 10/16/23 | |
| 33 | | | 3e | Lifting Mech Designs | 4 hrs | 4 hrs | Mon 10/16/23 | Mon 10/16/23 | |
| 34 | | | 3f | Cable Position Calcs | 2 hrs | 2 hrs | Mon 10/16/23 | Mon 10/16/23 | |
| 35 | | | 3g | Cable Force Calcs | 2 hrs | 2 hrs | Mon 10/23/23 | Mon 10/23/23 | |
| 36 | | | 3h | Articulation Cross Sectional Area | 1 hr | 1 hr | Mon 10/23/23 | Mon 10/23/23 | |
| 37 | | | 3i | Joint Analysis | 1 hr | 1 hr | Mon 10/30/2 | Mon 10/30/2 | |




Project: Sam Katsuda Senior Pr
Date: Sat 4/27/24

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

| ID | | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 38 | | | 3j | Motor Power Calcs | 2 hrs | 2 hrs | Mon 10/30/23 | Mon 10/30/23 | |
| 39 | | | 3k | Motor Mount Calcs | 1 hr | 1 hr | Mon 11/6/23 | Mon 11/6/23 | |
| 40 | | | 3l | Spool Dimensions | 2 hrs | 2 hrs | Mon 11/6/23 | Mon 11/6/23 | |
| 41 | | | 3m | Weight to Prevent Tipping | 1 hr | 1 hr | Mon 11/13/23 | Mon 11/13/23 | |
| 42 | | | 3n | Vertical Deflection | 2 hrs | 2 hrs | Mon 11/13/23 | Mon 11/13/23 | |
| 43 | | | 3o | Drawing Tree | 1 hr | 1 hr | | | |
| 44 | | | 3p | Side Assembly | 1 hr | 1 hr | Mon 11/13/2 | Mon 11/13/2 | |
| 45 | | | 3q | Articulation Structure | 1 hr | 1 hr | Wed 11/15/23 | Wed 11/15/23 | |
| 46 | | | 3r | Bridge Assembly | 1 hr | 1 hr | Wed 11/15/23 | Wed 11/15/23 | |
| 47 | | | 3s | Road Deck | 0.25 hrs | 0.25 hrs | Wed 10/11/2 | Wed 10/11/2 | |
| 48 | | | 3t | Lower Beam | 0.25 hrs | 0.25 hrs | Mon 9/18/23 | Mon 9/18/23 | |
| 49 | | | 3u | Upper Beam | 0.25 hrs | 0.25 hrs | Wed 10/25/2 | Wed 10/25/2 | |
| 50 | | | 3v | Cross Beam | 0.25 hrs | 0.25 hrs | Wed 10/25/2 | Wed 10/25/2 | |
| 51 | | | 3w | Vertical Beam | 0.25 hrs | 0.25 hrs | Wed 11/1/23 | Wed 11/1/23 | |
| 52 | | | 3x | Diagonal Beam | 1 hr | 1 hr | Wed 11/1/23 | Wed 11/1/23 | |
| 53 | | | 3y | Articulation Base | 0.25 hrs | 0.25 hrs | Wed 11/8/23 | Wed 11/8/23 | |
| 54 | | | 3z | Articulation Verticals | 0.25 hrs | 0.25 hrs | Wed 11/8/23 | Wed 11/8/23 | |
| 55 | | | 3aa | Articulation Cross Beams | 0.25 hrs | 0.25 hrs | Wed 11/8/23 | Wed 11/8/23 | |
| 56 | | | 3bb | Side Ends | 0.25 hrs | 0.25 hrs | Wed 11/15/2 | Wed 11/15/2 | |
| 57 | | | 3cc | Articulation Bottom Beams | 0.25 hrs | 0.25 hrs | Wed 11/15/23 | Wed 11/15/23 | |
| 58 | | | 3dd | Articulation Cross Beams | 0.25 hrs | 0.25 hrs | Wed 11/15/23 | Wed 11/15/23 | |
| 59 | | | 3ee | Articulation Vertical Beam | 0.25 hrs | 0.25 hrs | Wed 11/15/23 | Wed 11/15/23 | |
| 60 | | | 3ff | Articulation Reel Beam | 0.25 hrs | 0.25 hrs | Wed 11/15/23 | Wed 11/15/23 | |
| 61 | | | 3gg | Articulation Motor Platform | 0.25 hrs | 0.25 hrs | Wed 11/15/23 | Wed 11/15/23 | |

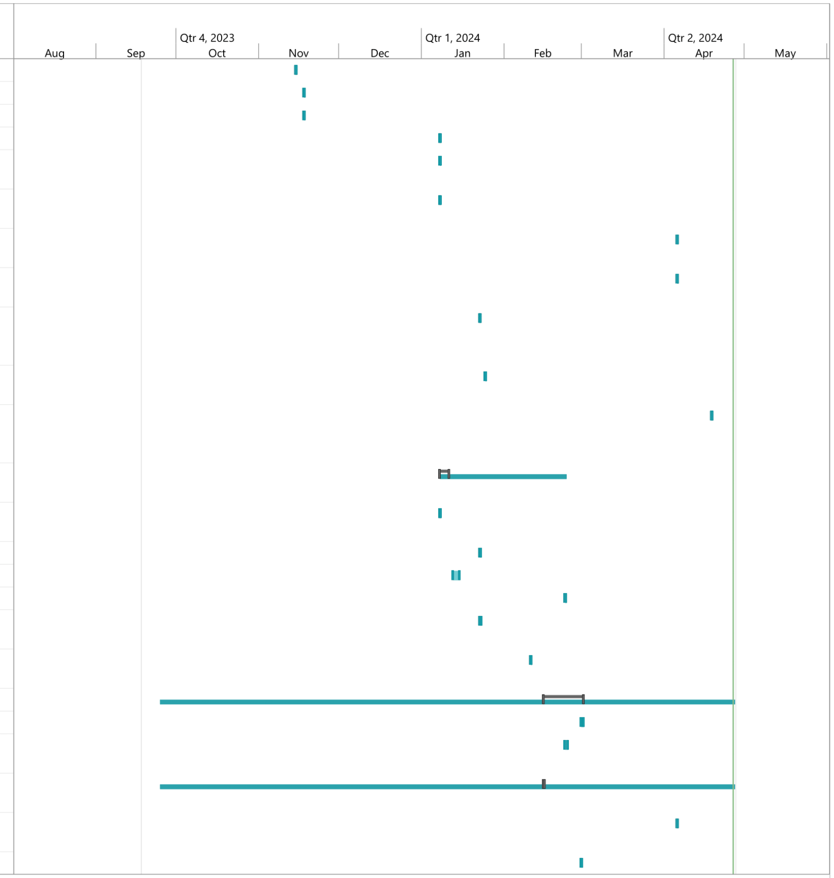



Project: Sam Katsuda Senior Pr
Date: Sat 4/27/24

| | | | | |
|---|---|---|---|---|
| Task | Project Summary | Manual Task | Start-only | Deadline |
| Split | Inactive Task | Duration-only | Finish-only | Progress |
| Milestone | Inactive Milestone | Manual Summary Rollup | External Tasks | Manual Progress |
| Summary | Inactive Summary | Manual Summary | External Milestone | |

Page 3

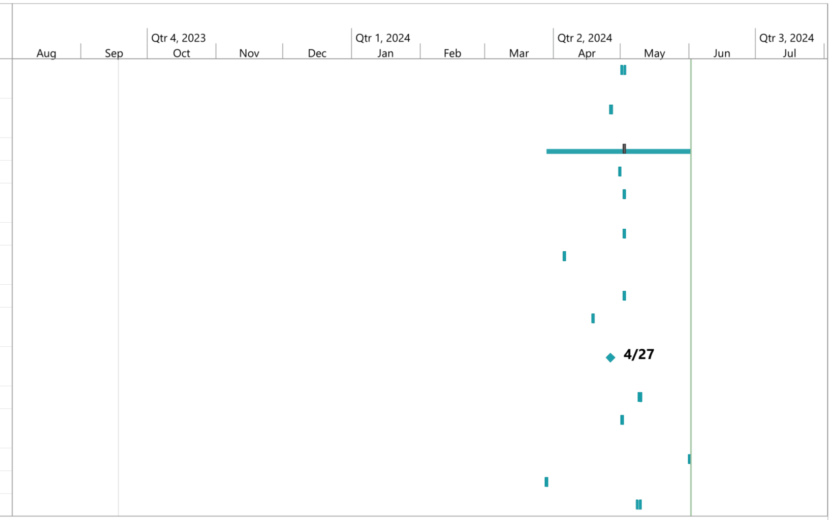
| ID | | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 62 | | | 3hh | Motor Mount | 0.25 hrs | 0.25 hrs | Wed 11/15/2 | Wed 11/15/2 | |
| 63 | | | 3ii | Cable Reel | 0.25 hrs | 0.25 hrs | Sat 11/18/23 | Sat 11/18/23 | |
| 64 | | | 3jj | Cable Passover | 0.25 hrs | 0.25 hrs | Sat 11/18/23 | Sat 11/18/23 | |
| 65 | | | 3kk | Motor Mount | 0.25 hrs | 0.25 hrs | Mon 1/8/24 | Mon 1/8/24 | |
| 66 | | | 3jj | Articulatin Pin Left | 0.25 hrs | 0.25 hrs | Mon 1/8/24 | Mon 1/8/24 | |
| 67 | | | 3kk | Articulation Pin Right | 0.25 hrs | 0.25 hrs | Mon 1/8/24 | Mon 1/8/24 | |
| 68 | | | 3ll | Articulation Pin Mount | 0.25 hrs | 0.25 hrs | Sat 4/6/24 | Sat 4/6/24 | |
| 69 | | | 3mm | Articulation Pin Extensions | 0.25 hrs | 0.25 hrs | Sat 4/6/24 | Sat 4/6/24 | |
| 70 | | | 3nn | Bridge AutoCAD Drawing | 1 hr | 1 hr | Tue 1/23/24 | Tue 1/23/24 | |
| 71 | | | 3oo | Articulation AutoCAD | 1 hr | 1 hr | Thu 1/25/24 | Thu 1/25/24 | |
| 72 | | | 3pp | Articulation Cycle Time Calculation | 1 hr | 1 hr | Fri 4/19/24 | Fri 4/19/24 | |
| 73 | | | **4** | **Part Construction** | **28 hrs** | **28 hrs** | **Mon 1/8/24** | **Thu 1/11/24** | |
| 74 | | | 4a | Gathering Materials | 2 hrs | 2 hrs | Mon 1/8/24 | Mon 1/8/24 | |
| 75 | | | 4b | Cut Wood | 3 hrs | 3 hrs | Tue 1/23/24 | Tue 1/23/24 | |
| 76 | | | 4c | 3-D Print | 12 hrs | 12 hrs | Sat 1/13/24 | Mon 1/15/24 | |
| 77 | | | 4d | Glue Wood | 2 hrs | 2 hrs | Sat 2/24/24 | Sat 2/24/24 | |
| 78 | | | 4e | Assemble,Prog Brain | 6 hrs | 6 hrs | Tue 1/23/24 | Tue 1/23/24 | |
| 79 | | | 4f | Sanding/part cleanup | 3 hrs | 3 hrs | Sun 2/11/24 | Sun 2/11/24 | |
| 80 | | | **5** | **Device Construction** | **19 hrs** | **88 hrs?** | **Fri 2/16/24** | **Fri 3/1/24** | |
| 81 | | | 5a | Bridge Assembly | 8 hrs | 8 hrs | Fri 3/1/24 | Fri 3/1/24 | |
| 82 | | | 5b | Assemble Lifting Tower | 6 hrs | 8 hrs | Sat 2/24/24 | Sat 2/24/24 | |
| 83 | | | 5c | Assembly Lift Controller | 3 hrs | **3 hrs** | **Fri 2/16/24** | **Fri 2/16/24** | |
| 84 | | | 5d | Post Testing Modifications | 1 hr | 1 hr | Sat 4/6/24 | Sat 4/6/24 | |
| 85 | | | 5e | Final Assembly | 2 hrs | 2 hrs | Fri 3/1/24 | Fri 3/1/24 | |




Project: Sam Katsuda Senior Pr
Date: Sat 4/27/24

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Task | | Project Summary | | Manual Task | | Start-only | | Deadline | |
| Split | | Inactive Task | | Duration-only | | Finish-only | | Progress | |
| Milestone | | Inactive Milestone | | Manual Summary Rollup | | External Tasks | | Manual Progress | |
| Summary | | Inactive Summary | | Manual Summary | | External Milestone | | | |

| ID | Indicators | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 86 | | | **6** | **Device Evaluation** | **13 hrs** | **13 hrs** | **Thu 5/2/24** | **Fri 5/3/24** | |
| 87 | | | 6a | Write Testing Procedures | 6 hrs | 6 hrs | Sat 4/27/24 | Sat 4/27/24 | |
| 88 | | | 6b | Block Slide Test | **1 hr** | **1 hr** | **Fri 5/3/24** | **Fri 5/3/24** | |
| 89 | | | 6c | Weight Test | 1 hr | 1 hr | Wed 5/1/24 | Wed 5/1/24 | |
| 90 | | | 6d | Dimension and Material | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 91 | | | 6e | Deflection | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 92 | | | 6f | Articulation Test | 1 hr | 1 hr | Sat 4/6/24 | Sat 4/6/24 | |
| 93 | | | 6g | Load Support | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 94 | | | 6h | Articulation Cycle Time | 1 hr | 1 hr | Fri 4/19/24 | Fri 4/19/24 | |
| 95 | | | **7** | **489 Deliverables** | **29 hrs** | **0 hrs** | **Sat 4/27/24** | **Sat 4/27/24** | |
| 96 | | | 7a | Create Poster | 6 hrs | 6 hrs | Fri 5/10/24 | Fri 5/10/24 | |
| 97 | | | 7b | Submit Source | 1 hr | 1 hr | Thu 5/2/24 | Thu 5/2/24 | |
| 98 | | | 7c | Finalize Report | 4 hrs | 4 hrs | Sat 6/1/24 | Sat 6/1/24 | |
| 99 | | | 7d | Abstract | 3 hrs | 3 hrs | Fri 3/29/24 | Fri 3/29/24 | |
| 100 | | | 7e | Website | 15 hrs | 13 hrs | Thu 5/9/24 | Fri 5/10/24 | |




Project: Sam Katsuda Senior Pr
Date: Sun 6/2/24

| | | | | |
|---|---|---|---|---|
| Task | Project Summary | Manual Task | Start-only | Deadline |
| Split | Inactive Task | Duration-only | Finish-only | Progress |
| Milestone | Inactive Milestone | Manual Summary Rollup | External Tasks | Manual Progress |
| Summary | Inactive Summary | Manual Summary | External Milestone | |

# APPENDIX F – Expertise and Resources

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Criterion | Weight | Best Possible | | | | | | | |
| 2 | | 1 to 3 | 3 | Warren | Score x Wt | Warren W/V | Score x Wt | Pratt | Score x Wt | |
| 3 | Cost | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | |
| 4 | Weight | 2 | 6 | 3 | 6 | 2 | 4 | 2 | 4 | |
| 5 | Prediction Precision | 2 | 6 | 3 | 6 | 2 | 4 | 3 | 6 | |
| 6 | Confidence - Failure loc | 3 | 9 | 1 | 3 | 2 | 6 | 3 | 9 | |
| 7 | Prismatic vs non Prismatic | 2 | 6 | 3 | 6 | 3 | 6 | 3 | 6 | |
| 8 | Manufacturability | 3 | 9 | 3 | 9 | 3 | 9 | 3 | 9 | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | | | | | | | |
| 13 | Total | 13 | 39 | | 33 | | 31 | | 36 | |
| 14 | NORMALIZE THE DATA (muliply by fraction, N) | | 2.56 | | 84.6 | | 79.5 | | 92.3 | Percent |
| 15 | | | | | | | | | | |
| 16 | Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | | | | Good? Then done. | | 85.5 | Average |
| 17 | | Poor Bias: | Standard Deviation is one or less digits | | | | Poor? Change something! | | 6 | Std Dev. |
| 18 | | | You can change the criteria, weighting, or the projects themselves… | | | | | | | |
| 19 | | | | | | | | | | |
| 20 | | Weighting/Scoring Scale | | | | | | | | |
| 21 | | 1 | Worst (too costly, low confidence, too big, etc.) | | | | | | | |
| 22 | | 2 | Median Values, or Unsure of actual value | | | | | | | |
| 23 | | 3 | Best (Low Cost, high confidence, etc.) | | | | | | | |
| 24 | | Criterion | | | | | | | | |
| 25 | | Cost | More mass is more cost | | | | | | | |
| 26 | | Weight | Is the Design Under the weight constraints | | | | | | | |
| 27 | | Prediction precision | Are the engineers calculations sufficient and correct? | | | | | | | |
| 28 | | Confidence -failure loc | Confidence level in the indicated failure location | | | | | | | |
| 29 | | Prismatic vs non prismatic | Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs | | | | | | | |
| 30 | | Manufacturability | Is it simple to produce? Are there multiple process for a single component? | | | | | | | |
| 31 | | | | | | | | | | |
| 32 | | Comments: | | | | | | | | |
| 33 | | Costs was scored low because balsa wood is cheap, with all of them needed potentially expensive elcectronic components for the lifting device | | | | | | | | |
| 34 | | Weight was scored in the middle because it must be below the 85g weight constraint per the requirements | | | | | | | | |
| 35 | | Prediction Prescision was also scored in the middle because the calculated values are important to the initial success of the project | | | | | | | | |
| | | …use the location of the failure point of the bridge is easy to find | | | | | | | | |
| | | …because what shapes are used is important in determining the forces in these | | | | | | | | |
| | | …e easy to produce as well as easily repicated | | | | | | | | |

Figure 6.1.1: Truss Style Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Laser | Score x Wt | Band saw | Score x Wt | Hand saw | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | |
| Availability | 2 | 6 | 2 | 4 | 2 | 4 | 3 | 6 | |
| Prediction-Precision | 2 | 6 | 3 | 6 | 2 | 4 | 1 | 2 | |
| Manufacturablity | 3 | 9 | 3 | 9 | 2 | 6 | 1 | 3 | |
| Prismatic vs non prismatic | 3 | 9 | 3 | 9 | 2 | 6 | 2 | 6 | |
| Total | 11 | 33 | | 29 | | 21 | | 20 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 3.03 | | 87.9 | | 63.6 | | 60.6 | Percent |

| | | | | | |
|---|---|---|---|---|---|
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 70.7 | Average |
| | Poor Bias: | Standard Deviation is one or less digits | Poor? Change something! | 15 | Std Dev. |
| | | You can change the criteria, weighting, or the projects themselves... | | | |

| Weighting/Scoring Scale | |
|---|---|
| 1 | Worst (too costly, low confidence, too big, etc.) |
| 2 | Median Values, or Unsure of actual value |
| 3 | Best (Low Cost, high confidence, etc.) |

| Criterion | |
|---|---|
| Cost | More mass is more cost |
| Availability | How readily avalable is it |
| Prediction precision | Are the engineers calculations sufficient and correct? |
| Manufacturability | Is it simple to produce? Are there multiple process for a single component? |
| Prismatic vs non prismatic | Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs |

| Comments: | |
|---|---|
| Comment about why you scored each design as you did. | |
| Laser | The laser scored low on cost and availability due to it being a high priced machine and only being availible during school hours |
| | It scored higher on the precision, manufacturing, and prismatic areas due to its ability to make extremely precise cuts that will result in the most accurate dimensions |
| Band Saw | The band saw scored similar to the laser in the areas of cost and availability as it is also a more expensive machine that is only available during school hours |
| | It scored a little lower in the precision, manufacturiability, and prismatic areas as it is not as precise as the laser cutter, but will still achieve good resuts |
| Hand Saw | The hand saw scored high in the cost and availabilty areas as the student already as a precision hand saw available that can be use any hour of the day |
| | It scored lower in the precision, manufacturabilty, and prismatic areas as it is contrained to how good the student is at cutting, which could result in not straight lines |

Figure 6.1.2: Wood Manufacturing Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Arduino | Score x Wt | Rasberry Pi | Score x Wt | Weights | Score x Wt |
|---|---|---|---|---|---|---|---|---|
| Cost | 2 | 6 | 2 | 4 | 1 | 2 | 3 | 6 |
| Functionality | 3 | 9 | 3 | 9 | 3 | 9 | 1 | 3 |
| Manufacturability | 3 | 9 | 2 | 6 | 1 | 3 | 3 | 9 |
| Confidence- Failure Loc | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Prismatic vs non-Prismatic | 2 | 6 | 2 | 4 | 1 | 2 | 3 | 6 |
| Total | 11 | 33 | | 25 | | 18 | | 26 |
| NORMALIZE THE DATA (muliply by fraction, N) | | 3.03 | | 75.8 | | 54.5 | | 78.8 Percent |

Decide if Bias is Good or Bad

Good Bias: Standard Deviation is two or more digits — Good? Then done. — 69.7 Average

Poor Bias: Standard Deviation is one or less digits — Poor? Change something! — 13 Std Dev.

You can change the criteria, weighting, or the projects themselves...

**Weighting/Scoring Scale**

1 Worst (too costly, low confidence, too big, etc.)
2 Median Values, or Unsure of actual value
3 Best (Low Cost, high confidence, etc.)

**Criterion**

Cost: More mass is more cost
Functionality: How well does it work as required
Manufacturability: Is it simple to produce? Are there multiple process for a single component?
Confidence -failure loc: Confidence level in the indicated failure location
Prismatic vs non prismatic: Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs

**Comments:**

Comment about why you scored each design as you did.

Arduino
It is effective in the areas of cost and functionallity due to its large following and cheap components
Suffers in manufacturability because it does require wiring to be done
Failure loc is a two as it is easy to identiy weak point, however there are multiple so it is hard to predict exactly
It requires a housing to be created which will use non prismatic shapes to allow for ports to be accessible and motor to mount to it

Rasberry Pi
Effective in functionallity as it can be programmed to lift the bridge at the push of oa button
Falls short in many areas due to its high complexity, high cost compared to the other options
Failure loc is similar in concept to the arduino as it can be identified, but it canniot be exact as there are many weak spots
it is non primsatic as it requires many different odd shaped parts to be manufactured to create a functioning piece

Weights
Effective in costs as it is only weights, and effective in being prismatic as it is a geometric shape, and is easy to manufacture
Confidenc loc is scored high because it is only two parts, a weight and a stand
Falls short in functionality as it cannot move the bridge at the push of a button, so is stuck in the up position

Figure 6.1.3: Articulation Brain Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Towers | Score x Wt | Pully | Score x Wt | Hydraulic | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Costs | 2 | 6 | 2 | 4 | 3 | 6 | 2 | 4 | |
| Weight | 3 | 9 | 2 | 6 | 3 | 9 | 3 | 9 | |
| Manufacturability | 3 | 9 | 2 | 6 | 3 | 9 | 2 | 6 | |
| Confidence Failure Loc | 2 | 6 | 2 | 4 | 3 | 6 | 3 | 6 | |
| Prismatic | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| Total | 11 | 33 | | 23 | | 33 | | 28 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 3.03 | | 69.7 | | 100.0 | | 84.8 | Percent |

| | | | | | |
|---|---|---|---|---|---|
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 84.8 | Average |
| | Poor Bias: | Standard Deviation is one or less digits | Poor? Change something! | 15 | Std Dev. |
| | | You can change the criteria, weighting, or the projects themselves… | | | |

**Weighting/Scoring Scale**

| | |
|---|---|
| 1 | Worst (too costly, low confidence, too big, etc.) |
| 2 | Median Values, or Unsure of actual value |
| 3 | Best (Low Cost, high confidence, etc.) |

**Criterion**

| | |
|---|---|
| Cost | More mass is more cost |
| Weight | Light weight scores better on the success equation |
| Manufacturability | Is it simple to produce? Are there multiple process for a single component? |
| Confidence -failure loc | Confidence level in the indicated failure location |
| Prismatic vs non prismatic | Is the shape prismatic (retangle, square, etc) or is it irregullarly shaped to meet the engineering needs |

**Comments:**

Comment about why you scored each design as you did.

| | |
|---|---|
| Towers | To is relatively low cost and weight as it uses a similar method to the pully, but with a secont tower |
| | Relatively easy to manufacture |
| | Fairly confident in where it will fail, but as there are two tower, it is still a little unsure |
| | Uses rectangles and triangles |
| Pully | Low cost and weight, easy to manufacture and predict failure points |
| | Utilizes triangles and rectangles so is prismatic |
| Hydraulic | relatively cost effective, low weight, one point of filure, geometic shapes |
| | Relatively easy to manufactre as it only requires mounting points and one hydrulic line |

Figure 6.1.4: Lifting Mech Decision Matrix

| Criterion | Weight | Best Possible | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 to 3 | 3 | High | Score x Wt | Mid | Score x Wt | Low | Score x Wt |
| Cost | 3 | 9 | 1 | 3 | 2 | 6 | 3 | 9 |
| Weight | 3 | 9 | 1 | 3 | 2 | 6 | 3 | 9 |
| Manufacturability | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Strength | 3 | 9 | 3 | 9 | 2 | 6 | 1 | 3 |
| Availability | 2 | 6 | 2 | 4 | 2 | 4 | 2 | 4 |
| Total | 12 | 36 | | 21 | | 24 | | 27 |
| NORMALIZE THE DATA (muliply by fraction, N) | | 2.78 | | 58.3 | | 66.7 | | 75.0 Percent |

Decide if Bias is Good or Bad

Good Bias: Standard Deviation is two or more digits — Good? Then done. — 66.7 Average

Poor Bias: Standard Deviation is one or less digits — Poor? Change something! — 8 Std Dev.

You can change the criteria, weighting, or the projects themselves...

**Weighting/Scoring Scale**

1 Worst (too costly, low confidence, too big, etc.)
2 Median Values, or Unsure of actual value
3 Best (Low Cost, high confidence, etc.)

**Criterion**

Cost: More mass is more cost
Weight: Light weight scores better on the success equation
Manufacturability: Is it simple to produce? Are there multiple process for a single component?
Strength: Will it be able to support required weight
Availability: How many different sizes are available and how easy is it to come by

**Comments:**

High Density
Higher cost and weight, so scored lower
Relatively available and easy to manufacture
Strongest of the 3

Mid Density
Slightly better cost and weight
Similar in manufacturability and availability
Will support weight but not as well

Low Density
Cheapest and lowest weight
Similar manufacturability and availability
Should support some weight, but would cut it close

Figure 6.1.5: Balsa Wood Type Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Polyvinyl | Score x Wt | Polyurethan | Score x Wt | Cycnoacylat | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 1 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | |
| Weight | 2 | 6 | 2 | 4 | 2 | 4 | 2 | 4 | |
| Effectivness | 3 | 9 | 3 | 9 | 2 | 6 | 2 | 6 | |
| Manufacturability | 2 | 6 | 3 | 6 | 2 | 4 | 2 | 4 | |
| Strength | 3 | 9 | 3 | 9 | 2 | 6 | 2 | 6 | |
| Total | 11 | 33 | | 30 | | 22 | | 23 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 3.03 | | 90.9 | | 66.7 | | 69.7 | Percent |

| | | | | | |
|---|---|---|---|---|---|
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 75.8 | Average |
| | Poor Bias: | Standard Deviation is one or less digits | Poor? Change something! | 13 | Std Dev. |
| | | You can change the criteria, weighting, or the projects themselves… | | | |

**Weighting/Scoring Scale**

| | |
|---|---|
| 1 | Worst (too costly, low confidence, too big, etc.) |
| 2 | Median Values, or Unsure of actual value |
| 3 | Best (Low Cost, high confidence, etc.) |

**Criterion**

| | |
|---|---|
| Cost | More mass is more cost |
| Weight | Light weight scores better on the success equation |
| Effectiveness | How well does it adhere to the material |
| Manufacturability | Is it simple to produce? Are there multiple process for a single component? |
| Strength | How strong is it |

**Comments:**

Comment about why you scored each design as you did.

Cost and weigth is similar in all of them as it is glue that will be used in small portions

Polyvinyl Acetat Effectiveness and Strength scored high as this is wood glue, and will be used to adhere to wood
Easy to manufacture as it can be rubbed on with a cue tip and wiped if extra is added before it dries

Polyurethane

Cycnoacrylates

Will work efectively for the situation and have the strength to do it, but wood glue will do the job better
Less easy to manufacture as it is harder to wipe off excess than wood glue due to the viscocity

Figure 6.1.6: Adhesive Type Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | Plastic | Score x Wt | Alumium | Score x Wt | Nylon | Score x Wt | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | 3 | 9 | 3 | 9 | 1 | 3 | 2 | 6 | |
| Weight | 2 | 6 | 3 | 6 | 1 | 2 | 2 | 4 | |
| Manufacturability | 3 | 9 | 3 | 9 | 2 | 6 | 2 | 6 | |
| Stength | 1 | 3 | 1 | 1 | 3 | 3 | 2 | 2 | |
| Criteria | 3 | 9 | 3 | 9 | 1 | 3 | 3 | 9 | |
| Total | 12 | 36 | | 34 | | 17 | | 27 | |
| NORMALIZE THE DATA (muliply by fraction, N) | | 2.78 | | 94.4 | | 47.2 | | 75.0 | Percent |

Decide if Bias is Good or Bad

| | | | |
|---|---|---|---|
| Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 72.2 Average |
| Poor Bias: | Standard Deviation is one or less digits | Poor? Change something! | 24 Std Dev. |

You can change the criteria, weighting, or the projects themselves...

**Weighting/Scoring Scale**

| | |
|---|---|
| 1 | Worst (too costly, low confidence, too big, etc.) |
| 2 | Median Values, or Unsure of actual value |
| 3 | Best (Low Cost, high confidence, etc.) |

**Criterion**

| | |
|---|---|
| Cost | More mass is more cost |
| Weight | Light weight scores better on the success equation |
| Manufacturability | Is it simple to produce? Are there multiple process for a single component? |
| Stength | How strong is it |
| Criteria | How well does it follow the requirements |

**Comments:**

Comment about why you scored each design as you did.

| | |
|---|---|
| Plastic | It is low cost, easy to manufacture, light weight, and fits the criteria |
| | Low strength, but not as necessary as it will no be under much weight |
| Aluminum | High cost, high weight, does not fit criteria as needs to be a plastic material |
| | High strength |
| | Relatively easy to manufacture |
| Nylon | Relatively low cost weight, and strength |
| | Somewhat easy to manufacture |
| | Fits the Criteria |

Figure 6.1.7: Lifting Component material Decision Matrix

| Criterion | Weight 1 to 3 | Best Possible 3 | 3-D Printing | Score x Wt | CNC | Score x Wt | Hand Tools | Score x Wt |
|---|---|---|---|---|---|---|---|---|
| Costs | 2 | 6 | 3 | 6 | 1 | 2 | 2 | 4 |
| Availability | 3 | 9 | 3 | 9 | 1 | 3 | 2 | 6 |
| Waste | 2 | 6 | 3 | 6 | 1 | 2 | 1 | 2 |
| Precision | 3 | 9 | 3 | 9 | 3 | 9 | 1 | 3 |
| Manufacturability | 2 | 6 | 3 | 6 | 3 | 6 | 1 | 2 |
| Total | 12 | 36 | | 36 | | 22 | | 17 |
| NORMALIZE THE DATA (muliply by fraction, N) | | 2.78 | | 100.0 | | 61.1 | | 47.2 Percent |

| | | | | |
|---|---|---|---|---|
| Decide if Bias is Good or Bad | Good Bias: | Standard Deviation is two or more digits | Good? Then done. | 69.4 Average |
| | Poor Bias: | Standard Deviation is one or less digits | Poor? Change something!! | 27 Std Dev. |
| | | You can change the criteria, weighting, or the projects themselves... | | |

**Weighting/Scoring Scale**

| | |
|---|---|
| 1 | Worst (too costly, low confidence, too big, etc.) |
| 2 | Median Values, or Unsure of actual value |
| 3 | Best (Low Cost, high confidence, etc.) |

**Criterion**

| | |
|---|---|
| Cost | How much would the process/materials cost |
| Availability | Is the process easily accessible to the student |
| Waste | Is the process efficient with waste production |
| Precision | How prceise is the process at manufacturing parts |
| Manufacturability | How easy would it be for the student to learn/preform this process |

**Comments:**

Comment about why you scored each design as you did.

| | | | | | |
|---|---|---|---|---|---|
| 3-D Printing | It is a low cost process, both the parts and the machine were very inexpensive | CNC- | Expensive machine and would need to buy blocks of plastic | Hand Tool | Relatively low cost with the exception of drills and batteries |
| | The student owns their own machine for 24/7 access | | School has a CNC however would need to schedule a time around others | | Student owns some tools, but not many so would need to purchase or borrow |
| | addative process so minimal waste | | subtactive so more waste creation | | subtracive and addative process so greater waste than 3-d printing |
| | able to follow very close precision and tolerances as it is computer run | | very prcise as it is also a computer run process | | not very precise as it is ceceptable to human error |
| | slight learning curve, but pleanty of resources for help | | difficult to manufacture as a program would need to be created for the part to be cut | | somewhat difficult, but relies on students skill with hand tools |

Figure 6.1.8: Articulation Component Manufacturing Process Decision Matrix

# APPENDIX G – Testing Report

## Appendix G1 (Articulation Height)

Introduction:

Requirements for this test are that the bridge had to be able to articulate up 140mm about the bottom middle of the bridge. What was analyzed was what height the bridge was able to achieve, how that compares to the 140mm requirement, and what could be improved upon in future designs/helped the bridge succeed. Some parameters of interest were the speed at which the bridge lifted and lowered, how much the bridge swayed while articulating, and how repeatable the test was. The predicted performance of the bridge was that it would be able to reach the 140mm mark based on the analysis done on the tower height(analysis 4) and the motor power(analysis 8). The tower was designed, so when the cable has reached a horizontal pulling position, the bridge is lifted 140mm, and the motor power was calculated to be sufficient to raise the bridge as well as maintain the lifted position. The data that was collected for this experiment was the height the bridge was able to reach, as well as a quick calculation for the percent off of 140mm that it was. This test was preformed on April 4th, 2024.

Method/Approach: To preform this test there are some things to note in the procedure

The resources needed involve the bridge and articulation structure as well as its associated components, an elevated surface for the bridge to sit on, as well as materials to record results of the test(detailed list of resources can be found in the test procedures below). Data will be captured using a measuring tape that will extend level to the base of the bridge up to the bottom middle point of the bridge. The height will be recorded on a data sheet and then plugged into an equation to find the percent off of 140mm the bridge reached.

To overview the test procedures, the bridge will be set up and the motor will be plugged in to receive power. Then the cable will be attached, the motor will be powered on, and the bridge can be lifted. Once it has reached its max height, a measurement will be taken an recorded(In depth procedure can be found in the test procedures section below). Limitations of this operation are that it needs to be done on a level surface to receive accurate data, and also needs to be done near a power source as it requires USB charging for the motor to function. In terms of the precision of the data, it is relatively precise. It is done with a measuring tape, so it could be more precise by using laser measurements, but as the main goal of the test is to see if the height reached is greater than 140mm, then hand measurements will suffice. Accuracy of the data is also decent as there will be markings of the proper point on the bridge to measure to.

Data found from the test will be recorded on a data sheet that by the end should have 3 heights, 3 error percentages, and an average for both of those. Using this data it can then be determined if the bridge was able to articulate over 140mm or not. It can also be discussed what may have happened in the test to cause the bridge to not be able to pass and how that can be addressed for future iterations. For best presentation, using a table will be most effective.

## Test Procedure

Summary: The purpose of this test is to find the height to which the bridge is able to articulate vertically about the bottom middle of the bridge. The minimum height requirement for this test is 140mm, so in testing it will be found whether or not the bridge was able to reach this requirement and if not why it may have failed and if succeeded what helped it reach that point.

Time: The test was completed on Thursday April 4th, 2024 in the evening(6:00pm to 7:00pm pst) is students house. The setup took 15 minutes, assembling the bridge, getting power connected to the motor, and assembling the stands. Afterwards the tests were ran taking 30 minutes. Disassembly and cleanup took 15 minutes.

Place: Students house, Ellensburg WA

Resources:

- Webcam/phone
- Tripod
- Laptop w/ Logitech software and Arduino software
- Arduino usb connecting cable
- Balsa wood bridge
- Articulation structure
- Motor
- Motor mount
- Cable
- Books to raise the bridge above table level
- Measuring tape
- Table
- Paper
- Pensil
- Chair

Risks: This test cannot be completed without electrical power as the motor needs power to be ran. All materials must be collected for the beginning of the test process. Student could be susceptible to splinters as dealing with wood. Student should be careful when handling the electrical components as there are exposed wires.

Test Procedure:

1. To begin, place the bridge on the abutments with 400mm gap between the two stands. Ensure that the bridge is at even spacing on the two platforms so allow the weight to be distributed evenly.
2. Place the articulation structure on one end of the bridge(lined up so both side profiles face the same way, longways, and the center of the bridge is centered with the center of the articulation structure). Attach the bridge to the articulation system by placing the connecting pins to the holes in the side of the bridge and the holes on the top of the base of the articulation structure.
3. Place the motor on the base of the articulation structure so the reel on the motor is aligned with the cable pass over at the top of the structure.

4. Place the weights on top of the motor mount. If not placed on the motor mount will not function and the bridge will not lift.
5. Once the bridge and articulation structure are secured together, and the motor is secured down with the weights, the cable can be run from the motor reel over the pass over, and connected to the top middle cross beam on the bridge.
6. Once the cable is connected, the bridge is assembled and ready for testing.
7. To test, press and hold the on button on the Arduino. This will activate the motor for testing

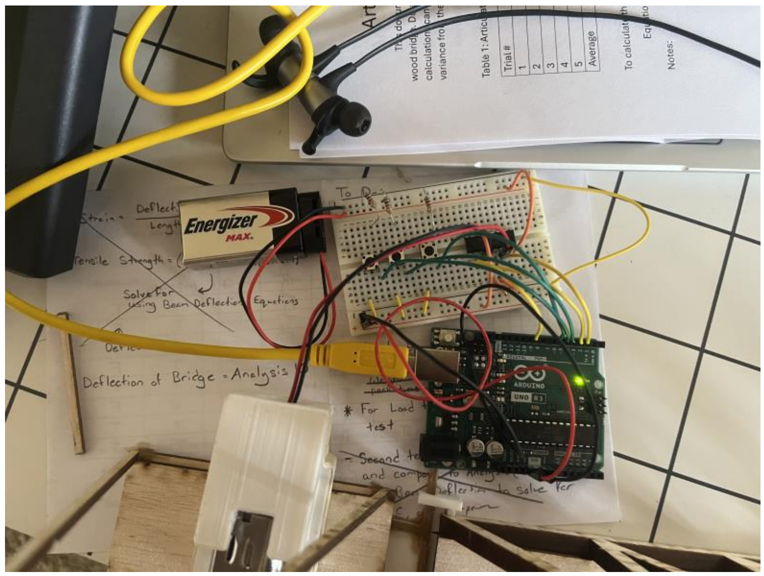



Figure G1.1: Arduino Setup

8. Then press the speed switch button to put the motor into higher gear and begin lifting the bridge.
9. Once the bridge has reached max height, take a measurement of the height the bridge is at. Record this number

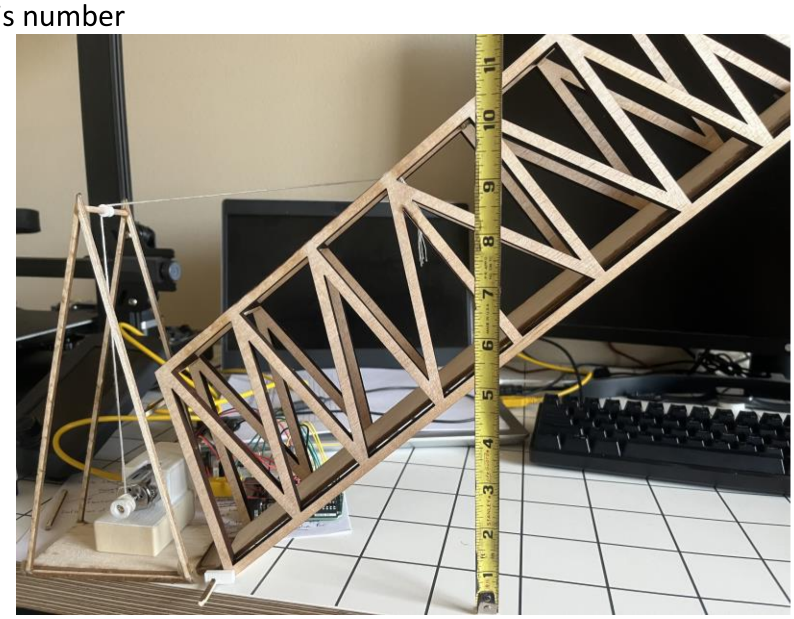


Figure G1.2: Result Measurement

10. Ensure that the bridge is now in low speed, and press the button that switches the direction the motor moves.
11. Preform step 7-10 for 3 total tests giving three total heights.

## Deliverables

The parameter values were the height the bridge was able to achieve. It was found that the bridge was able to achieve an average height of 142.6 mm. This was over the value that was determined in the analysis of the articulation structure, most likely due to the bridge lifting mechanism being stopped by human reaction time. This caused the height achieved to be higher than the calculated height, but still successful in meeting the minimum requirement of 140mm of vertical lift. The calculated values were the percent off of 140mm the bridge was able to achieve. After preforming calculations, it was found it was 1.86% over the minimum requirement which is perfectly acceptable. If the student wanted to get the bridge closer to the 140mm mark sensors could be used to auto stop the bridge, but for being mostly hand used it worked perfectly fine. The success criteria value was that the bridge needed to be articulate 140mm vertical about the bottom middle of the bridge. It was found that it was successful achieving an average height of 142.6 mm as stated above. As the requirement only had a minimum value this is well within the acceptable range for passing the test. After preforming the test, it was found that some issues that were found was that the bridge lifts very fast. This is due to the motor torque being higher when the rpms are higher, so in order to achieve the required torque to lift the bridge, the motor needs to be ran at a higher speed. To fix this in the future, the student would use a different motor that had a higher torque at lower rpms to raise the bridge at a slower more steady rate. For the time being the motor will suffice, but ideally a new motor would be used. Another issue was that the motor requires two power sources with how the design was. The simple solution to this was using a power bank to provide the second power source to the motor so the test could be preformed anywhere even if USB plugs were not available. Overall, it was determined that the test was successful fitting the requirement of lifting over 140mm about the bottom middle of the bridge.

# Appendix G1.1 – Procedure Checklist

## Articulation Test Procedure Checklist

- [x] Bridge is on level surface for testing
- [x] Battery and USB are plugged
- [x] Pins are attached between the bridge and the articulation structure
- [x] Cable is attached to bridge, over the articulation structure on the cable Passover, and attached to the motor
- [x] Data sheets are accessible
- [x] Proper recording tools are accessible

# Appendix G1.2 – Data Forms

## Articulation Test Documentation

This document is to be used when preforming the articulation test on the balsa wood bridge. Data should be recorded in the corresponding boxes, and equations for calculations can be seen below the table. Notes can be made at the bottom for any notable variance from the desired results.

Table 1: Articulation Test Results

| Trial # | Articulation Height(mm) | Percent off 140mm |
|---|---|---|
| Trial 1 | | |
| Trial 2 | | |
| Trial 3 | | |
| Average | | |

To calculate the percent change use the equation seen below(Equation 1)

Equation 1: $C = (h2 - 140mm/140mm) * 100\%$

Notes:

## Articulation Test Evaluation Sheet

1. What height was the bridge able to Achieve. ______________
2. Was this greater than 140mm.     Y     N
3. What went well in the test
4. What was noticed that could be improved upon in future iterations

# Appendix G1.3 – Raw Data

## Articulation Test Documentation

This document is to be used when preforming the articulation test on the balsa wood bridge. Data should be recorded in the corresponding boxes, and equations for calculations can be seen below the table. Notes can be made at the bottom for any notable variance from the desired results.

Table 1: Articulation Test Results

| Trial # | Articulation Height(mm) | Percent off 140mm |
|---|---|---|
| Trial 1 | 143.9mm | 2.79% |
| Trial 2 | 141.5mm | 1.07% |
| Trial 3 | 142.4mm | 1.71% |
| Average | 142.6 mm | 1.86% |

To calculate the percent change use the equation seen below(Equation 1)

Equation 1: C = (h2 – 140mm/140mm) * 100%

Notes:

This was the results of 3 good datapoints in a row. Since the system relies a little on reaction time, a few practice runs were done beforehand to learn how the system acts. After learning the system these 3 points were taken.

For future iterations a sensor could be used to stop the bridge allowing for more precise results.

# Appendix G1.4 – Evaluation Sheet

## Articulation Test Evaluation Sheet

1. What height was the bridge able to Achieve. 142.6mm
2. Was this greater than 140mm. (Y) N
3. What went well in the test
   Able to reach the minimum articulation height, with smooth lift
4. What was noticed that could be improved upon in future iterations
   Motor moves to fast, so could use a motor with better low end torque so it can move slower and more controlled

# Appendix G1.5 – Schedule (Testing)

| ID | | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 86 | | | **6** | **Device Evaluation** | **13 hrs** | **13 hrs** | **Thu 5/2/24** | **Fri 5/3/24** | |
| 87 | | | 6a | Write Testing Procedures | 6 hrs | 6 hrs | Sat 4/27/24 | Sat 4/27/24 | |
| 88 | | | 6b | Block Slide Test | **1 hr** | **1 hr** | **Fri 5/3/24** | **Fri 5/3/24** | |
| 89 | | | 6c | Weight Test | 1 hr | 1 hr | Wed 5/1/24 | Wed 5/1/24 | |
| 90 | | | 6d | Dimension and Material | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 91 | | | 6e | Deflection | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 92 | | | 6f | Articulation Test | 1 hr | 1 hr | Sat 4/6/24 | Sat 4/6/24 | |
| 93 | | | 6g | Load Support | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 94 | | | 6h | Articulation Cycle Time | 1 hr | 1 hr | Fri 4/19/24 | Fri 4/19/24 | |
| 95 | | | **7** | **489 Deliverables** | **29 hrs** | **0 hrs** | **Sat 4/27/24** | **Sat 4/27/24** | |
| 96 | | | 7a | Create Poster | 6 hrs | 6 hrs | Fri 5/10/24 | Fri 5/10/24 | |
| 97 | | | 7b | Submit Source | 1 hr | | | | |
| 98 | | | 7c | Finalize Report | 4 hrs | | | | |
| 99 | | | 7d | Abstract | 3 hrs | 3 hrs | Fri 3/29/24 | Fri 3/29/24 | |
| 100 | | | 7e | Website | 15 hrs | 13 hrs | Thu 5/9/24 | Fri 5/10/24 | |

The test(6f on Ghant) was completed on Thursday April 4th, 2024 in the evening(6:00pm to 7:00pm pst). The break down of the hour can be seen below

- 15 minutes setup and assembly
- 30 minutes completion of the testing
- 15 minutes cleanup and disassembly

The final report and writeup for the testing was completed on April 6th, 2024

# Appendix G2 (Articulation Cycle Time)

## Introduction

The requirement for this test was the cycle time for the bridge must be under 60 seconds(requirement D11), that is articulating up and down as well as the 10 second hold at the peak for the requirement of being able to stay at max articulation for 10 seconds(Requirement D10). What was analyzed in this test was how long it took the bridge to cycle, and how that compares to the 60 second requirement. Similar to test G1 some parameters of interest were the speed at which the bridge lifted and lowered, how much the bridge swayed while articulating, and how repeatable the test was. Based on the calculations preformed in analysis 13, it was determined that the cycle time for the bridge would be just over 17 seconds. This was done using unit cancelation and the circumference equation to determine the speed the bridge would lift and lower based on its set RPM and cable displacement. The data that was collected following the testing was the cycle time for the bridge, what percent off 60 seconds it was, and how close it was to the calculated values.

## Method/Approach

The resources needed involve the bridge and articulation structure as well as its associated components, an elevated surface for the bridge to sit on, as well as materials to record results of the test (detailed list of resources can be found in the test procedures below). Data will be captured using a stopwatch and a video captured on a webcam that will allow for more precise measurements to be taken than if done during the actual articulation cycle. The cycle time will be recorded on a data sheet and then plugged into an equation to find the percent off of 60 seconds the bridge's cycle time was.

To overview the test procedures, the bridge will be set up and the motor will be plugged in to receive power. Then the cable will be attached, the motor will be powered on, and the bridge can be lifted. Once it has reached its max height, the motor is put into low gear to allow the bridge to pause for 10 seconds at the peak per the requirements before the motor is switched directions to allow for the bridge to lower(In depth procedure can be found in the test procedures section below). Limitations of this operation are that it needs to be done on a level surface to receive accurate data, and also needs to be done near a power source as it requires USB charging for the motor to function. In terms of the precision of the data, it is relatively precise as the time will be taken off a video which can be analyzed in depth. It is done with a stop watch, but could also be done by video analysis by cutting the videos start to the moment the bridge lifts and the moment the bridge fully lowers and taking the time stamp, but as the main goal of the test is to see if the cycle time is lower than 60 seconds and the bridge is able to hold max height for at least 10 seconds, so hand timing was sufficient. Accuracy of the data is also decent as the videos can be rewatched to ensure the proper timing is done.

Data found from the test will be recorded on a data sheet that by the end should have 5 times, 5 error percentages, and an average for both of those. Using this data it can then be determined if the bridge was able to preform a full cycle in under 60 seconds and maintain max articulation for at least 10 seconds. It can also be discussed what may have happened in the test to cause the bridge to not be able to pass and how that can be addressed for future iterations. For best presentation, using a table will be most effective.

## Test Procedure

Summary: The purpose of this test is to find the cycle time of the bridge articulation, that being moving up and down and a 10 second pause at the peak. The max time requirement for this test was 60 seconds, so in testing it will be found whether or not the bridge was able to reach this requirement and if not why it may have failed and if succeeded what helped it reach that point.

Time: The test was completed on Friday April 19th, 2024 in the evening(6:00pm to 7:00pm pst) is students house. The setup took 15 minutes, assembling the bridge, getting power connected to the motor, and assembling the stands. Afterwards the tests were ran taking 30 minutes. Disassembly and cleanup took 15 minutes.
Place: Students house, Ellensburg WA
Resources:

- Webcam/phone
- Tripod
- Laptop w/ Logitech software and Arduino software
- Arduino usb connecting cable
- Balsa wood bridge
- Articulation structure
- Motor
- Motor mount
- Cable
- Books to raise the bridge above table level
- Measuring tape
- Table
- Paper
- Pencil
- Chair

Risks: This test cannot be completed without electrical power as the motor needs power to be ran. All materials must be collected for the beginning of the test process. Student could be susceptible to splinters as dealing with wood. Student should be careful when handling the electrical components as there are exposed wires.

Test Procedure:

1. To begin, place the bridge on the abutments with 400mm gap between the two stands. Ensure that the bridge is at even spacing on the two platforms so allow the weight to be distributed evenly.
2. Place the articulation structure on one end of the bridge(lined up so both side profiles face the same way, longways, and the center of the bridge is centered with the center of the articulation structure). Attach the bridge to the articulation system by placing the connecting pins to the holes in the side of the bridge and the holes on the top of the base of the articulation structure.

3. Place the motor on the base of the articulation structure so the reel on the motor is aligned with the cable pass over at the top of the structure.
4. Place the weights on top of the motor mount. If not placed on the motor mount will not function and the bridge will not lift.
5. Once the bridge and articulation structure are secured together, and the motor is secured down with the weights, the cable can be run from the motor reel over the pass over, and connected to the top middle cross beam on the bridge.
6. Once the cable is connected, the bridge is assembled and about ready for testing.
7. Before beginning articulating the bridge set the tripod and webcam up to see the bridge and press record. Having video of the bridge will allow the time test to be preformed after so the student can focus on the lifting procedures.
8. To test, press the on button on the Arduino. This will activate the motor for testing

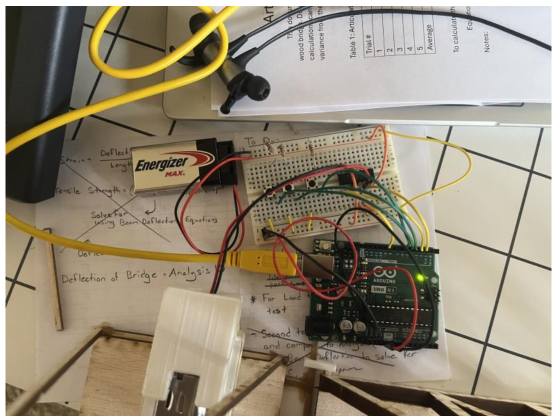



Figure G2.1: Same Setup as G1.1

9. Then press and hold the speed switch button to put the motor into higher gear and begin lifting the bridge.
10. Once the bridge has reached max height, pause for 10 seconds, and then press the button that switches the motor direction. Releasing the speed button will automatically put the bridge into low gear.
11. Once the bridge has fully reached its resting position, stop the recording and use a stopwatch to time the full cycle of the bridge.

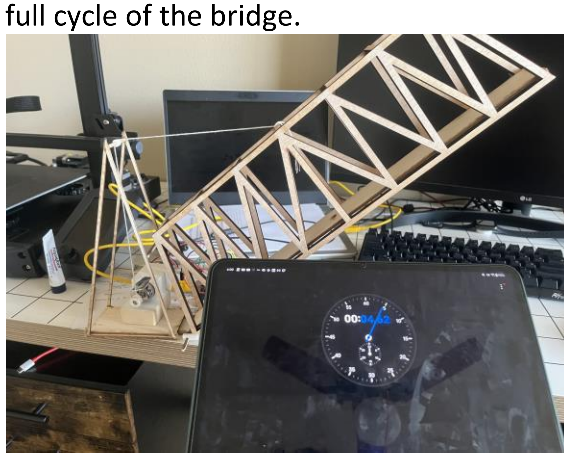


Figure G2.2: Timing Setup(Used for Time Estimation)

12. Record this time on the provided data sheet in the proper section.
13. Preform step 7-12 for 5 total tests giving three total heights.

## Deliverables

The parameter values for this test were the cycle time the bridge was able to achieve in its articulation. Following testing it was found that the average cycle time of the bridge was around 15.216 seconds which is 74.64% below the required 60 seconds. This was under the calculated value of 17.36 as seen in analysis 13. This is most likely due to the bridge lowering being much faster than the calculated value as the motor did not have enough low end torque to hold the bridge while moving downward. This meant that rather than slowly lowering the bridge, it would more slam down which is not ideal. This would decrease the time from the calculated as it did not account for the motor not having the resistance to hold the bridge from freefalling. The calculated time for moving downward was just over 5 seconds, but when preforming the test it was definitely much faster, and ended up being closer to 1 or 2 seconds. To get results closer to the calculated values, a motor that has enough torque to hold the bridge could be used or change the gearing on the current motor. While there were elements that could be improved, the test was successful in the end with the bridge being able to maintain articulation for 10 seconds and run a full cycle under 60 seconds. For future iterations of the test, ideally the cycle time would be a bit higher since there is plenty of room before reaching the 60 second mark. Slowing it down would create a more controlled cycle which would be ideal. This could be fixed as mentioned with a motor change for one with better low end torque, or the addition of gears to allow for a lower gear ratio, slowing down the lifting and lowering. Another issue that was noticed was the cable would fall off the reel as it was to thin, so creating a thicker reel for the cable to sit on would create a more consistent lift. Overall, the bridge was successful though at reaching the requirements of a cycle time under 60 seconds and maintaining max articulation for 10 seconds, so it does pass the test.

# Appendix G2.1 – Procedure Checklist

## Articulation Time Test Checklist

- Bridge is on level surface for testing
- Battery and USB are plugged in
- Pins are attached between the bridge and the articulation structure
- Cable is attached to the bridge, over the articulation structure on the cable Passover, and attached to the motor
- Data sheets are accessible
- Proper recording tools are accessible

# Appendix G2.2 – Data Forms

## Articulation Time Documentation

This document is to be used when preforming the articulation time test on the balsa wood bridge. Data should be recorded in the corresponding boxes, and equations for calculations can be seen below the table. Notes can be made at the bottom for any notable variance from the desired results.

Table 1: Articulation Time Test Results

| Trial # | Articulation Cycle Time(sec) | Percent off 60s |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| Average | | |

To calculate the percent change use the equation seen below (Equation 1)

Equation 1: C = (t2-60s/60s)*100%

Notes:

# Articulation Time Test Evaluation Sheet

1. How long did it take the bridge to complete one cycle? _____________
2. Was the time below 60s? Y N
3. What went well in the test
4. What was noticed that could be improved upon in the future?

# Appendix G2.3 – Raw Data

## Articulation Time Documentation

This document is to be used when preforming the articulation time test on the balsa wood bridge. Data should be recorded in the corresponding boxes, and equations for calculations can be seen below the table. Notes can be made at the bottom for any notable variance from the desired results.

Table 1: Articulation Time Test Results

| Trial # | Articulation Cycle Time(sec) | Percent off 60s |
|---|---|---|
| 1 | 16.08 sec | -73.2% |
| 2 | 14, 47 sec | -75.88% |
| 3 | 15.76 sec | -73.73% |
| 4 | 14.55 sec | -75.75% |
| 5 | 15.22 sec | -74.63% |
| Average | 15.216 sec | -74,64% |

To calculate the percent change use the equation seen below (Equation 1)

Equation 1: C = (t2-60s/60s)*100%

Notes:

Times were somewhat sparatic, so could in future tests use different motor as the current one is a little inconsistant with response times

# Appendix G2.4 – Evaluation Sheet

## Articulation Time Test Evaluation Sheet

1. How long did it take the bridge to complete one cycle? 15. 216
2. Was the time below 60s? (Y) N
3. What went well in the test

   The test was passed and the bridge was able to maintain 10 second pause at the peak

4. What was noticed that could be improved upon in the future?

   - Motor is weak
     - Creates inconsistencies
     - Does not raise sometimes
   - Arduino program needs some refinement
     - Does not always turn on when intended

# Appendix G2.5 – Schedule (Testing)

| ID | | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 86 | | | **6** | **Device Evaluation** | **13 hrs** | **13 hrs** | **Thu 5/2/24** | **Fri 5/3/24** | |
| 87 | | | 6a | Write Testing Procedures | 6 hrs | 6 hrs | Sat 4/27/24 | Sat 4/27/24 | |
| 88 | | | 6b | Block Slide Test | **1 hr** | **1 hr** | **Fri 5/3/24** | **Fri 5/3/24** | |
| 89 | | | 6c | Weight Test | 1 hr | 1 hr | Wed 5/1/24 | Wed 5/1/24 | |
| 90 | | | 6d | Dimension and Material | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 91 | | | 6e | Deflection | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 92 | | | 6f | Articulation Test | 1 hr | 1 hr | Sat 4/6/24 | Sat 4/6/24 | |
| 93 | | | 6g | Load Support | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 94 | | | 6h | Articulation Cycle Time | 1 hr | 1 hr | Fri 4/19/24 | Fri 4/19/24 | |
| 95 | | | **7** | **489 Deliverables** | **29 hrs** | **0 hrs** | **Sat 4/27/24** | **Sat 4/27/24** | |
| 96 | | | 7a | Create Poster | 6 hrs | 6 hrs | Fri 5/10/24 | Fri 5/10/24 | |
| 97 | | | 7b | Submit Source | 1 hr | | | | |
| 98 | | | 7c | Finalize Report | 4 hrs | | | | |
| 99 | | | 7d | Abstract | 3 hrs | 3 hrs | Fri 3/29/24 | Fri 3/29/24 | |
| 100 | | | 7e | Website | 15 hrs | 13 hrs | Thu 5/9/24 | Fri 5/10/24 | |

The test(6h on Ghant) was completed on Thursday April 19th, 2024 in the evening(6:00pm to 7:00pm pst). The break down of the hour can be seen below

- 15 minutes setup and assembly
- 30 minutes completion of the testing
- 15 minutes cleanup and disassembly

The final report and writeup for the testing was completed on April 19th, 2024

# Appendix G3 (Weight to Failure)

## Introduction

The requirement for this test was that the bridge needed to be able to lift a minimum load of 20 kg (Requirement 12) as well as deflect a maximum of 25mm under the load (Requirement 9). The elements that were analyzed were the load that the bridge was able to carry, and whether that was greater or less than the required load. The deflection test aimed at determining the max deflection of the bridge under max load as well as if it was above or below the 25mm maximum. To preform this test, the bridge was placed upside down in the Instron, with a pulling mechanism routed through the hole in the road deck. This allowed the bridge to be in tension as it would in a weight test. The parameters that were to be examined were the weight the bridge could hold, and how much it deflected at that load. The predicted values for the bridge load were 20kg, as the bridge was designed around the minimum requirements, and the defection was predicted to be 6.869mm. The bridge was designed around the 20kg, so the analysis was done to determine the cross-sectional area of the beams necessary to support the load. The deflection calculated using an online calculator. The data collected following the testing was the max load the bridge could support, the max deflection the bridge underwent, and what percent off these values were from the requirements.

## Method/Approach

The resources needed for this test are the bridge, the Instron the jig to hold the bridge, and the mechanism to apply a tension force to the bridge (Detailed lists of the materials needed can be found in the test procedures section below). Data was captured on the Instron computer, which could then be placed in excel and examined. The data was then recorded on the data sheets and then plugged into an equation to determine the percent off 20kg the bridge was as well as the percent off 25mm the bridge was.

To overview the test procedures, the jig will be mounted to the Instron, then the plate will be placed on the top end of the road deck. The rod will be passed through the hole in the plate and the deck. A nut is then placed on the end of the rod to keep the plate in place. Then the bridge is mounted to the jig and the Instron for testing (In depth procedures can be found in the test procedures below). Limitations of this test are that it requires an Instron, as well as a jig that may not be accessible to everyone. It also requires that the student have access to Instron data that could be accidently lost, so ensuring that data is kept safe is important. Another limitation is that if the test were not to be preformed correctly, then number of trials may be affected as there was only one bridge manufactured, so ensuring the testing is done correctly and the bridge is not fractured will allow for more than one test.

Data found from this test will be recorded on a data sheet that by the end of the testing should have a max load the bridge was able to maintain, a deflection the bridge was able to reach. And two percentages, being how close was the bridge able to reach the 20kg requirement and how close the bridge was able to be to the 25mm deflection maximum. This data was examined to show whether the bridge was able to pass the 20kg load test and the 25mm max deflection test. It can also be discussed what happened in testing to cause the bridge to pass or fail the test and what could be done to address this in future iterations of the bridge. Data for the bridge could be demonstrated in both a table and a graph.

## Test Procedure

Summary: The purpose of this test was to find the max load the bridge was able to maintain, the defection of the bridge under the max load, and whether it reached the 20kg load mark and stayed under the 25mm defection max. The failure points were also examined to show where improvements could be made as well as what worked in the design.

Time: The test was completed on Friday May 3rd, 2024 in the Morning (8:00am to 10:00am pst) is room 127 in Houge at CWU. The setup took 15 minutes, mounting the bridge to the jig, and placing it in the machine. Afterwards the tests were ran taking 5 minutes. Extra time in the schedule was allotted for viewing other students test performance adding an additional 40 minutes. Disassembly and cleanup took 5 minutes.

Place: Room 127 in Houge at CWU, Ellensburg WA

Resources:

- phone
- Computer with Instron Software
- Instron
- Jig
- Road Deck Plate
- Threaded Rod
- Nut
- Balsa wood bridge
- Table
- Paper
- Pencil
- Chair

Risks: This test cannot be completed without electrical power as the Instron needs power to be ran. All materials must be collected for the beginning of the test process. Student could be susceptible to splinters as dealing with wood. Student should be careful when handling the Instron as it is a large piece of machinery.

Test Procedure:

1. To begin, grab the bridge and place the plate on the top end of the road deck. Ensure that the hole in the plate and the hole in the road deck are aligned.
2. Push the threaded rod through the holes and screw the nut on the top. Pull the rod so the nut rests on top of the plate.
3. Place the jig in the bottom of the Instron and push the safety pin through.
4. Place the bridge properly in the jig (upside down, so road deck is on the top end), and the rod is attached to the top mounting hole on the Instron and put the safety pin through.
5. Once the bridge has been securely mounted, the Instron can be ran. Ensure to video the process as it should be put in the website.

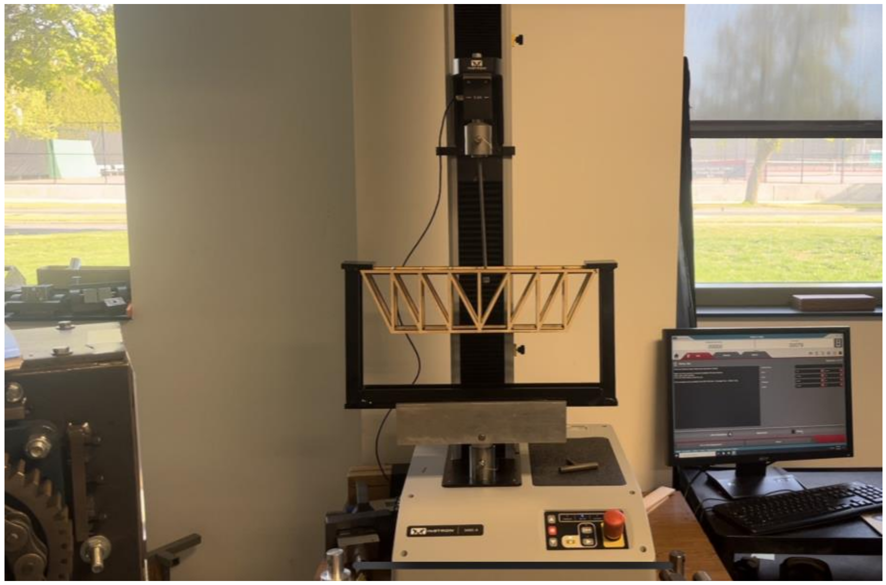


Figure G3.1: Instron Mounting Final Setup

6. Following testing, data can be acquired from the Instron and put in excel to create graphs.
7. Record the max deflection and the max load from the Instron on the datasheet along with any notes from testing.

## Deliverables

The parameters for this test were the load the bridge was able to maintain and the deflection of the bridge at that load. After preforming the test, it was found that the bridge was able to support a load of 9.7 kg before fracture while deflecting 4.03 mm. Both values were under the predicted calculations of 20kg and 6.869mm. There are multiple things that could have led to the load being much less than the required. For one thing, it was noticed after testing that the direction of the grains on the wood were long ways of the bridge, so under a tension load it was trying to split apart the grains where it may have been weaker than orienting them, so the grains were shifted 90 degrees. This way the bridge under tension would not be having its grains split apart but elongated leading to higher tensile strength. Another aspect that could have affected the results was that the hole in the road deck was not centered due to a beam being placed in the middle of the bottom middle of the bridge. This caused the load to pull at an angle rather than straight down, putting stresses on the beams that was not accounted for in calculations. When looking at the material properties for balsa wood, just general numbers were used as manufacturer specs were not given. As there are different grades of balsa wood, the numbers used may have not been applicable to the materials used in the final construction leading to the lower load capacity.

While there were many areas of the bridge that failed, they were in a predictable manor. The bridge broke at the base of the beams closest to where the load was. This was to be expected with how the construction was. What was also noticed was that the breaks were shifted to the side where the hole was shifted, meaning one side of the bridge had more breaks than the other. This would make sense as that side of the bridge was under much more stress than the other. For future iterations of the bridge, having the hole in the center will allow for a more even pull, and minimize the unaccounted-for stresses in the beams. Another modification would be that the bridge would be constructed to have the grains of the bridge stacked top to bottom but having them stacked left to right would ensure that they do not get pulled apart like they did in the current design when under tension. Another modification would be that if the same grade of balsa was used, then increasing the cross-sectional area of the beams would allow for a greater stress to be held, and if the cross-sectional area were to stay the same, then using a different grade of balsa with a higher tensile strength would also work.

In the end, the bridge was unable to maintain the required load, so it failed that test. The bridge did manage to deflect less than 25mm under load, so it did technically pass, although it did not reach the max load, so there is still some question there. Modification will need to be done in future iterations to allow it to pass.

# Appendix G3.1 – Procedure Checklist

## Load/Deflection Test Procedure Checklist

- Bridge is securely mounted in the jig for testing on the Instron
- The proper load bearing tool is mounted on the Instron
- Data sheets are accessible
- Proper Recording tools are accessible
- Student is wearing the proper PPE
- Flash drive is accessible to retrieve data from the Instron

# Appendix G3.2 – Data Forms

## Load/Deflection Test Documentation

This document is to be used when preforming the load and deflection test on the balsa wood bridge. Data should be recorded in the corresponding boxes, and equations for calculations can be seen below the table. Notes can be made at the bottom for any notable variance from the desired results.

Table 1: Load and Deflection Results

| Trial # | Max Load(lbs) | Max Deflection(in) |
|---|---|---|
| 1 | | |

Notes:

## Load/Deflection Test Evaluation Sheet

1. What was the Max Load the bridge could carry? ______________
2. Was this greater than 20kg? Y N
3. What was the Max Deflection on the bridge due to the load? _____________
4. Was this less than 25mm? Y N
5. What went well during this test?

6. What could be improved in future iterations to allow for more successful testing?

# Appendix G3.3 – Raw Data

## Load/Deflection Test Documentation

This document is to be used when preforming the load and deflection test on the balsa wood bridge. Data should be recorded in the corresponding boxes, and equations for calculations can be seen below the table. Notes can be made at the bottom for any notable variance from the desired results.

Table 1: Load and Deflection Results

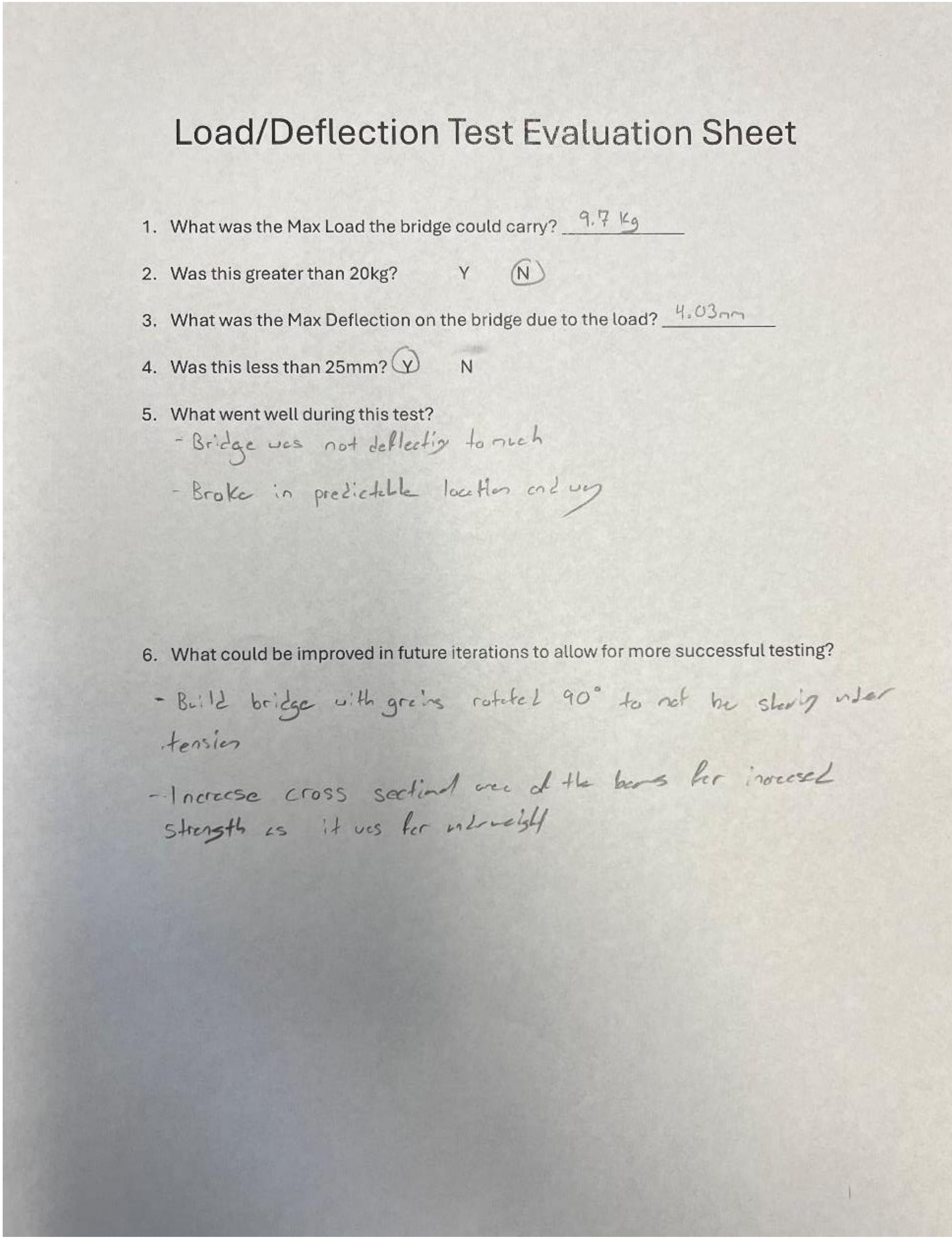
| Trial # | Max Load(lbs) | Max Deflection(in) |
|---|---|---|
| 1 | 9.7 Kg | 4.03mm |

Notes:

Lower then the required weight, deflection cannot be evaluted due to load not being achieved

- Broke along the grain
- Broke in the middle

# Appendix G3.4 – Evaluation Sheet



## Load/Deflection Test Evaluation Sheet

1. What was the Max Load the bridge could carry? 9.7 Kg
2. Was this greater than 20kg? Y (N)
3. What was the Max Deflection on the bridge due to the load? 4.03mm
4. Was this less than 25mm? (Y) N
5. What went well during this test?
   - Bridge was not deflecting to much
   - Broke in predictable location and way
6. What could be improved in future iterations to allow for more successful testing?
   - Build bridge with grains rotated 90° to not be shearing under tension
   - Increase cross sectional area of the bars for increased strength as it was far underweight

# Appendix G3.5 – Schedule (Testing)

| ID | | Task Mode | Task | Task Name | Baseline1 Estimated Duration | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|---|---|---|
| 86 | | | **6** | **Device Evaluation** | **13 hrs** | **13 hrs** | **Thu 5/2/24** | **Fri 5/3/24** | |
| 87 | | | 6a | Write Testing Procedures | 6 hrs | 6 hrs | Sat 4/27/24 | Sat 4/27/24 | |
| 88 | | | 6b | Block Slide Test | **1 hr** | **1 hr** | **Fri 5/3/24** | **Fri 5/3/24** | |
| 89 | | | 6c | Weight Test | 1 hr | 1 hr | Wed 5/1/24 | Wed 5/1/24 | |
| 90 | | | 6d | Dimension and Material | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 91 | | | 6e | Deflection | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 92 | | | 6f | Articulation Test | 1 hr | 1 hr | Sat 4/6/24 | Sat 4/6/24 | |
| 93 | | | 6g | Load Support | 1 hr | 1 hr | Fri 5/3/24 | Fri 5/3/24 | |
| 94 | | | 6h | Articulation Cycle Time | 1 hr | 1 hr | Fri 4/19/24 | Fri 4/19/24 | |
| 95 | | | **7** | **489 Deliverables** | **29 hrs** | **0 hrs** | **Sat 4/27/24** | **Sat 4/27/24** | |
| 96 | | | 7a | Create Poster | 6 hrs | 6 hrs | Fri 5/10/24 | Fri 5/10/24 | |
| 97 | | | 7b | Submit Source | 1 hr | | | | |
| 98 | | | 7c | Finalize Report | 4 hrs | | | | |
| 99 | | | 7d | Abstract | 3 hrs | 3 hrs | Fri 3/29/24 | Fri 3/29/24 | |
| 100 | | | 7e | Website | 15 hrs | 13 hrs | Thu 5/9/24 | Fri 5/10/24 | |

The test(6e and 6g in Ghant) was completed on Friday May 3rd, 2024 in the Morning (8:00am to 10:00am pst) is room 127 in Houge at CWU. The break down of the hour can be seen below

- 15 minutes setup and assembly
- 40 minutes waiting for other student completion
- 5 minutes cleanup and disassembly

The final report and writeup for the testing was completed on May 3rd, 2024

# Appendix G4.1 – Misc Test Results

## Bridge Requirement Documentation

1. Was the vehicle able to transverse the bridge with no restrictions? (Y) N
2. Was the bridge able to span the gap of 400mm? (Y) N
3. What was the final weight of the bridge? 45.4g
4. Was this weight below 85g? (Y) N
5. If a weight of 0.098 Newtons is applied to the lifting mechanism, can a standard sheet of copy paper be placed between the bridge and the abutments?

   (Y) N

- The dimensional constraints were met and the weight constraints were met

# APPENDIX H – Resume

## Sam Katsuda

Central Washington University

Sam.katsuda@gmail.com

## OBJECTIVE

My objective is to explore different areas of engineering to determine what I am passionate about and want to follow through with as a career path. My preferred industries are automotive

## EDUCATION —

Central Washington University, Ellensburg WA

- Final Two Years Bachelors in Mechanical Engineering Technology
- Minor in Mathematics
- Two Years Track and Field

Oregon Institute of Technology, Wilsonville OR

- First Two Years of Bachelor in Mechanical Engineering

Clackamas Community College, Clackamas OR

- Associates of Arts
- Two Years Track and Field

## EXPERIENCE

*June 2021 - Present*

Maintenance Assistant • Material Handler • Allied Systems Company

Maintenance:

- Repair and Maintain Machines
- Clean and Organize Facilities

Material Handler:

- Stock Parts as they are added to Inventory
- Manage Inventory
- Pick Parts for Kits
- Deliver Parts to Different Branches of Company

*August 2018 – March 2020*

Lifeguard • Swim Instructor • Tigard Tualatin Aquatic District

Lifeguard:

- Keep Patrons of the pool safe
- Maintain Facilities
- Take Calls and Complete Front Desk Work

Swim Instructor:

- Teach Customers How to Swim
- Motivate Swimmers to Improve and Continue to Work
- Prepare Swimmers for Level Progression

## KEY SKILLS —

Positive Open Mindset

Hardworking

4 Years AutoCAD

SolidWorks

2 years Maintenance

# COMMUNICATION

As a Swim Instructor, I had to be comfortable being the one in charge and leading the group, as well as the one responsible for teaching the students the proper swim techniques.

As a Lifeguard I had to be comfortable taking charge of the situation and taking action when necessary. Not only did I have to be assertive, but also welcoming during the front desk work to the incoming customers.

As a Maintenance Assistant, I had to take on jobs that I was not 100% sure I would be able to complete on my own. This lead me to have to be comfortable asking questions when necessary.

# LEADERSHIP

As a lifeguard and swim instructor I had to know when to take charge. It was a matter of safety that I was able to be assertive when rules were broken or situations looked like they could become dire.

# REFERENCES

[Available upon request.]