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Balsa Wood Bridge

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BALSA WOOD BRIDGE

By

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Abstract

Faculty at Central Washington University proposed a challenge to mechanical engineering students that could be accomplished in an in-home setting. The goal was to create a balsa wood bridge, weighing no more than 85 grams, that can support a load over an open span and raise above its resting position by means of a mechanical system. To produce a successful solution to the problem, a vertical lift bridge was created consisting of two lifting towers and a load bearing bridge. Using equations of static equilibrium and strength of materials, the required width for each member was determined. Project requirements were accounted for with multiple supporting analysis on various parts in the design. The contents of each structure were limited strictly to balsa wood and glue, by evaluating both the tensile and shearing strength of each, stress concentrations were identified and mitigated. The construction of the device was achieved by setting up multiple fixtures to manufacture and join each component of the assembly. Testing is achieved with multiple nondestructive procedures first, followed by a final load bearing test. The device when tested can successfully raise and lower through use of the articulating components. When at rest the device can support the static testing load of 20kg and meets the weight requirement at 84.4 grams.

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1. INTRODUCTION

a. Description

The problem presented is to determine a way to create an articulating balsa wood bridge that can support a considerable amount of weight while maintaining low structure weight. While resting on two abutments the bridge must only exert vertical forces and must span a large opening. The bridge must be able to raise above resting height to allow passage bellow. Limitations have been placed on the objects weight, size, and material

b. Motivation

Due to the lack of resource availability caused by the current world pandemic, the scope of senior projects was limited. A small selection of potential projects was presented and selected by students to conduct through the remained of the school year. The intent of the articulating balsa wood bridge was to challenge students to determine the most efficient way to create a moving structure that is both light in weight and rigid.

c. Function Statement

The basic purpose of the projected structure is listed below. By stating the basic purpose of the project, possible solutions can be listed and evaluated. Understanding the purpose of the structure will allow for the refinement of requirements and limitations.

1. The structure must span a divide while supporting a load
2. The bridge must allow passage for structures moving perpendicular to the span of the bridge that pass above the bridges resting height

d. Requirements

In order to satisfy the overall goal of this project the following conditions must be met. Any deviation from these parameters will indicate an undesired result or function. By quantifying the design requirements, the evaluation of the structure's success may be conducted.

1. The bridge, excluding the articulating components, must weigh less than 85 grams
2. The constructions of the structure must consist of balsa wood and glue of any kind
3. At least 50 percent of the road deck section must be able to raise 140 mm above its resting height and remain at the height for at least ten seconds
4. The bridge must span an opening of 400mm
5. While resting on abutments the bridge shall not exert lateral force
6. A 38mm solid balsa wood rood deck must lay the full length of the bridge
7. Any curved roads must be smooth and not exceed a grade height difference of 25mm
8. The road deck must contain enough room for a 32mm x 25mm car can pass through
9. The addition of 10g to the lifting mechanism must allow for a piece of printer paper to pass underneath one end of the bridges 'lift points'
10. The bridge must support a minimum of 18.2kg to 20kg
11. Tolerances must be xxxmm +/- 8mm, xxmm +/- 1mm, xxg +/- 1.5g

e. Engineering Merit

The information required for this project will employ different aspects of math, physics, and engineering. Understanding basic concepts of material loading, static equilibrium, and mechanical design are essential for the successful completion of the criteria.

f. Scope of Effort

The bridge will consist of balsa wood and glue of any type. The articulating components shall not provide structural support, however, may be a combination of other materials. Upon completion the structure will consist of the combination of the two

g. Success Criteria

Bridge spans distance, supports load, and articulates.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

By using the first proposed drawing and eliminating the top truss section, a great reduction in weight will be seen. Unlike the other potential truss designs, this one will only use one cross member between each vertical segment. The focus of this selection is based around the idea of lowest weight with most even load distribution

b. Design Description

The forces that each joint will experience during testing will depend on the angle each cross member is placed at. By selecting a design that uses a single diagonal to separate each vertical member, rather than and equilateral triangle or X design, the angle at which the cross member is placed can be made steeper. By placing each diagonal member at a sharper angle to horizontal, more of the tensile and compressive loading on the top and bottom sections of the truss can be dispersed.

c. Benchmark

Similar balsa wood bridge completions are held by multiple colleges across the nation. One example of this can be found at the University of Louisiana. Ground rules for this challenge are nearly the same as those discussed in this document. The bridge must span a length of at least 350mm, only consist of balsa wood and glue, and must be able to support 25kg. A notable difference from Louisiana's requirements is that the bridge doesn't have to articulate, and the performance grading is based around the bridges load to weight ratio, with the load not exceeding 25kg.

d. Performance Predictions

Based on the static equilibrium analysis conducted to the truss pattern, the bridge should support 20kg before failure.

e. Description of Analysis

The strength of the selected truss was determined with static equilibrium equations. By applying the maximum load to the center of the truss, the reactions in each support member was found. By identifying load concentrations throughout each truss design, the analysis of which design would distribute the weight more evenly could be evaluated. After testing two variations of the same truss design with different diagonal support angles, it was clear that maximizing this angle will provide more support for vertical loading. Given that the weight is fully distributed along the truss members, the first points to break would be along the truss joints. To increase the boding strength at each location, gusset plates will be glued to each joint. Adding addition material at its highest stressed locations will ensure the bridge doesn't fail before reaching the maximum testing load. Another portion of the analysis was devoted to increasing the area of which the road deck contacted the bridge. By increasing the bottom component, not only does the overall supporting strength increase but the new geometry allows the road to rest on a portion of the bottom member for the entire length. These updates support the assumptions used the static analysis of the bridge, that it was loaded in the center of each truss.

f. Scope of Testing and Evaluation

The extent to which the bridge will be evaluated is dependent on four constraints: being material, weight, dimension, and success of articulation. The first three tests performed are visual or non-destructive while the third will be load bearing. The structure will be composed of balsa wood and glue, any components added for articulation will not provide extra strength. The total weight of the bridge is less than 85 grams not including components for articulation. Evaluation of dimensions are as follows, it must clear an open span of 400mm and cannot be wider than 60mm. The bridge must maintain enough space to allow for a 32x25mm block (representing a car) to pass through the entire structure. A 38mm wide solid piece representing a road will run the full length of the bridge and will contain only an 8mm hole in the center designated for testing. Finally, the road height must be within 12mm of the abutment level. For the articulation the bridge must raise its midpoint 140 mm above its resting position and be able to remain still for 10 seconds at this level without intervention. When at rest, the addition of 10g to the lifting mechanism should allow for a piece of 20lb printer paper to slide between abutments and bridge. The final test will be weight bearing, a 20kg weight will hang from the center of the bridge from a rod that's positioned in the 8mm hole, connected to a 38 mm square washer on top of the road.

g. Analysis

i. Analysis 1

The First analysis was done to determine internal forces in a general truss shape using a 58-degree angle

ii. Analysis 2

Using the data collected in the first analysis, the final truss angles and height were determined. These calculations represent the internal forces on the first portion of the truss using a 63.43-degree angle.

iii. Analysis 3

This section shows the individual loadings of tension (T) or compression (C) in each member of the truss when 20kg is added in the center. The result of this shows the center top members experience the most force and are in compression.

iv. Analysis 4

Using the maximum loading in the top portion of the truss and the maximum yield stress of balsa wood, the required area for the truss member was found. Using a square shaped member, the minimum required base and width was 5.3mm

v. Analysis 5

To find the force needed to lift the bridge a pulley analysis was done. Using a simply pulley design and the mass number referenced form solid works, the force to pull was determined. As the design requirement stated that the pulling force must lift will no more than 10g applied.

vi. Analysis 6

To determine if the cross members could hold a distributed load in the center of the bridge, a bending analysis was done. By referencing the modulus of rupture for balsa wood (Matweb.com) and using the stress flexure formula, the failing stress was found. The first value used was 6.35mm, after preforming calculations it was verified that the load would be supported.

vii. Analysis 7

This analysis was done to see how the tower behaves with and without the bridge loading on it. The results show that the forces acting on each vertical member is minimal

viii. Analysis 8

When the bridge will be lifted using pulleys, a downward force will be exerted in the center of the tower's front member. A bending analysis was done to see if the force placed on the member would overcome the modulus of rupture for balsa wood. Using a 6mm cross member will ensure proper support.

09. Analysis 9

This analysis was done to observe the distributed force along the bottom of the road deck when the bridge is loaded

10. Analysis 10

By comparing the tensile strength of the rope with the required tension in the rope during the lift, its seen that the rope will support the bridge with a SF of 2871

11. Analysis 11

This was done as an update to former plans presented. The new pulling force required to lift the bridge will be 5 grams on either end. The bridge will free stand in its maximum height with the use of a cord cleat. The rope will be looped around the cleat multiple times creating enough friction to be held in place. The new cord used will be 95 Cord which is a size of paracord that can withstand 95 pounds of tensile force and measures 1.8mm in diameter.

12. Analysis 12

A calculation preformed using the surface area of a gusset plate and the strength of glue shows how much stress can be handled before the glued section breaks.

h. Device: Parts, Shapes, and Conformation

The projects initial design was based on common bridge truss shapes and components. Using square pieces rather than round would allow for easier manipulation of its geometry as square pieces don't have the tendency to roll around or shift. Square pieces, much like round piece provide equal support in the x and y axis and will not bend or buckle as easily as a more irregular shape.

i. Device Assembly

A Balsa wood bridge will be built to span the distance between abutments at 400mm. Along with weight and dimension requirements, the bridge will support a weight of 20kg placed at the center of the road. A truss system will be implemented to withstand the vertical force on the bridge. The road will be able to reach a height of 140mm above resting position using a vertical lift system. Once at the maximum height, the cord can be tied off on the cord cleat that this placed on the tower assembly. This feature will allow objects to pass below that would otherwise be blocked by the bridge.

j. Technical Risk Analysis

Technical risks involved with the bridge related to how compromises in the design will affect the performance of the structure. The limitation that carries the most influence on level of risk is the weight limit of the structure. The focus was on the most efficient way to create and translate strength while meeting the requirements.

k. Failure Mode Analysis

The types of failure involved in this structure mostly reference axial, bending, and shear stress. The highest opportunity for failure is when a load will be placed at the center of the bridge. All joints will experience axial and shear force, while the top and bottom truss members along with the road will experience bending stress. The design width for all components is larger than the minimum calculated width to promote a safe a sturdy structure.

l. Operation Limits and Safety

The bridge must not exceed the weight of the design load at 20kg. Overloading may result in failure of the bridge. Objects larger than 47mm x 38mm will not be able to pass through. Horizontal force should not be placed on the free-standing towers, excess force could result in the structure falling. Weight should remain center loaded if possible, and off center loaded bridge could result in an early failure of components.

3. METHODS & CONSTRUCTION

a. Methods

The equations used to support this design are related to statics and strength of materials. After the initial drawings were done, the components were broken down into internal forces. Using the values of axial stress in each member, a suitable cross section for each component was determined. By applying the maximum values for stress found when one truss experiences a point load at its center, a minimum of a 5.3mm square cross section was calculated for its highest stressed members. Knowing the size of components that will be used will help the process of drafting models, performing analysis, and planning for construction. Creating a basic model that adheres to the design constraints can be manipulated and improved towards the final design. Using Solid Works, the initial full assembly will be referenced with 'mass properties' in the Model environment to certify that the weight constraint is met. Further reinforcement or improvement will be made until all factors have been accounted for. A 5g buffer for added glue was left available for the construction of the bridge. An estimated 5% of the bridges weight will be in glue; if the design of the bridge was maxed out at 85g, the addition of glue would place it overweight.

The stock wood material purchased for the construction of the bridge all come in standard widths and will just need to be cut to length and angle. To ensure each member of the bridge is in close tolerance, proper fixturing is required to produce consistent results. In order to create an effective fixture, the six degrees of freedom need to be restricted. Using the 3-2-1 locating method for all square stock material, effective part locating can be achieved with a flat sanded piece of plywood, locating pins, and table clamps. In addition to fixing the part in place, a blade guide made from a smooth aluminum angle bar was added to setups where square material was being cut. Much of the material used for each structure is 6.35mm square stock while only a few pieces vary. Creating these setups for all the square stock will provide quick part cycle times and will cover most all material needed for the bridge. The remaining material is thin balsa wood sheets and dowels used for the articulating components. With the balsa sheets being as thin and soft as they are, clean cuts can be achieved with a hobby knife and an edge to cut along. Circular markings will be made with a locking compass while all straight markings will be made with a steel ruler. As each piece is cut out by hand, light sanding can be done to blend any sharp edges to smooth contours, or to correct any imperfections.

i. Process Decisions

The first major change in the design was based around the road decks ability to hold the weight without falling through. Although the truss was designed to support the load, this would be useless without the road. Before changes, the entirety of the road was supported by the ends of the members laid beneath, relying on just the strength of glue and minimal surface area to hold strong. By increasing the cross section of the bottom beam from 6.35 to 9.50mm, a 3mm wide self on either side of the road will add extra support and eliminate dependency on the glue in that section. The change may have added more weight however the necessity of a strong road system warrants the additional support. The next update to the bridge was intended to increase the strength of each joint. The addition of gusset plates was added to maximize the bonding surface area of each load supporting joint; Because gusset plates are very thin and span a large area, they will add a lot of insurance without contributing to much weight. Deciding to add gussets was a relatively easy decision for the fact that the additional weight, if needed, could be compensated for by removing a less crucial component of the design such as a set of top crossing members.

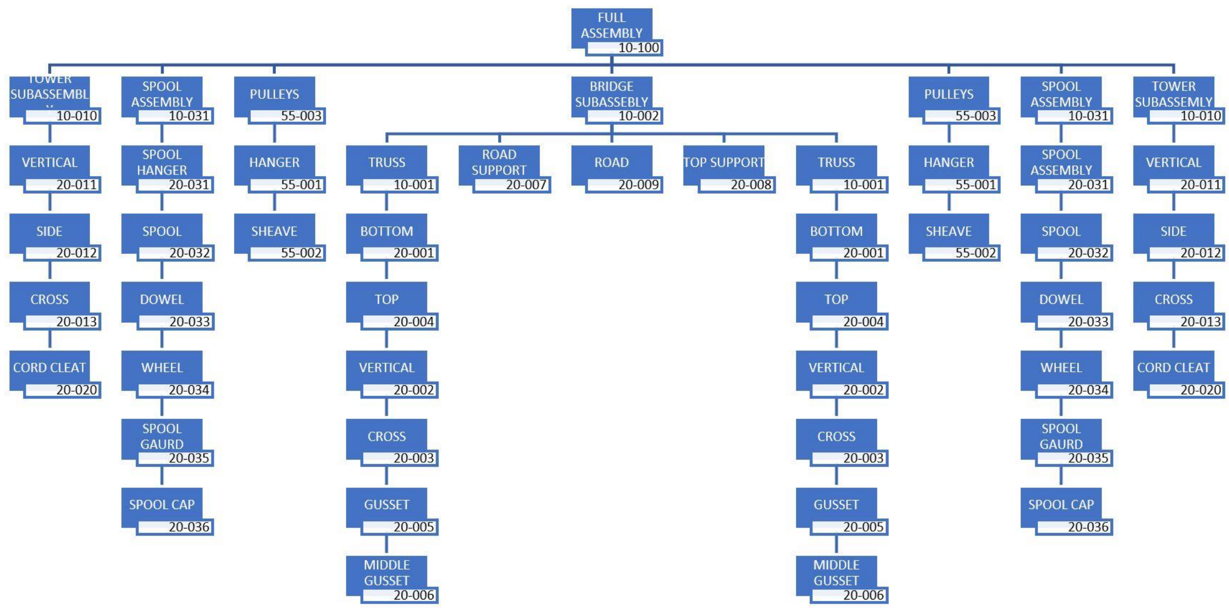
b. Construction

i. Description

The beginning part of construction will rely on parts arriving on schedule. Once pieces arrive, cutting each to the proper length and angle will follow. As pieces begin to accumulate keeping track of every member will make the process as a whole run much smoother and more efficiently. Staying organized will look like grouping finished material together by dimension, this may seem insignificant, however pieces are very similar and cannot be disassembled after being glued. Using multiple fixtures and clamps will provide that each piece is securely fashioned and aligned straight. Each cut will be made with a hobby knife, using a straighter blade rather than one with teeth will eliminate the tendency for grain to rip away. All balsa material is soft and small enough to be cut by hand, while pieces like the 1 in dowel will need to be cut with a miter saw and drilled on the drill press. Even with the level of control on a piece with the setups described, each part will come out slightly different. To promote part uniformity, light sanding with 400 grit paper will correct the abnormalities encountered throughout. Once all pieces have been cut and evaluated, the first sub-assemblies will begin to take shape. Most of the construction will be based around carefully assembling balsa wood pieces together with glue. Leaving enough time for the glue to cure in between the assembly steps is critical for ensuring each piece will retain maximum strength. To keep pieces from moving during the setting period, a combination of table and hand clamps will hold parts in place. The order components will be assembled will follow the process laid out in the drawing tree seen in the following section and in appendix B. In preparation for assembling components, locating surfaces should be fashioned to ensure pieces are positioned when initially glued, and will remain fixed throughout the drying time. Its important static pressure is applied to each joined surface for at least 20 minutes or until the glue dries to retain a strong bond. Each part will go through multiple drying cycles because every component can't be added at the same time. Once all sub-assemblies have been complete, the pullies and rope will be the last components to finalize the devices construction.

ii. Drawing Tree, Drawing ID's

The drawing tree will be split into multiple subassemblies, all of which have been laid out in the solid works assembly environment and displayed in the assembly drawing tree. (Also shown in appendix B)



iii. Parts

The full bridge assembly will consist of mostly balsa wood being held together by glue. The articulating components will contain a total of 8 small brass pulleys, 2 pieces of 95 Cord, 2 cord cleats, and 2 spool assemblies. Each articulation component will be glued where necessary. Two different stock sizes of balsa wood square dowels and sheets will be used for the structure.

iv. Manufacturing Issues

The size of components used in this device makes certain material such as the thin sheets especially susceptible to splitting and cracking. The grain size of the wood rivals' components being produced, when larger drills such as the ¼ in used to make the spool hanger, was used on thin sheets, the grain was more prone to catching and would split the top end of the hanger. Another issue that was considered during construction was how susceptible to failure a part would be depending on how the glue will be applied. only does extra glue contribute to the 5% total weight margin that has been defined, but it can greatly affect the strength of the assembly. Using too much glue greatly reduces the ultimate shear strength while not enough, will not properly join the pieces. While working with such small components it's important to realize how little it will take to provide good surface coverage.

v. Discussion of Assembly

The device will consist of five different sub-assemblies, each containing at least two components. As seen in appendix B drawing tree the full assembly will contain two Towers and a Bridge. The towers will be broken into five segments, excluding the cord cleat and the spool, the rest of the structure will compose of side, vertical, and cross members. When assembling these components to create the Tower, all components on each surface must be glued at the same time. As a result of this process, assembly of the tower will be broken into three steps; gluing each side section first, then joining the two sides with the components that make up the back surface. The Bridge will consist of three different parts and two Truss subassemblies. The two Trusses will be joined first with the road support, following with the top support, and finishing with installing the road in place. It's important that the road support is done before the road to ensure all support members are aligned with the bottom of the truss. The truss will be constructed from 4 variations of support members and 2 variations of gussets. The order will begin with the Bottom and Vertical; after they have cured, the side and top will be added, to finish the subassembly the gussets will be glued last. The assembly of the Tower and Bridge should require minimal manufacturing as parts will arrive at their stock width, making only the need for one cut.

4. TESTING

a. Introduction

Testing will be performed in spring quarter. The main deliverables driving the design includes the maximum weight of the bridge, the length and dimensions of the structure, and the ability to articulate. Two different nondestructive procedures will precede third and final weight bearing test. The parameters set for this project requires that multiple aspects of the design are within tolerance. Measurements were made using a steel ruler and recorded using the datasheets prepared. The final test will revolve around the weight placed at the center of the bridge. In this phase of testing, the bridge will experience the highest values of stress. Including what has previously been stated, the following will be testing in the spring quarter: Weight of bridge, Free hanging length, height of road from base, overall width of bridge, clearance through the roadway, and force to lift bridge from rest.

b. Method/Approach

Non-destructing testing will take place before loading the bridge. Simple measurements using a steel ruler and scale will be used to evaluate the success of specific requirements. The first test to be completed was the measurement of the bridges overall mass, this value excludes the components for articulation. Following this was the bridges length, this was verified that it is longer than 400mm when resting on abutments. Other dimensions such as the inside width and height, road height from abutments, and outside width was measured. After dimensions and weight have been evaluated, the bridges maximum lifting height was tested. Lastly the bridge will be verified for the support of 20kg in the center. The Final test will be evaluated by placing a weight in the center of the road deck. The weight will hang from a bar attached to a 38mm washer on which the bolt will be housed on, this washer will sit on the bridges surface and will extend through the bottom. An 8mm hole in the center of the road will allow for this. The approach taken when loading the bridge with weight should be slow and steady to avoid any impact loading or uneven distribution. If the bridge succeeds in holding the test weight, a video will be taken to demonstrate its effectiveness.

c. Test Procedure

Using a scale and a ruler, most of the testing can be done in a free table space. Two of three test procedures were based in non-destructive motions and consisted entirely of verifying physical dimensions, taking a short time trial, and measuring the force to engage the lifting mechanism. The first test to be conducted was the articulation portion. The process for this test was broken down into three sections corresponding with each requirement. The basic extent of the test was taking measurements before and after raising the bridge. The first attempt at the procedure revealed some issues that needed to be addressed. Updates to the procedure were made to include more specific instructions and images of each step. One of the more relevant changes in the process was to clamp or weigh down both ends of the model to reduce movement when the bridge is being raised and lowered. Before this step was added, the excessive motion of the bridges towers during each use caused frequent jamming of the bridge. Improving the finer detailed specific aspects of the procedure resulted in a less problematic, more repeatable practice. For the weight bearing test two sturdy and flat surfaces of equal height will be needed to support the bridge on either end, allowing enough room below the bridge to hang weights.

d. Deliverables

The bridge must not exceed 85 grams in weight, excluding all components used for articulation. The bridge must clear an open span of 400mm and provide enough room to allow a 32mmx25mm block to pass through. The road deck must measure 38mm in width and be within 12mm of the abutments. The road deck must span the entire length of the bridge, be of one uniform piece, and have no holes other than an 8mm at its center. The bridge must support a minimum static load of 20kg. When raised, the bridges center must reach a height 140 mm above resting position. One at its maximum height, the bridge must be capable of remaining in place for at least ten seconds without intervention. Ten grams applied to the articulation system must create enough of a gap to allow for a piece of printer paper to be slid between the bridge and abutment. These deliverables will be photographed as they are evaluated. After going through the first test, aspects of performance were compared with the predicted results. The parameters of the articulating test included three different recordings and required the system to smoothly raise and lower. To properly evaluate the function of the design the maximum height, time at rest in raised position, and force required to lift one end of the bridge was recorded, the basic requirements for each are 140 mm, 10 seconds, and 10 grams respectively. The predicted values met two of the three requirements, the bridge was able to reach a height of 150 mm as predicted and could remain in its resting position for as long as needed. Due to excess friction in each spool, the force to lift one end of the bridge was closer to 15 grams of weight which exceeds the intended mark. This evaluation was done by weighing an object and attaching it to a handwheel with some spare string, after the weight has been placed a single piece of printer paper (standard 20lb paper) was attempted to be slid in-between the bridge and resting surface. The overall process was done multiple times to verify its function and repeatability, after doing so, a few small notes were made regarding the proper operation of the device. To ensure either rope does not fall off its intended pulley, extra caution should be used when fastening the rope to the cord cleat. Rather than raising and lower with no regard for speed, it's important to slowly transition into motion especially when lowering. Attempting to operate the bridge in quick motions could cause the rope to dismount from either top pulley. If the pulleys are not in proper sync the chances of experiencing a jam between the two towers is much more likely.

5. BUDGET

a. Parts

All parts were ordered at the start of the quarter however the procurement of each piece is dependent on the shipping alone. The parts for this project will consist of Balsa wood, wood, Glue, string, and pulleys. Although the bridge and towers will be entirely balsa wood, the spool assembly designated for articulation of the bridge will be a mix of balsawood and white birch. Two variations of square stock and thin sheets will be used in the assembly of the bridge and towers. The bottom section of the truss will use 3/8” square dowels components while the rest of the truss and tower will be made from ¼” square dowels. The road and gusset will be cut from two different sized sheets, 3mm for the road and 2mm for the gussets. All attached parts will be joined with Gorilla brand wood glue. For the articulating portion of the design, the bridge will be lifted by a set of small brass pulleys mounted on either end of the tower and bridge. Paracord will be used for the operation of the system.

b. Outsourcing

Nearly all the material will be shaped using fixtures and a hobby knife however the birch dowels will need to be cut to length and drilled in three locations. The cost for these parts was not included due to the insignificance of processing time. A miter saw and drill press would be the best options for efficiently producing these parts. The balsa sheets will be shaped using a sharp blade, careful marking and fixturing. Simple fixtures and the use of clamps inhibit the movement of parts while cutting and gluing. For purposes of testing, a sturdy five-gallon bucket with rope will be used to attach to the bridge.

c. Labor

The device will be constructed primarily in an at home setting, material will be hand cut using multiple fixtures. The fragile nature of the small balsa pieces being used restricts the speed at which each piece is cut. If this process is rushed the material is likely to crack or break away rather than providing a clean and accurate cut. The majority of the budget will consist of the initial design and analysis of the device, followed by the construction of parts.
After seeing how much estimates were off for the design and analysis’ portion, adjustments to include ‘time buffers’ was done. The time required to manufacture all parts ranked as the second highest consumer of labor, however, was finished according to the estimates. The remainder of the labor will be spent recording final thoughts about the process, the estimated time to accomplish this was exaggerated and will not reflect the actual lower number of hours.

d. Estimated Total Project Cost

The cost for labor was not included in this model as parts will be made with hand tools in a home setting. The estimated total for this project will be around $165, this includes the cost for shipping and taxes. The rates of balsa wood far outweigh the cost of other components included in the full assembly. By placing the order all at once, an overall better shipping rate was given rather than ordering components as they were needed. The breakdown for each sock component can be seen in Appendix C.

e. Funding Source

The funding for the project will be provided by the student designing. No outside contributions will aid in gathering the material required or tools used for the assembly of the bridge.

6. Schedule

The schedule for this project is constrained by the MET 489 course and is shown in appendix E. The start and end times are indicated with a 'x', while highlighted spaces show the tentative schedule for each task.

a. Design

Fall quarter was intended for all design aspects of the device. These tasks include drawing models of the product, preforming analysis on important features, and documenting the progress of each task for project costs and scheduling. Each task was to be laid out with an estimated time needed for completion, as show in Gannt Chart Appendix E. The nature of the project is that many tasks were revisited and revised multiple times such as the drawing and analysis portion. Although the initial estimates may have been somewhat accurate for the first go, any updates or changes resulted in the accumulation of more time. Other tasks depended on the timely completion of subsequent processes. An example of this would be the creation of the pulley system or tower assembly. Since the bridge portion will be the driving design feature, the tower or pulleys can't be designed until the weight and dimensions are known for the bridge. The importance of proper time management is a key factor in the success of all tasks contributing to the completion of the product.

b. Construction

To begin winter quarter, all parts were purchased for the construction of the entire device. Based on the information gathered during fall quarter, an appropriate amount of stock material was ordered to account for any minor mistakes or out of dimension parts. Most all the material showed up within two weeks of purchase, except for the 2mm and 3mm balsa sheets. Before arriving on the first week of February, the prior shipping information estimated it would arrive on the first or second week of march. This would have been a major issue if the parts were to arrive so close to the deadline, however, wasn't the case. As shown in Appendix E, the schedule for manufacturing parts was laid out at the end of fall quarter. The latest task to be complete was to cut all parts to dimension, this was a limiting factor as parts couldn't be assembled until manufactured. After creating fixtures and setting up everything needed to cut parts, the allotted time for this task was estimated at 2 hours. This proved to be unfeasible, as 6 hours has been used to produce the total of required parts. This change in schedule isn't of too much concern in area of completing a finished product by the end of the quarter as a one week 'cushion' was added to the schedule to account for any unforeseen changes. When enough components were cut for a sub assembly, pieces began to be glued together. Leading with the truss and towers, components were joined creating the first assemblies well before all components were produced. Late sections such as the bridge that was finished past schedule was being assembled as the spool assemblies were being manufactured. This overlap in tasks was a result of extensive time spent developing pieces and assembling components in stages. The final device was finished during the final week of construction
The following is a brief timeline of events in winter quarter
Week 7 – all pieces cut to proper length and laid out for assembly
Week 9 – all balsa wood structures glued and cured
Week 10 – all articulating components attached and secured

c. Testing

The order testing was to be completed in was dependent on which quality was being evaluated. Testing began with all non-destructive procedures first and ended with the main weight bearing challenge. Before anything was attempted, the testing procedures were developed to ensure nothing was missed and done in the right sequence. As seen in the Gantt chart, item 10d-creating test sheets was started the last week of march, while test procedures wouldn't be evaluated until the second week of April. Preparing all the necessary datasheets and laying out the steps to be taken makes up most of the total time needed to complete this portion of the project. Starting each task on time was critical for the deliverables of this quarter. Gathering enough data on the bridge by the halfway point of the quarter was expected in order to participate and present in events such as SOURCE. Completing test procedures is a vital part of this phase of the project, however interpreting data and reflecting on the results is also a large part of the process. Making performance predictions and comparing to the actual data is first step in completing these discussions. Looking at items 11c &11e shows that developing the report and creating presentations began just after 10h-Preforming Evaluations. These tasks were completed ahead of schedule and allow more time for the final report to be complete. The stages of each testing phase were divided throughout the quarter.
Week 3 – Testing equipment outfitted

Week 6 – Testing completed
Week 9 – Report completed

7. Project Management

Every project contains a level of risk that has the potential to influence in a positive or negative way. Identifying potential risk and creating a plan to control and respond to such an occurrence will benefit the success of the project. The main risk for this project is components failing under the testing load. Possible causes for this point towards the strength of any glued joints or the accuracy of which members were manufactured. By applying a tolerance on manufactured parts, the consistency at which there are produced will be controlled. Developing a consistent method for applying glue in the construction phase will also help ensure all joints are bonded correctly.

a. Human Resources

Guidance throughout this project was given by MET faculty Professor Pringle, and Dr. Choi. Any questions pertaining to project specifics were quickly answered by these individuals.

b. Physical Resources

A variety of tools will be necessary for the construction of this project. Stock material will need to be cut to length and angle, clamps and fixtures will be needed when gluing parts together and measuring devices will be needed to evaluate the final assembly. Using a small sharp blade and some fixturing, clean and precise cuts will be made according to design specs. After initial cuts have been made and evaluated, parts will be set in jigs with clamps to ensure proper pressure and alignment are accounted for when setting the glue. The result will be verified with a caliper indicator. Risk involving this step of the project is how the glue will be set, if for any reason components shift during the curing process and don't pass tolerance, they will be rejected and need to be remanufactured. This risk will again be controlled using jigs and fixtures.

c. Soft Resources

The following resources were implemented in the project and play a role in design decisions. Without the help of these software's, the project certainly would have made a different approach to the solution. The risk involved in using these resources are minimal as they were very accessible at any given point. The biggest opportunity for interference would be in the case of a Solid Works Crash. This program has been known to randomly shut down without saving during a drawing session, however this did not happen throughout the process.
MD Solids 4.0, Solid Works 2019, Online web resources

d. Financial Resources

The main source of funding will come from the student designing the bridge, no external funding will be gathered for the completion of this project. A budget has been set for the project that provides an accurate number for the total amount needed to execute. If for any reason the budget is exceeded, a small reserve fund will be implemented to cover any extra cost.

8. DISCUSSION

a. Design

The design began with some simple brainstorming, sketches of familiar bridges and visual inspection of geometry. A thought from early on was to use a vertical lift bridge system rather than a drawbridge system; this design would allow for a more ridged halfway point and would require fewer moving parts. The initial thought was to keep the design as simple as possible as complex geometries could be difficult to handle at the scale the project is intended for. The constraints of the project depend on weight, strength, and articulation. Finding the most efficient strength to weight pattern was the first obstacle. Using equations of statics and strength of materials, internal loadings were determined for different structures with arbitrary loads placed in their center. With the help of MD Solids, a software that calculates internal loading for various truss designs, it was verified that using a Pratt style truss would more efficiently dissipate loads. In the process of finding a suitable pattern, an observation of the cross members was made. In order to maximize the bridges ability to resist weight in the vertical direction, the angle of the cross members should be oriented closer to 70 degrees. If the angle were to be made any steeper, the number of sections would increase requiring more material, while making the angle shallow would reduce vertical strength and provide unnecessary support in the horizontal direction. By creating a truss pattern, each section can be joined with straight members that share dimensions. Limiting the variation in components allows for reduced cost, quicker manufacturing, and reduced complexity. Before being able to model the bridge, finding a suitable cross section for each member in the truss seemed to be the most important. Using the equation for axial stress the required section modulus for each component was found. Referencing the highest value for stress determined in analysis 3, the minimum required section was calculated to be 5.3mm for a square piece. Selecting a 6.35mm section, a standard size dowel available, the structure should resist the testing weight. After verifying in solid works that the total mass is less than or close to the maximum allowed weight, the next structures could be designed. A tower designated for lifting the bridge will be placed on either end will be equipped with pulleys. Understanding that the tower will only need to support the weight of the bridge and not the testing weight; It can be made in a more conservative manner. The idea was to use the same width of material as the truss and design to simply resist the 6 degrees of freedom. The result was a lightweight, tall, and simple structure. The challenge with this was to keep the structure from being wider than 60mm while maintaining the minimum 38mm inside width. The first plan was to have the ends of the bridge protrude into the tower structure by about 20mm. The reason behind this was that the tower would be able to ‘guide’ the bridge in a straight path during a bridge lift. After adjusting the width of the tower members in attempt keep the structure within the 60mm maximum, it was decided that it couldn’t be done without sacrificing too much member cross section. The update placed the outside of the tower in line with the outside of the truss, making them co-linear. At this point most of the assembled bridge has been completed. The remaining components needed for completion involve the pulley system. Before this task was pursued, the focus was spent on reinforcing the bridge. An observation made when considering how the structure will be tested was made regarding support for the road. The cross members that will lay under the road and connect the two truss structures were originally 38mm across which is the same width of the road, this would mean the road laid on top would only contact these members. In other words, the integrity of the road depended on the end grain cross sections that are to be glued to the side of the bottom truss member. The first major change was to increase the width of the bottom truss member width to 9.5mm and decrease the length of the road supporting members. The update allows for a 3mm ledge on the inside of the truss for both sides of the bridge. The road now lays on top of the road supporting members along with two ledges that hold the outside edges of the road. Rather than relying on the shearing strength of the glued joints under the road, the bottom truss will now disperse that force. Verifying that the system is still under 85 grams, reinforcement could continue. The next update to the structure was to add gusset plates to provide additional support for the load bearing truss components. These gusset plates will maximize the mating surface area of joint and allow more glue to securely bond the structure. The overall weight of the gusset plates was minimal compared to any other component, giving more reason to add them to the final assembly. A large portion of time was spent in solid works adjusting dimensions and changing features. When sketching assemblies with thin lines on paper, the finer details of how components attach went un-noticed and don’t get planed for. When it came time to model the parts a lot of time was spent deciding how exactly the joints would attach and what would be the strongest option. Being able to see how everything looked when fully assembled brought a higher level of understanding to design decisions. Using solid works was a great tool when it came to design for weight. Adjusting and getting immediate feedback to how it affects the project constraints allowed for extremely efficient processing of dimensions. The bridge was designed to be about 80 grams, leaving up to 5 grams for added glue. The remained of the project was to design a pulley system that would raise the bridge with a force less than 10 grams and finding a way to hold at the top position. Pulleys and rope that were of suitable size were quickly found online. By using 3 pulleys on either end, the force required to lift was within parameters.

b. Construction

The first components to be manufactured consisted of all square stock material. Most of the components needed a flat 90-degree cut while two variations need a 74-degree angle cut on the end. Using a slotted piece of aluminum angle bar, locating pins, and table clamps a fixture was created to align each piece to the proper angle and length. With the quantity of parts involved and the precision required, using fixtures is much more practical than measuring, marking, and cutting each piece by hand. The initial setup did a great job of locating the part as intended however the material was left hanging freely over the edge while the part was secured to the table, this promoted increased movement of the material during the cut as vibrations were created from the free hanging end. The first parts cut from this were successful as only four pieces were need at that length. For the next parts, the angle bar was pushed inward allowing for the extra material to rest on the flat surface. Using a similar locating and clamping procedure the remaining square stock was successfully cut to length. Throughout this process each piece required light sanding to correct any small defects caused by blade deflection. After taking measurements of finished parts, an observation was made that any part that deviated no more than 0.5mm could be considered acceptable, while a 1mm variation would be too large and would create an uneven mating surface. The method used proved to be successful, while each different process produced only 1-2 rejects, reliable parts were produced with a quick part turnover. After verifying that each part was within tolerance and was indeed the part of interest, pieces were joined. The main approach used, was to create locating points using 1mm nails, this allows multiple components to rest against an accurately positioned surface while being clamped into place. By first drawing an x and y axis on the fixturing board, a relative location can be established. Pins were set in pairs and spaced according to the assembly drawing sheet. The first assembled piece to be attempted was the truss, this part would be staged in three sections and would require curing time between each operation. Beginning with the bottom of the truss, vertical components were positioned flat against the table and locating pins then glued and clamped into place. To make sure glued components don't stick to the table surface, a single layer of wax covered paper was used as a mediator. After waiting for the first round to dry, the second round was done using the same method. Before finishing the truss, light sanding was done to each contact point to ensure the top of the truss sits flush on each component set. Once fit was proper, the top portion was glued in place. This process worked very well for both trusses and was used for all other components in assembly. The next structures to be done were the lift towers, in a similar fashion all components were set in place with pins and was pressed flush with the table. A difference between this approach versus the bridge is all components on one surface are being glued at the same time rather than in stages. The all at once approach worked well for each section of the tower, however attempting this with as many components as the truss would likely produce uneven sections as parts would be more prone to shifting when being glued. The Bridge was the next component to be assembled, the two trusses are connected by the top cross and road support. These pieces were checked for fit before joining the bridge together, once verified that they align flush, components were fixed in place. To finish the bridge the road deck was manufactured, its important that both sides are straight as the road must by slid through the entire length of the bridges opening. With a snug fit against each truss's upright components, the road was glued to the bottom ledge and the road supports. Although the gussets were intended to be added following the assembly of the truss, however these were not added until the complete assembly of the bridge. Waiting to add them until this point provided a more even clamping surface allowing better control of part placement. A large portion of the assembly process required that parts be left alone while the glue sets. The abundance of waiting periods between assembly provided ample time to trace out components of the spool assembly and begin manufacturing related components. All pieces in the spool assembly could be cut by hand, excluding the spool which needed the attention of a miter saw and drill press. Cutting the spool components by hand worked well however took two tries, the nature of balsa wood makes it very weak along the grain when working with sheets. Cutting along the grain will cleanly split the wood when the blade was set, while cutting across the grain will crush or rip away the wood. After the first attempt, it was clear that a more patient hand was necessary to make a clean part. Until this point all pieces had been manufactured and assembled without any real issues. Creating properly centered holes in each end of the spool was one of the more challenging tasks. Any deflection in the drill bit largely reflected on the surface of the wood, quickly making defects as holes couldn't be too far from true center. After two mistakes the third and fourth were a success after making sure the center punch mark was more prevalent and a slight plunge motion was used will the drill. With all the components manufactured the last parts to be added are the spool assemblies and pulleys. Each piece was glue to it perspective location and set to dry, once the glue set the rope was connected and the lifting mechanism was tested for function. The device works, however may need minor adjustments to obtain smooth lifting and lowering. The cord used seems to be too stiff for the weight of the bridge giving the pulleys very poor response time as the pulleys are getting caught up, using a smaller cable such as fishing line would improve the lifting ability of the design.

c. Testing

The initial stages of testing involved some careful thinking and a fair amount of preparing before anything physical with the bridge could be done. Some of the more intuitive requirements such as the structures material and the weight of the bridge were verified during the construction portion of the project, leaving only three tests to be completed. Creating a series of testing procedures to make sure each evaluation is valid and repeatable was the first step in this process. The initial procedures included all the requirements however lacked detail in some of the finer aspects of the process. An example of specifics that were added to one procedure, is the speed at which the handwheels should be operated and why to turn each one a certain direction. Some of the information wasn't included the first time because it seemed intuitive, however the adjustments provided a better description. The first test to be evaluated involved the capabilities of the bridges articulating system. Although a reference to this was not provided, each lifting tower was glued to a thin piece of wood, leaving the centered bridge free hanging between the two. This was done to represent how the towers would be fixed in place, given a real application, to ensure they don't move during the lifting motion. The intentions of the design included the smooth operation of the system during raising and lowering. This test was split into three different sections to satisfy the specific requirements and prove the overall success of the design. After seeing the bridge in action, notes were made about its general performance. One change as a result of testing was type of cord used in the pulley system. The weight of the balsa wood bridge compared to the stiffness of the cord interfered with how the system operated. Although the bridge could raise and lower, it wasn't very smooth and tended to resist motion. The cord was replaced with light duty yard string, this replacement is nearly equal in diameter to the initial cord and is much more flexible. After installing the new string, the bridge was more responsive and less problematic during each attempt. Returning to the test and repeating it with the new string yielded more accurate results. Three of the four standards were met, the bridge was able to successfully raise and lower, reach more than 140mm from resting position, and remain at top resting height for more than ten seconds. The fourth requirement of adding 10 grams to the lifting mechanism to raise the bridge from the ground failed. This requirement was attempted by weighing something, tying it to a piece of string, and hanging it from a handwheel. Heavier objects were added until the bridge responded to the weight, requiring closer to 20 grams in the end. The excess friction in each pulley contributes to this result, if each spool was constructed with more precision a different outcome would be achieved. The operation that affected this result was the center drilling of each spool drum. The overall diameter of the drum section was only 1", when using a small diameter, the effect of being off center is amplified. Even a fraction of an inch off will result with a linear travel of twice the amount when put in circular motion. No adjustments could be made to improve the outcome of this failed evaluation of the force required to lift.

The second test deals with basic dimension requirements that guided aspects of the design. Although it may seem trivial, evaluating and recording that all points are met certifies that a design is proper. This task was done using a steel ruler to measure all points of interest, this method produced results accurate to .5mm. Calipers weren't used for this process because the level of precision involved did not necessitate the use of anything more complex. After going through each of the measurements, surprisingly one did not pass. The height of the road deck from ground level was to be within 12mm of the abutments however is 12.5mm in height. Thinking back to the start of the design, initial models of the bridge included and accounted for this requirement however when changes to the design were done and material was added to the bottom members, the requirement was lost in the details. Reviewing the bridge criteria document shows a tolerance section was included and indicates the allowance of a 1mm deviation from any two-digit integer in the design. Even though this tolerance may validate the success of this test, that fact is the detail was overlooked. The rest of the measurements showed that all other aspects of the initial requirements were met. The bridge was constructed with a high level of accuracy and no obvious variation could be seen between similar parts. Included as part of the dimensional evaluation was a quick passageway demonstration that verifies objects can travers the bridge freely. Using a 500mm string, a 32x25mm block was tied to the end and pulled through the length of the bridge. This was an extremely simple task, however the motion of the block through the center shows that without the additional room included in the roadway, the block would be more prone to jam or get caught on the inside. The actual available space inside the roadway was 38mm wide by 46mm high, leaving plenty of space for wider and taller objects.

The third test to be completed was the final load bearing evaluation. While the first two tests were low risk and needed only physical dimensions and measurements, this test was saved for last due to the potentially destructive nature of the parameter. This test began with outfitting the bridge with the necessary I-Bot and washers to evenly distribute weight across the bridge. The bridge was detached form the pulley system and placed on two equal level surfaces, 400mm apart, about three feet from the ground. In between two surfaces, below the bridges center, a five-gallon bucket was attached to the I-Bolt using a tie down with a hook on the end. The sand used was weighed and set aside before the operation began. When everything was ready, sand was incrementally added to the bucket until the target weight of 20kg was reached. Once this weight was achieved, a video was taken to demonstrate its ability to hold the static load, unchanged for a short duration of time. After completing the video, the weight was removed from the apparatus and the results were recorded to the data sheet. During the test, little to no deflection was observed when the maximum weight was hanging form the bridge. Although the design was intended for 20kg, this result likely indicates that within reason, more weight could be applied before failure. The extent of this procedure only demanded for the static testing of the target weight. Other methods of applying force such as side, uneven, or shock loading were not attempted but could help better describe the design. The execution of this task many have been slightly time consuming to gather the necessary testing equipment, but the process went exactly as planned. All the testing preformed throughout the quarter was included in these three sections. Data sheets and procedures to accompany each parameter can be found in the Appendix G file.

9. CONCLUSION

The initial proposed challenge suggested a balsawood bridge be created to support a load, articulate, and span an open distance, while weighing less than 85 grams. Along with various specific requirements the device constructed throughout winter quarter was designed to meet these needs. A more crucial requirement driving the design was the bridges ability to support a 20-kg load at its center. The design depended heavily on the engineering behind the selection of dimensions and assembly of each structural component. The predicted values for each evaluation indicated that all aspects would be the requirement baseline. The bridge easily supported the weight, showing no apparent deflection under load. This device meets all but one of the parameters initially defined for a successful project. Although the engineering premise behind this solution is correct, as result of construction, the force required to lift the bridge exceeded its intended value. The focus of this development was placed on the structural analysis and physical creation of the device, however other areas of project management were exercised to demonstrate a complete senior proposal. The schedule and budget for the device reflects what was achieved and shows the progression of each phase. Other than meeting the required parameters for the bridge, the completion of this project proved to be ahead of schedule and within budget. Based on the information provided in this document, a successful model can be created to accomplish similar results.

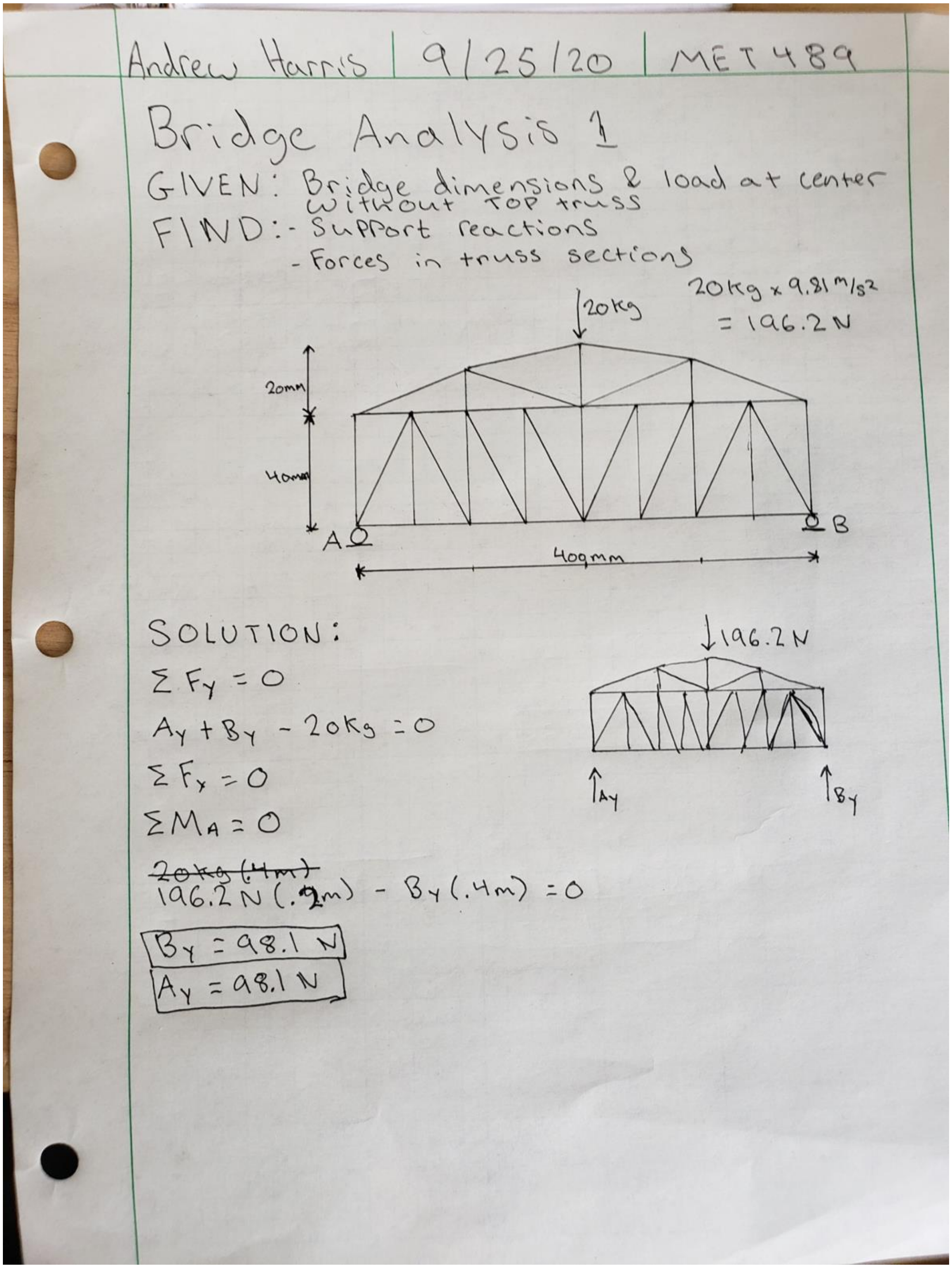
10. ACKNOWLEDGEMENTS

Thanks to the support of MET Faculty, Senior projects were able to push forward despite the given circumstance of the COVID-19 global pandemic. Adjustments to the online atmosphere and new way of communicating were difficult for everyone. The continued effort and support from faculty, and resources made available by CWU is recognized and appreciated.

References

APPENDIX A – Analysis

Appendix A-1 – Analysis 1



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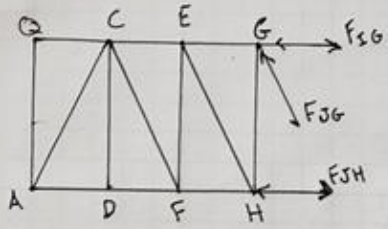
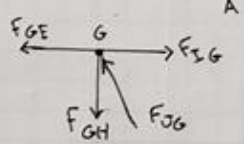


Joint G



$\Sigma F_y = 0$

$F_{JG} \sin 58 - F_{GH}$

$F_{GH} = 98.1N$

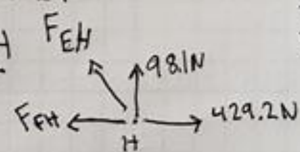
$\Sigma F_x = 0$

$F_{IG} + F_{GE} - F_{JG} \cos(58)$

$490.5\,N + F_{GE} - 115.67 \cos 58$

$F_{GE} = 429.2\,N$

Joint H



$\Sigma F_y = 0$

$98.1N - F_{EH} \sin 58$

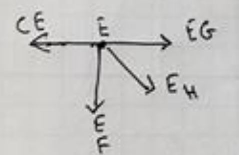
$F_{HE} = 115.67\,N$

$\Sigma F_x = 0$

$429.2N - F_{EH} \cos 58 - F_{FH}$

$F_{FH} = 367.9\,N$ (T)

Joint E



$\Sigma F_y = 0$

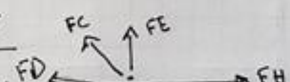
$F_{EF} = 98.1N$ (T)

$\Sigma F_x = 0$

$-429.2N + F_{CE} + F_{EH} \cos 58$

$F_{CE} = 367.9\,N$ (C)

Joint F



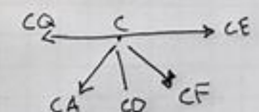
$F_{FC} = 115.67\,N$

$\Sigma F_x = 0$

$367.9N - F_{FD} - F_{FC} \cos 58$

$F_{FD} = 306.6\,N$ (T)

Joint C



$\Sigma F_x = 0$

$-367.9N + F_{CA} \cos 58 + 115.67 \cos 58$

$F_{CA} = 578.58\,N$

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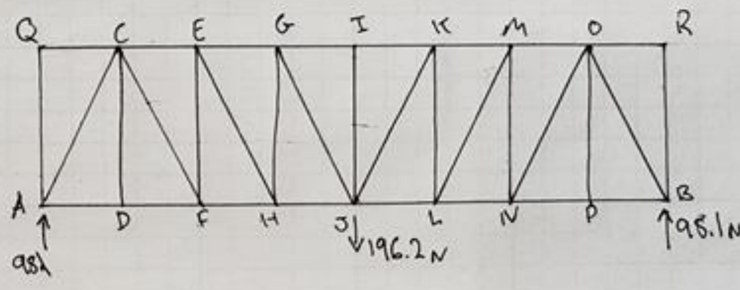
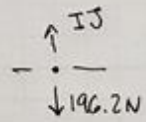


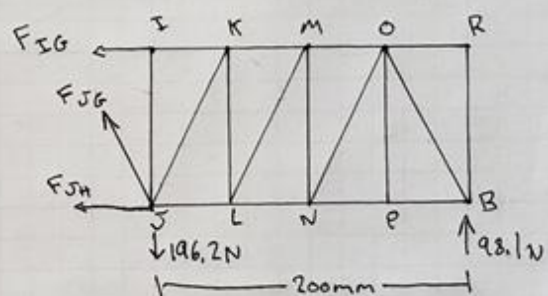
Joint I



$\Sigma F_y = 0$

$F_{IJ} - 196.2 = 0$

$F_{IJ} = 196.2$



Section 1

$\Sigma M_J = 0$

$98.1N(.2m) + F_{IG}(.04m)$

$F_{IG} = 490.5N (C)$

$\Sigma F_y = 0$

$-196.2N + 98.1 + F_{JG} \sin 58$

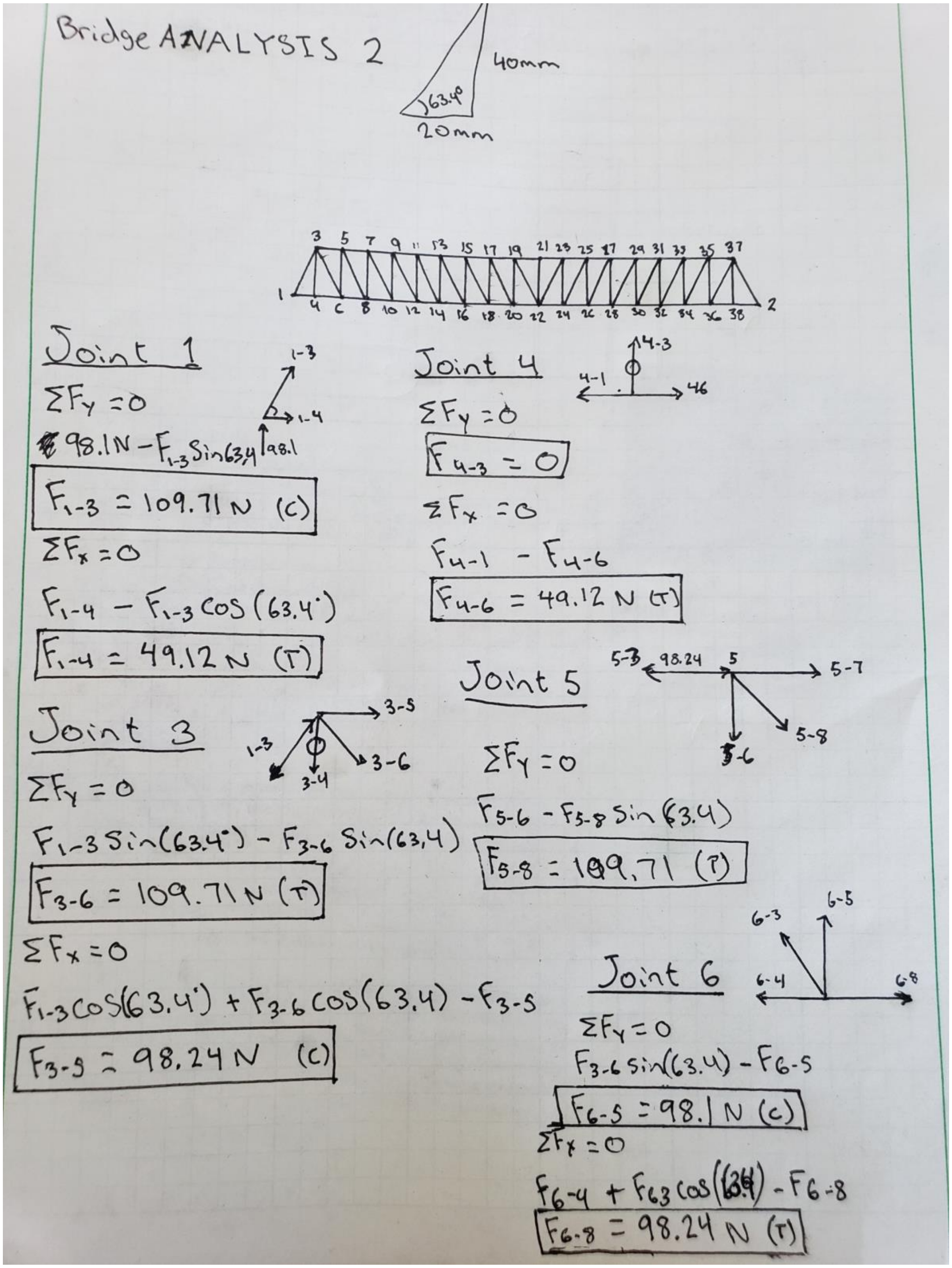
$F_{JG} = 115.67 N (C)$

$\Sigma F_x = 0$

$490.5 - F_{JG} \cos 58 - F_{JH}$

$F_{JH} = 429.2 N (T)$

Appendix A-2 – Analysis 2



Bridge ANALYSIS 2

40mm

63.4°

20mm

Joint 1

$\Sigma F_y = 0$

$98.1N - F_{1-3} \sin 63.4$

$F_{1-3} = 109.71\,N$ (C)

$\Sigma F_x = 0$

$F_{1-4} - F_{1-3} \cos(63.4°)$

$F_{1-4} = 49.12\,N$ (T)

Joint 3

$\Sigma F_y = 0$

$F_{1-3} \sin(63.4°) - F_{3-6} \sin(63.4)$

$F_{3-6} = 109.71\,N$ (T)

$\Sigma F_x = 0$

$F_{1-3} \cos(63.4°) + F_{3-6} \cos(63.4) - F_{3-5}$

$F_{3-5} = 98.24\,N$ (C)

Joint 4

$\Sigma F_y = 0$

$F_{4-3} = 0$

$\Sigma F_x = 0$

$F_{4-1} - F_{4-6}$

$F_{4-6} = 49.12\,N$ (T)

Joint 5

$\Sigma F_y = 0$

$F_{5-6} - F_{5-8} \sin(63.4)$

$F_{5-8} = 109.71$ (T)

Joint 6

$\Sigma F_y = 0$

$F_{3-6} \sin(63.4) - F_{6-5}$

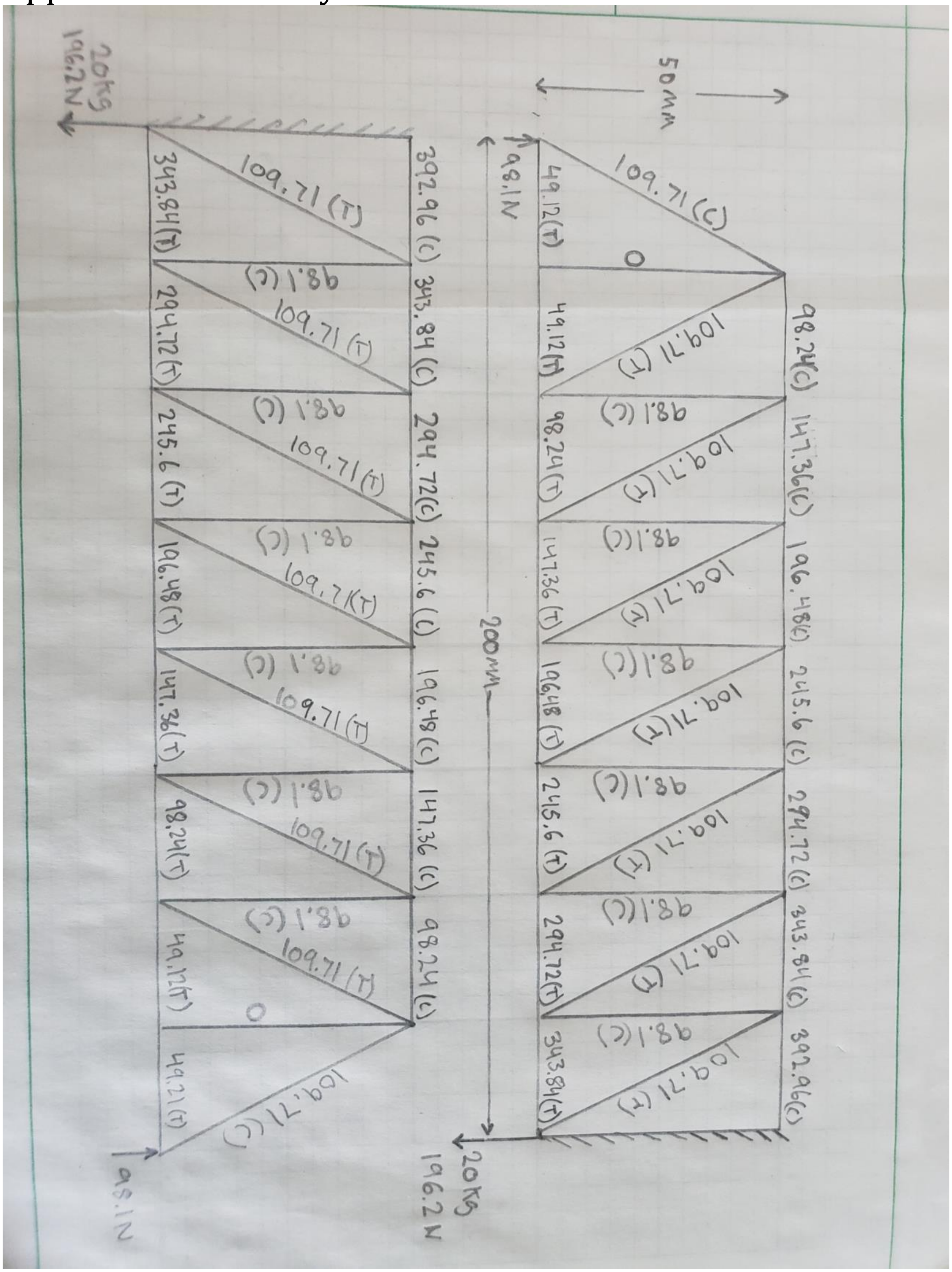
$F_{6-5} = 98.1\,N$ (C)

$\Sigma F_x = 0$

$F_{6-4} + F_{63} \cos(63.4) - F_{6-8}$

$F_{6-8} = 98.24\,N$ (T)

Appendix A-3 – Analysis 3



Appendix A-4 – Analysis 4

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Given: Truss design internal loadings

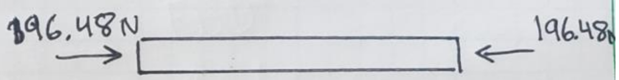
Find: Suitalbe cross sectional area for truss members

Assume: Bridge loadings are dispersed accross two truss patterns, Bridge is in equilibrium

Method: 1) Determine section modulus

2) calculate cross section

Solution: FBD



From Matweb

Tensile Strength, Ultimate

$\sigma = 73.0\,MPa$ (Axial)

Compressive Yield Strength

$\sigma = 6.90 - 9.00\,MPa$

~~Required Section modulus~~

~~$S = M/\sigma_D$~~

Normal Stress

$\sigma_a = F/A$

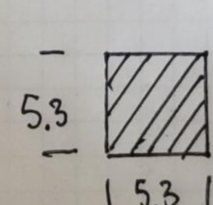
$6900000\,Pa = \frac{196.48\,N}{A}$

$A = \frac{196.48\,N}{6900000\,Pa}$

$= 2.84 \times 10^{-5}\,m^2$

$\sqrt{2.84 \times 10^{-5}\,m^2} = .0053\,m$

$= 5.3\,mm$



Appendix A-5 – Analysis 5

Andrew Harris | 10/16/20 | MET 489

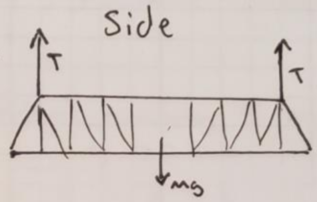
GIVEN: Bridge Truss Weight (Solidworks) 27.87g
↳ use 30g

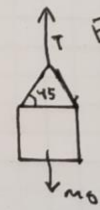
FIND: Pulley Component Analysis

METHOD: 1) FBD 2) Rope Tension 3) Pulleys

SOLUTION:

$mg = .030kg \times 9.81 m/s^2$
$= .2943 N$





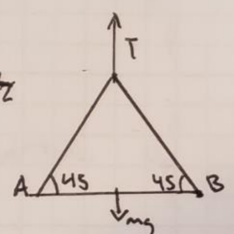
$\Sigma F_y = 0$

$2T - mg = 0$

$T = mg/2$

~~= .02778kg/2~~
~~= .01389~~

$T = .147 N$



ROPE TENSION

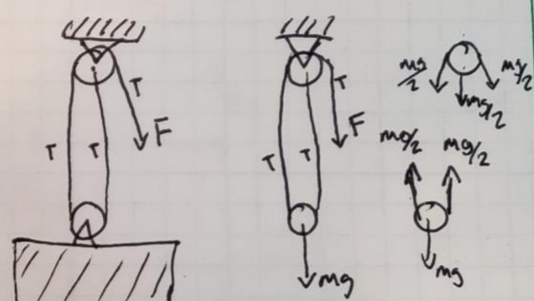
$F_A \sin 45 + F_B \sin 45 - T = 0$

$T = (F_A + F_B) \sin 45$

$F_A + F_B = .2081 N$

$F_A = .104 N$
$F_B = .104 N$

Pulleys



$F_{Pull} = Mg/2$

Each Side of Bridge will Pull ½ of Truss weight

$½ \times 30g = 15g$

$F_{Pull} = 15g \times 9.81/2 = .0735 N$

Force of lift must be less than 10g (Requirement)

$.0735 (N) / 9.81 (m/s^2) = 7.5g$ ✓

Appendix A-6 – Analysis 6

Andrew Harris | 10/16/20 | MET489

Given: Bridge Truss Road section

Find: Bending Stress in cross members in between Truss

Assume:
- Even distribution of weight
- Static loading

Method: FBD, V&M, Flexure formula

Solution:

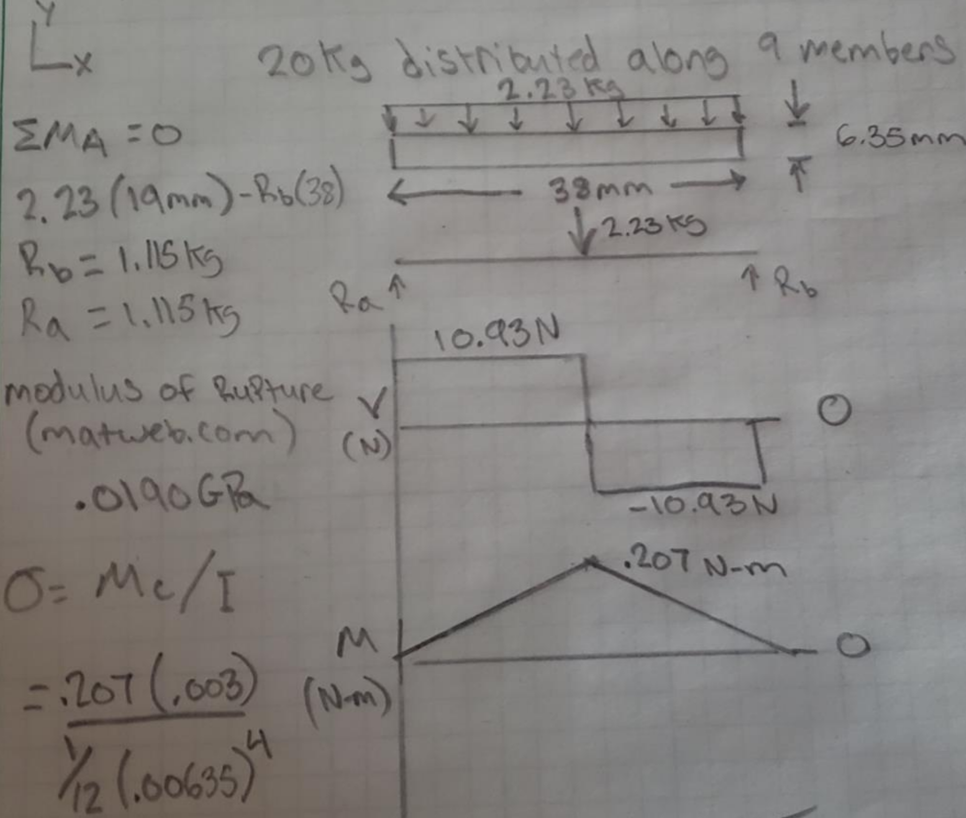
20 kg distributed along 9 members

$\Sigma M_A = 0$

$2.23(19mm) - R_b(38)$

$R_b = 1.115\,kg$

$R_a = 1.115\,kg$



modulus of Rupture (matweb.com)

.0190 GPa

$\sigma = Mc/I$

$= \dfrac{.207(.003)}{\frac{1}{12}(.00635)^4}$

$= 4.58 \times 10^6\,Pa < 19 \times 10^6\,Pa$ ✓

Cross members will support load

Appendix A-7 – Analysis 7

Andrew Harris | 10/23/20 | MET489

Anaysis 07

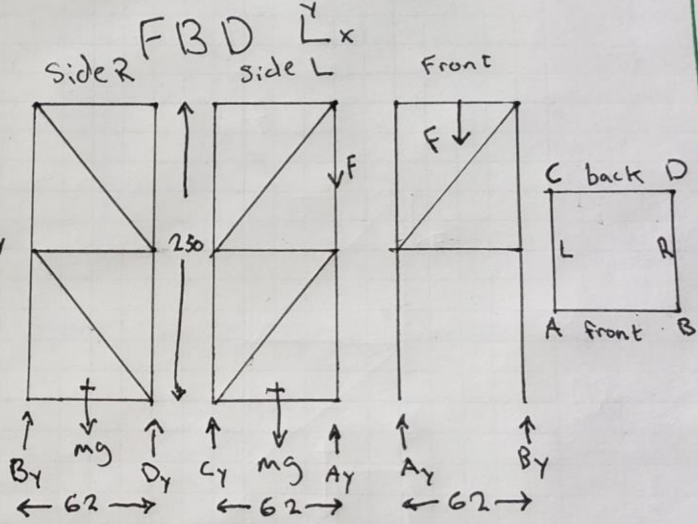
Given: TOWER dimensions (solid works)
MASS: 11.92g

Find: Tower Equilibrium

Assume: Steady loading
No external forces

Method: FBD, Static eqilibrium

FBD



Solution:

Support reactions with no loading

$\Sigma F_y = (A_y + B_y + C_y + D_y - mg) = 0$

$A = B = C = D$

$\Sigma F_x = 0$

$\Sigma M_A = 0$

$-mg\,(31mm) + B_y\,(62mm)$

$.01192\,kg(9.81\,m/s^2)(.031m) + B_y(.062\,m)$

$B_y = .0584/2 = .0292\ N$

$A_y = .0292\ N$

$C_y = .0292\ N$

$D_y = .0292\ N$

Support reactions with Bridge Load

$\Sigma F_y = 0$ $\qquad A_y = B_y$

$-mg - F_{Bridge} + A_y + B_y$

$-mg - F_{Bridge} + 2A_y$

$-.0584 - (16.79g \cdot 9.81\,m/s^2) + 2A_y$

$A_y = .1115\ N$
$B_y = .1115\ N$
$C_y = .0292\ N$
$D_y = .0292\ N$

Appendix A-8 – Analysis 8

Andrew Harris | 10/23/20 | MET489

Given: - Bridge weight & TOWER dimensions
- Analysis of support reactions

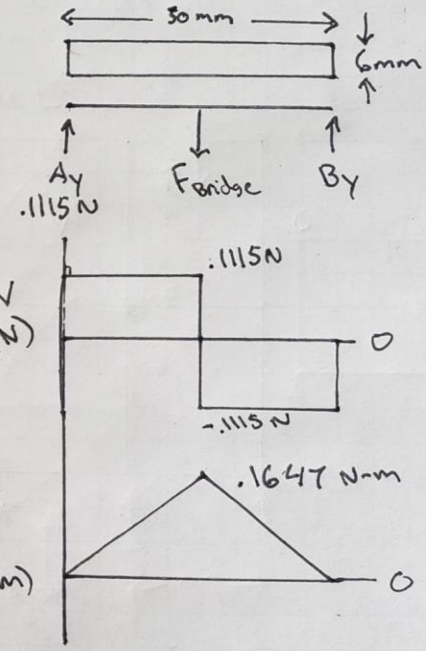
Find: Bending Stress in cross member anchored to Pulley

Assume: Steady loading (constant velocity)
smooth acceleration from rest

METHOD: V & m, FBD, Flexure formula

Solution

FBD



Modulus of Rupture (Matweb.com)
.0190 GPa

Flexure Formula

$\sigma = Mc/I$

$= \dfrac{.1647 (N\text{-}m)(3mm)}{1/12\,(.008)^4}$

$= 4.57 \times 10^6$ Pa

$4.57 \times 10^6 < .019 \times 10^9$ ✓

6mm cross member will support the weight

Appendix A-9 – Analysis 9

Andrew Harris | 10/30/20 | MET 489

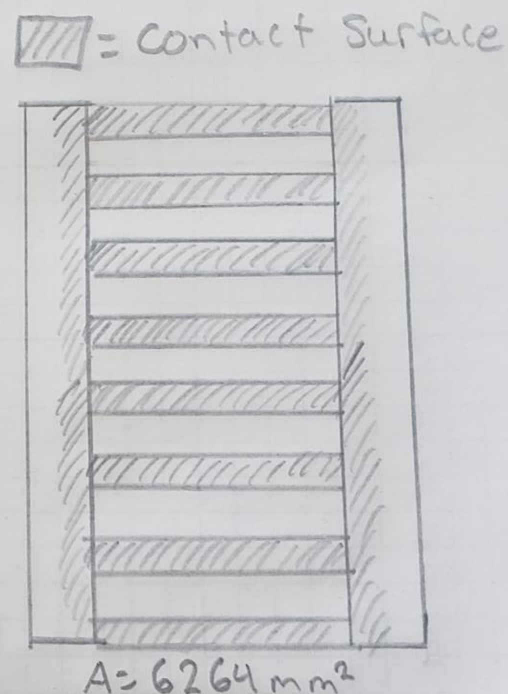
Analysis 09

Given: Bridge design in Solidworks

Find: - Updated distributed load for road
- verify shear is less than material max

Assume: Steady loading

Method: avg stress



Solution:

From Solidworks
Area of road contact

$201\,mm^2 \times 18$ members $= 3618\,mm^2$

$3mm \times 441mm \times 2 = 2646$

Total Area $= 6264\,mm^2$

$\sigma_{Avg} = 196.2\,N / 6264\,mm^2$

$= .031\,N/mm^2$

$= 31321\,Pa$

Shear Strength Mattweb

1.10 MPa

31,321 Pa << 1,100,000 Pa ✓

Appendix A-10 – Analysis 10

Andrew Harris | 10/30/20 | MET489

Analysis 10

Given: Analysis 06 cable tension

Find: Maximum Cable Tension

Assume: Steady loading

Method: Compare Tensile Strength

Solution:

From Amazon.com

Paracord 95 cord

Tensile strength 95 lbs or 422N

Required Tension: .147 N

422N >> .147N

S.F. = 422/.147 = 2871 ✓

Appendix A-11 – Analysis 11

Andrew Harris | 11/6/20 | MET489

Analysis 11

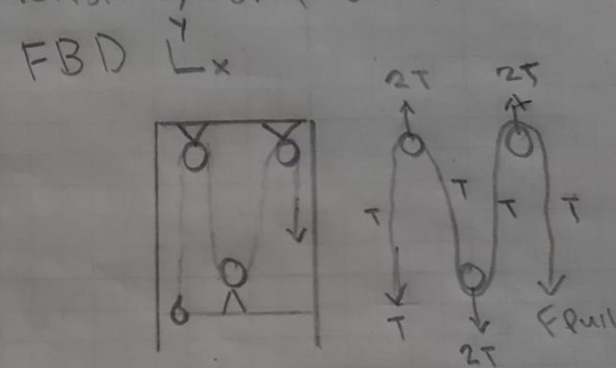
Given: Analysis 5 Pulley system

Find: Updated Pulley design

Assume: - Even loading
- Frictionless Pulleys

Method: FBD, Rope tension, Cord cleat

Solution:

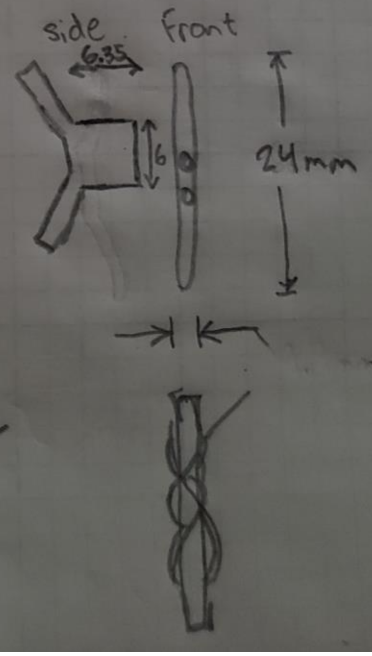


Weight of Bridge
30 g

$F_{pull} = \frac{1}{3}(15\ g)$
$= 5\ g$

Meets design req.
$F_{pull} < 10\ g$ ✓

Use 95 cord (Paracord) 1.75 mm
Strength = 95 lbs
95 lbs >> 30 g ✓



Using a cord cleat to stop rope at max bridge height

Frictional forces created from overlapping will hold rope in place ✓

Appendix A-12 – Analysis 12

Andrew Harris | 11/6/20 | MET489

Analysis 12

Given: Gusset Plate design

Find: Maximum Shear Strength

Assume: - Steady loading

- Thin layes of glue (increased Shear Strength)

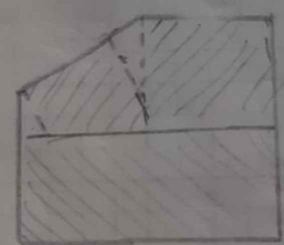
Method: FBD, Gusset contact area, Shear Strength

Solution:

From Solidworks

Area of contact $120mm^2$

$120mm^2 = .186 in^2$



Performace of cured material on wood

Gorilla Glue

Tensile Shear Strength = 3500 PSi

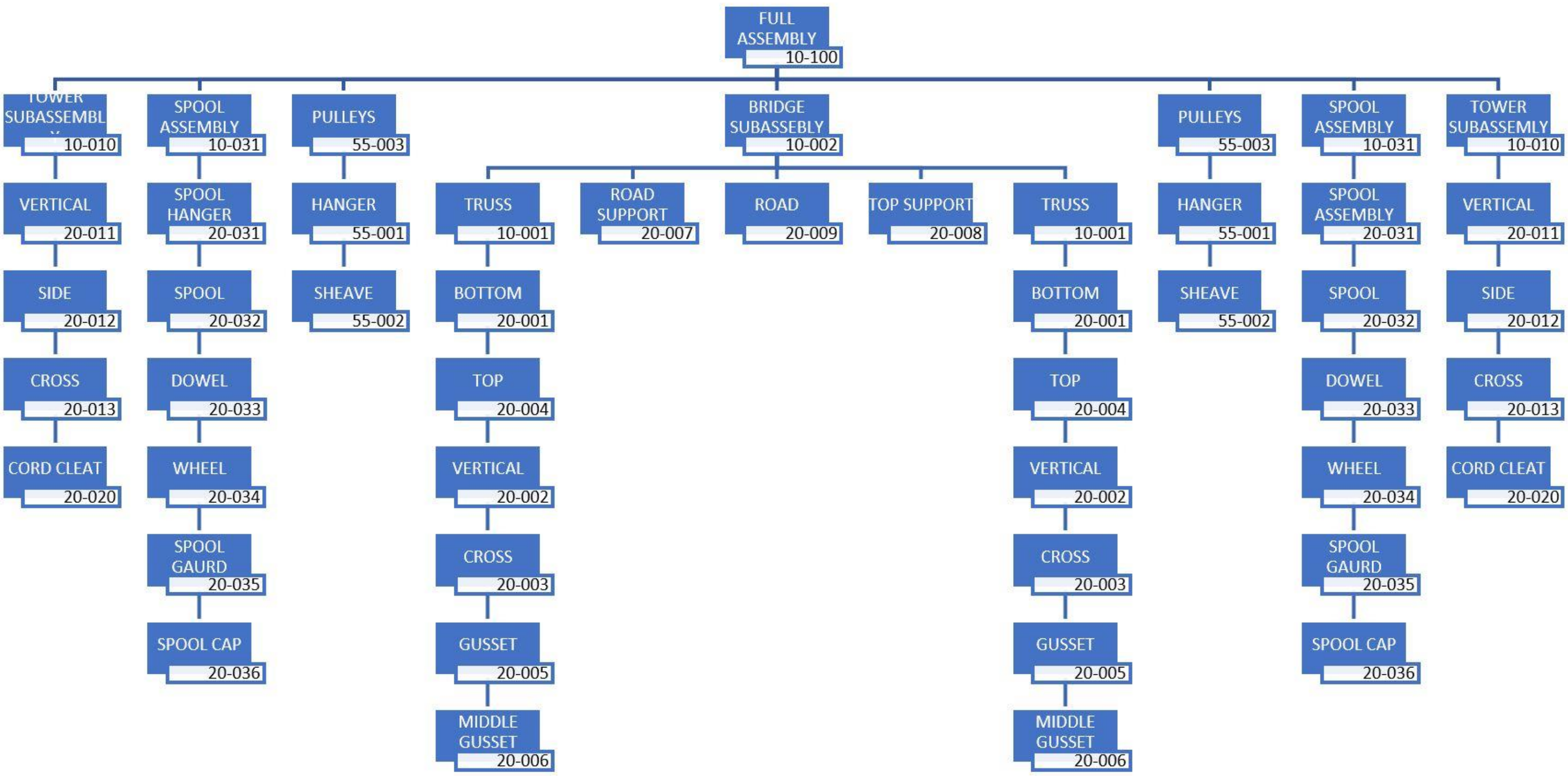
$$\frac{3500 \text{ lbs}}{in^2} \times \frac{.186 \ in^2}{1} = 651 \text{ lbs}$$

Gussets will withstand 651 lbs of Stress before failing

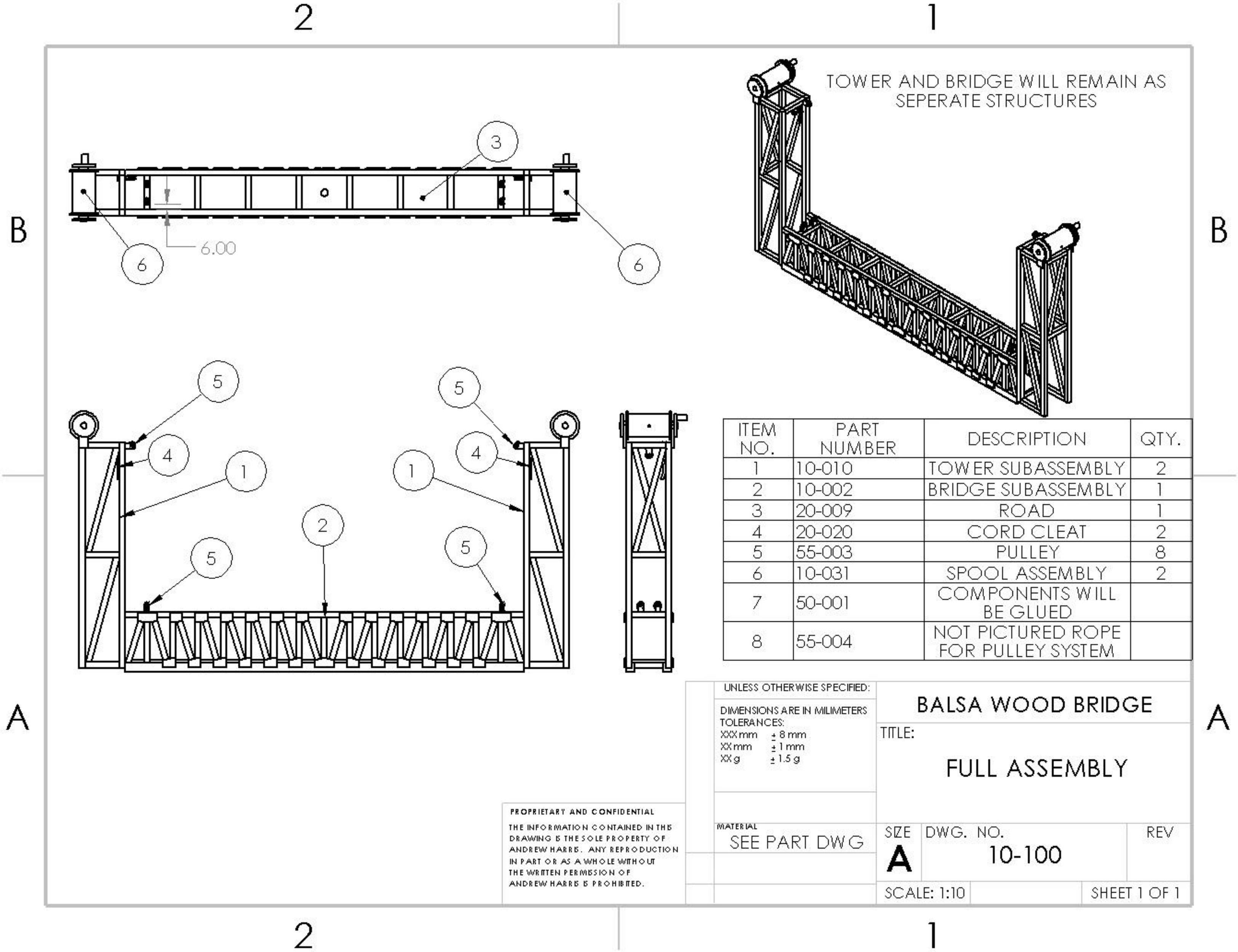
∴ wood will fail before Glue

APPENDIX B - Drawings

Appendix B – Drawing Tree



Appendix B – FULL ASSEMBLY



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10-010	TOWER SUBASSEMBLY	2
2	10-002	BRIDGE SUBASSEMBLY	1
3	20-009	ROAD	1
4	20-020	CORD CLEAT	2
5	55-003	PULLEY	8
6	10-031	SPOOL ASSEMBLY	2
7	50-001	COMPONENTS WILL BE GLUED	
8	55-004	NOT PICTURED ROPE FOR PULLEY SYSTEM	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILIMETERS
TOLERANCES:
XXX mm ± 8 mm
XX mm ± 1 mm
XX g ± 1.5 g

BALSA WOOD BRIDGE

TITLE:

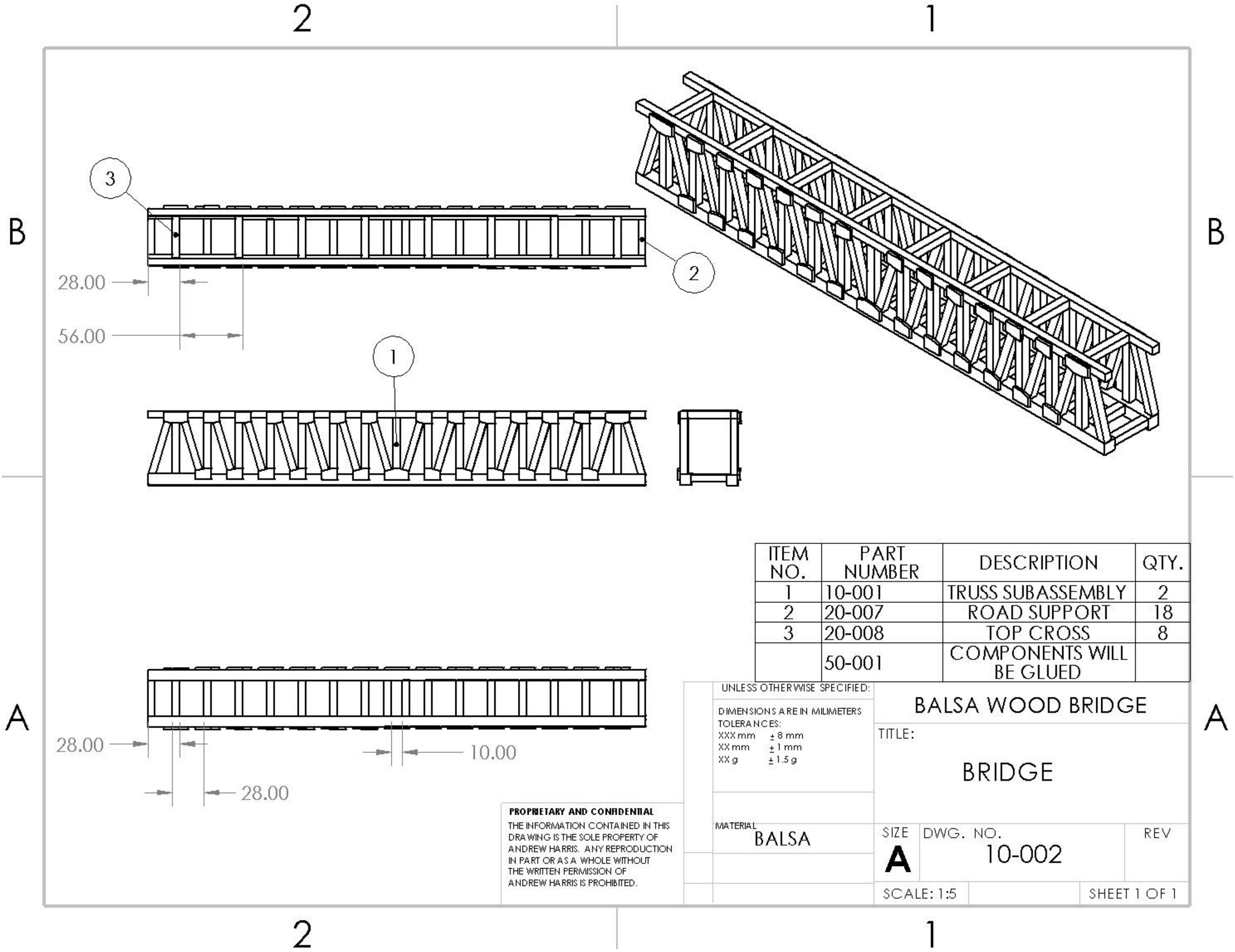
FULL ASSEMBLY

MATERIAL: SEE PART DWG

SIZE: A | DWG. NO. 10-100 | REV

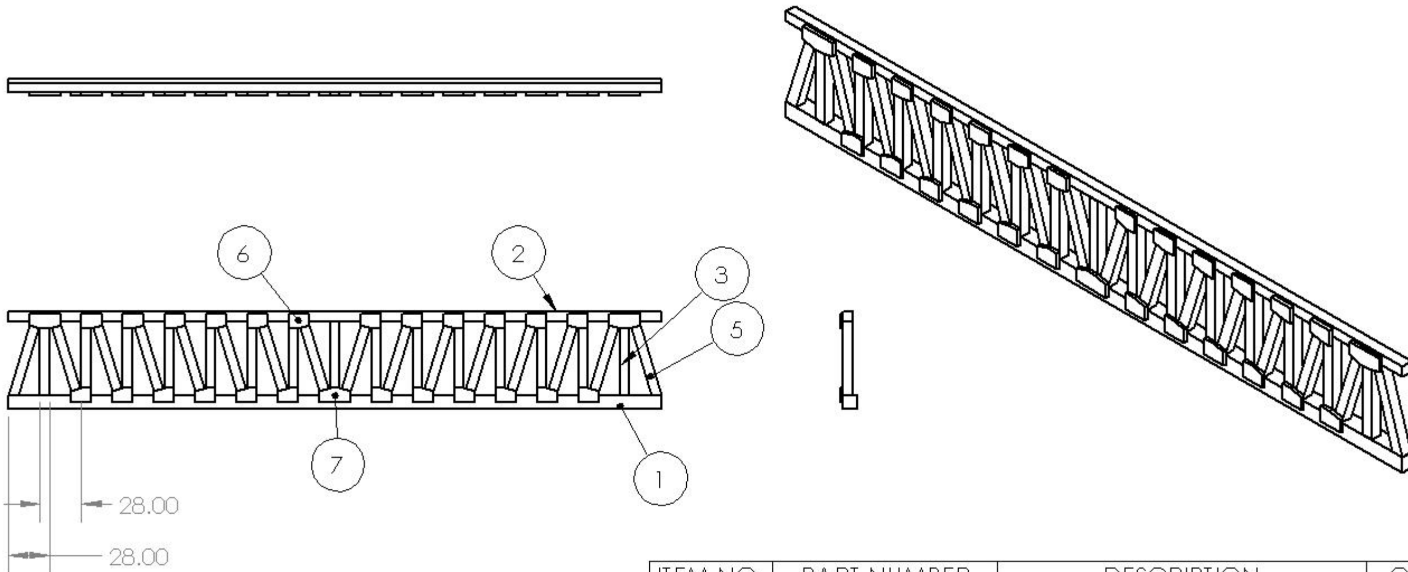
SCALE: 1:10 | SHEET 1 OF 1

Appendix B – BRIDGE



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10-001	TRUSS SUBASSEMBLY	2
2	20-007	ROAD SUPPORT	18
3	20-008	TOP CROSS	8
	50-001	COMPONENTS WILL BE GLUED	

Appendix B – TRUSS



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-001	BOTTOM OF TRUSS	1
2	20-004	TOP OF TRUSS	1
3	20-002	VERTICAL MEMBER	15
5	20-003	CROSS MEMBER	16
6	20-005	GUSSET	24
7	20-006	MIDDLE GUSSET	3
	50-001	COMPONENTS WILL BE GLUED	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILIMETERS
TOLERANCES:
XXX mm ± 8 mm
XX mm ± 1 mm
XX g ± 1.5 g

BALSA WOOD BRIDGE

TITLE:

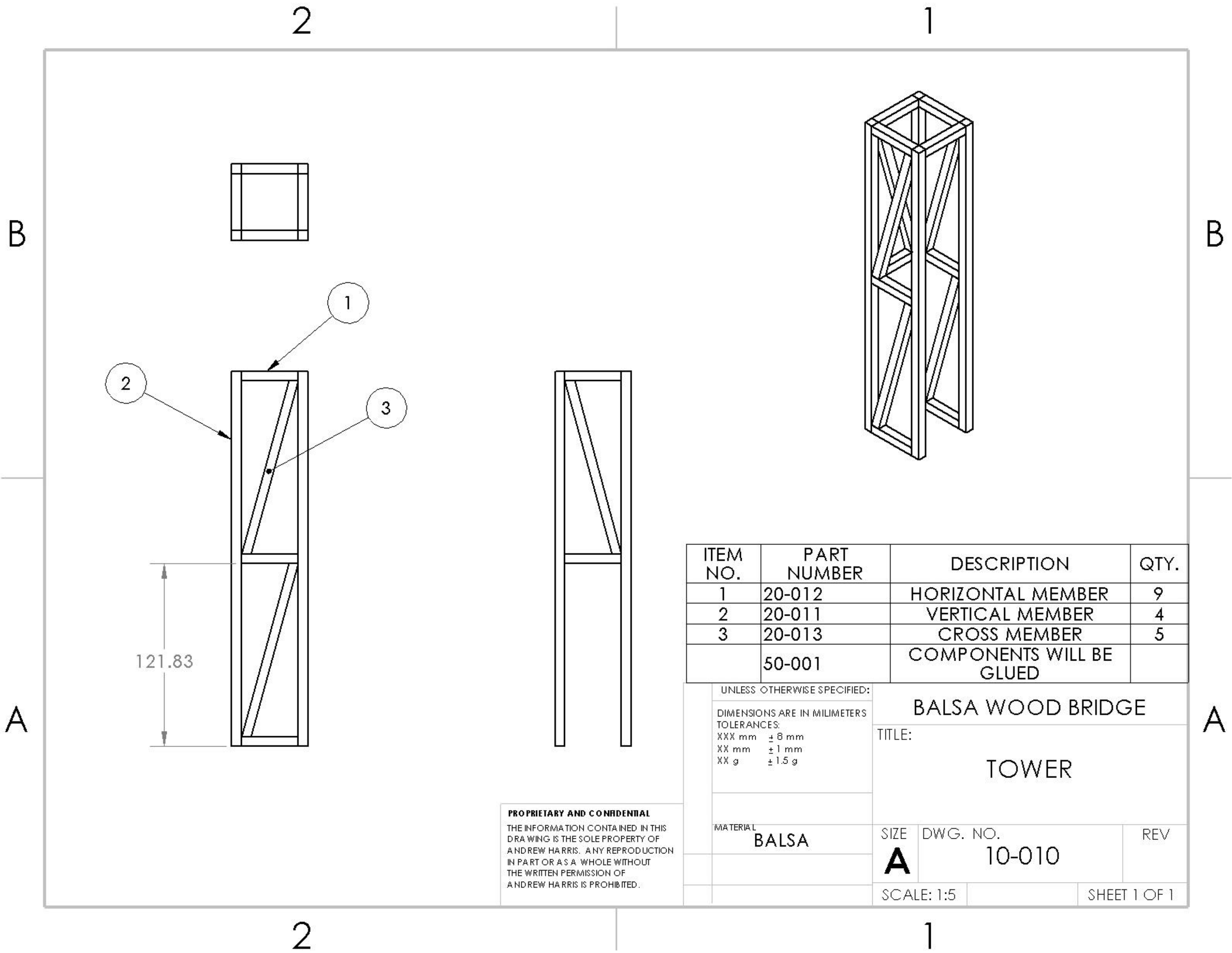
TRUSS

MATERIAL: BALSA

SIZE: A
DWG. NO.: 10-001
REV

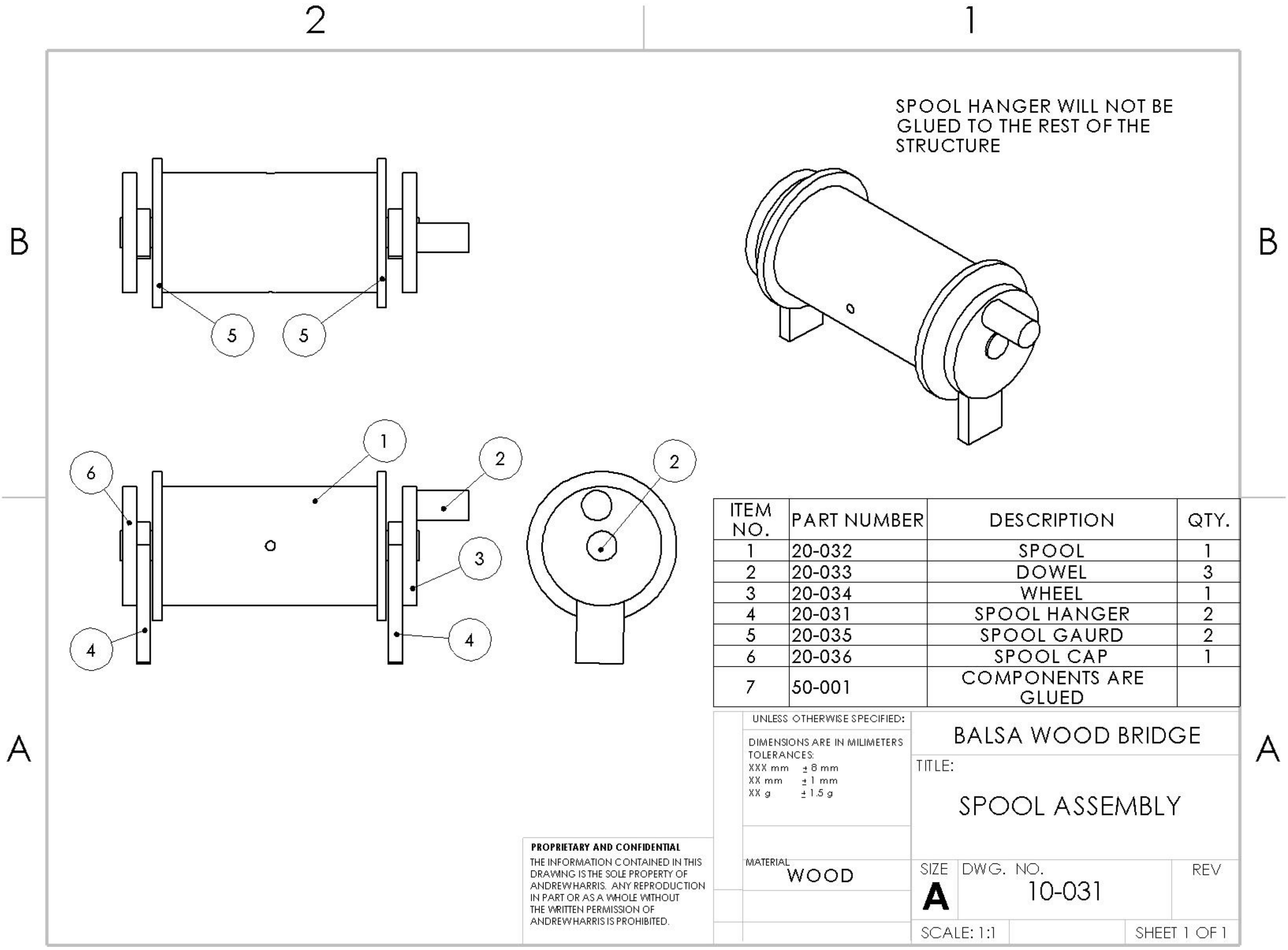
SCALE: 1:5
SHEET 1 OF 1

Appendix B – TOWER



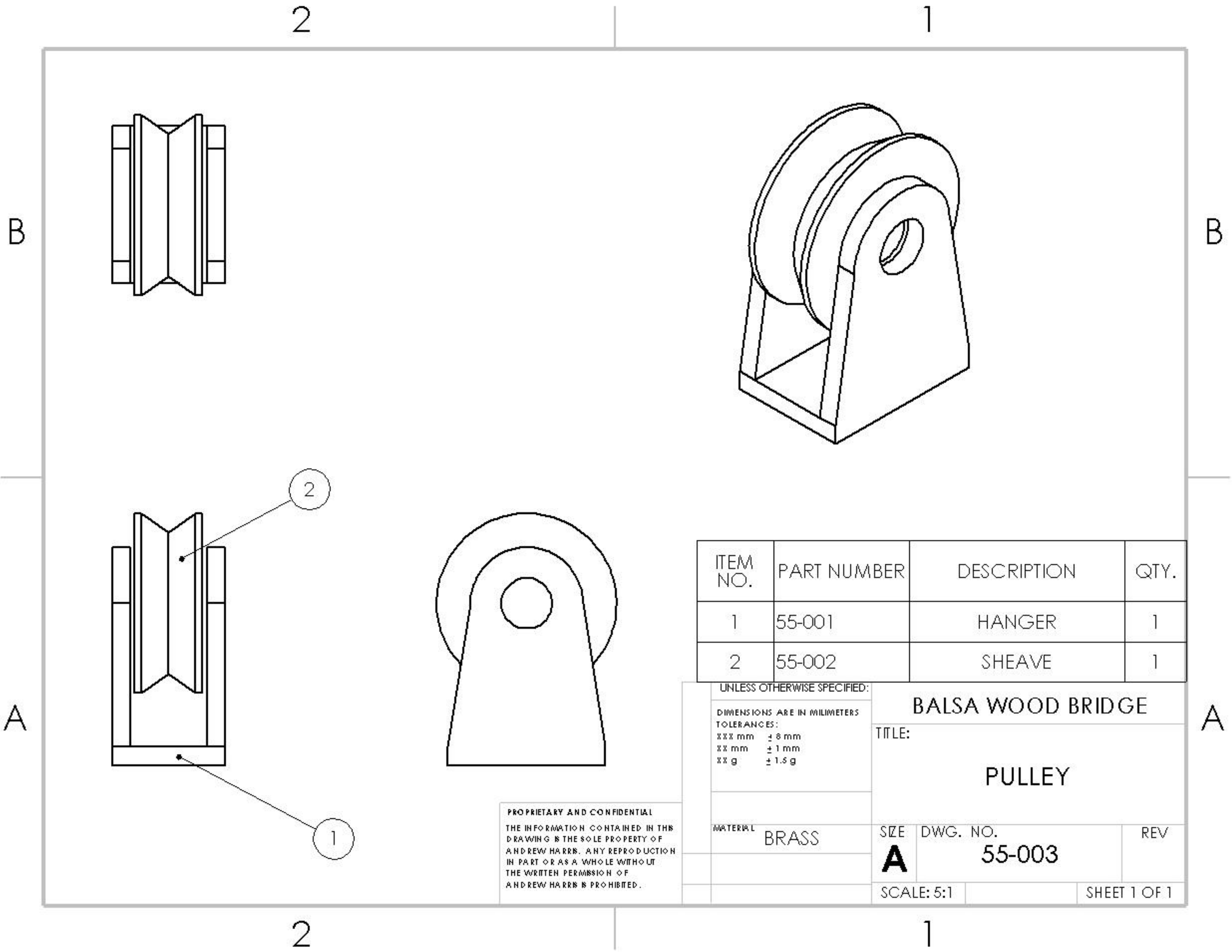
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-012	HORIZONTAL MEMBER	9
2	20-011	VERTICAL MEMBER	4
3	20-013	CROSS MEMBER	5
	50-001	COMPONENTS WILL BE GLUED	

Appendix B – SPOOL ASSEMBLY

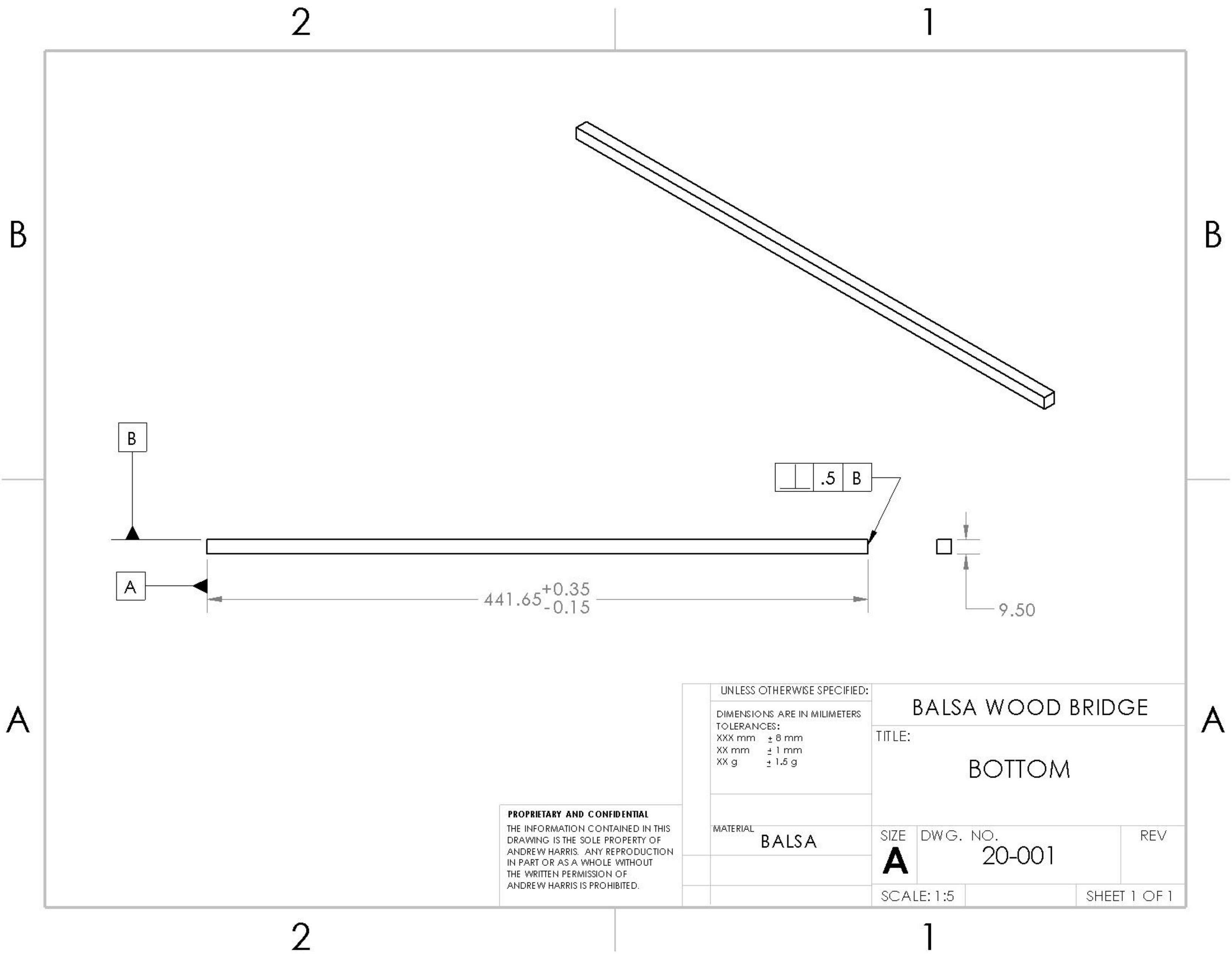


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	20-032	SPOOL	1
2	20-033	DOWEL	3
3	20-034	WHEEL	1
4	20-031	SPOOL HANGER	2
5	20-035	SPOOL GAURD	2
6	20-036	SPOOL CAP	1
7	50-001	COMPONENTS ARE GLUED	

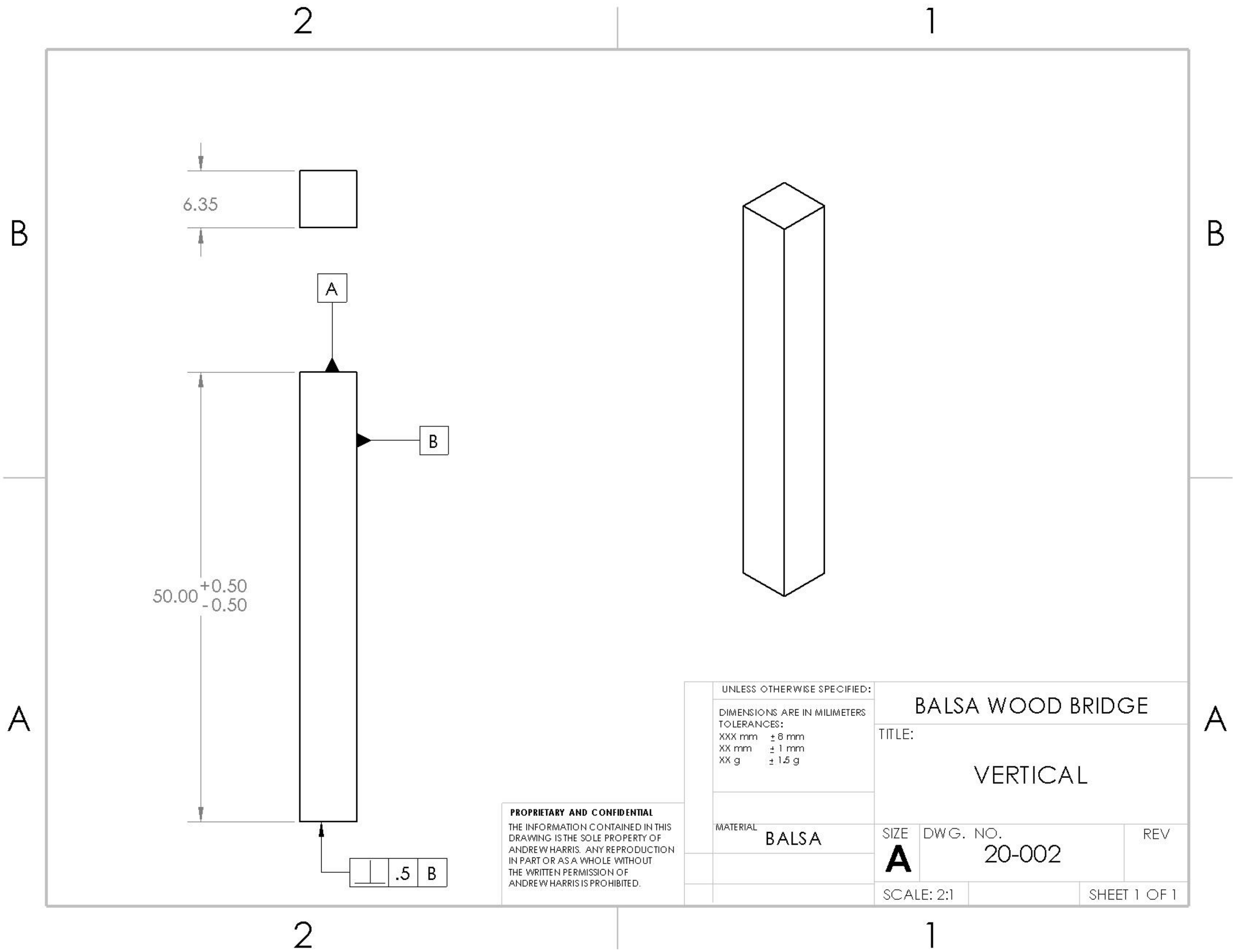
Appendix B – PULLEY



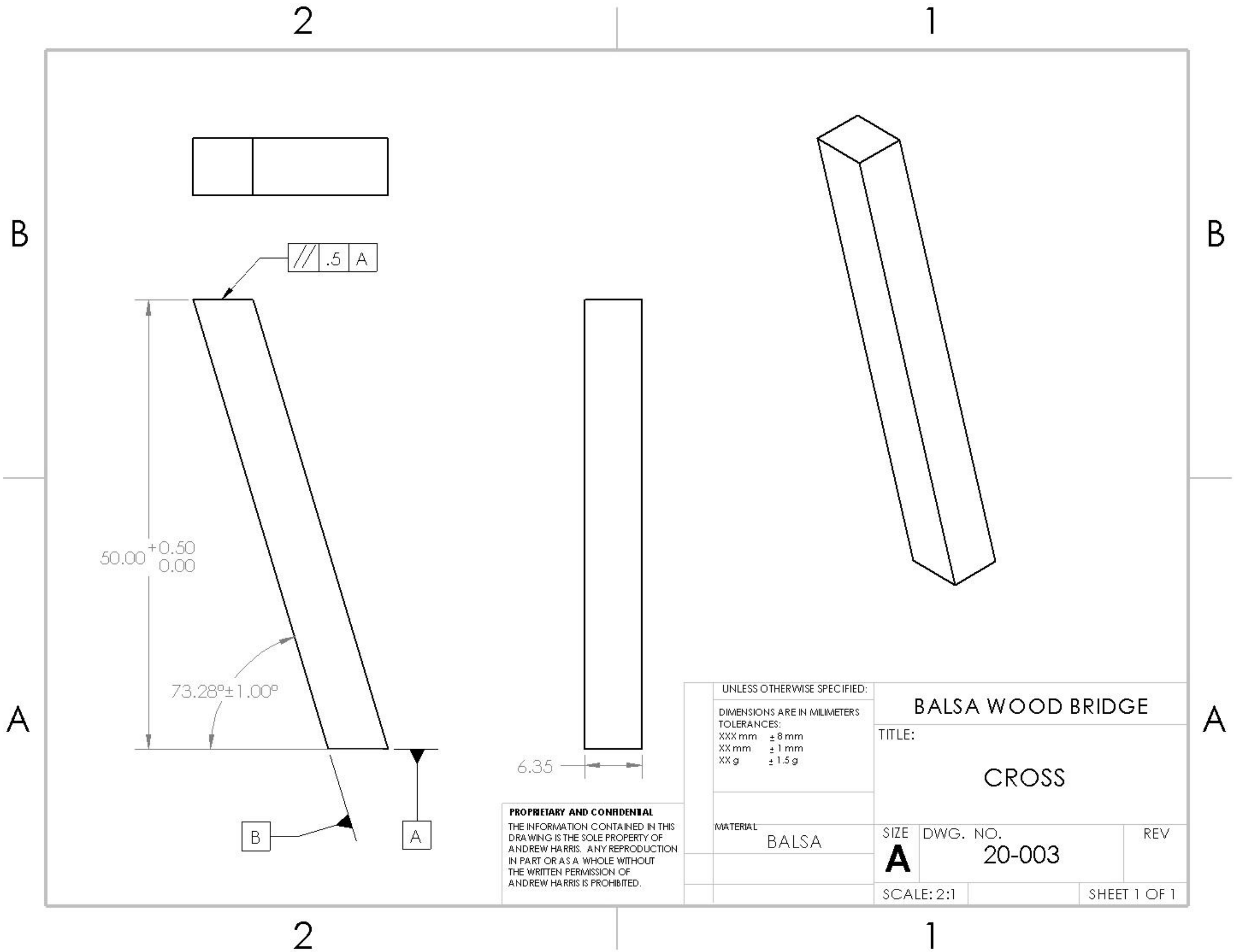
Appendix B – BOTTOM



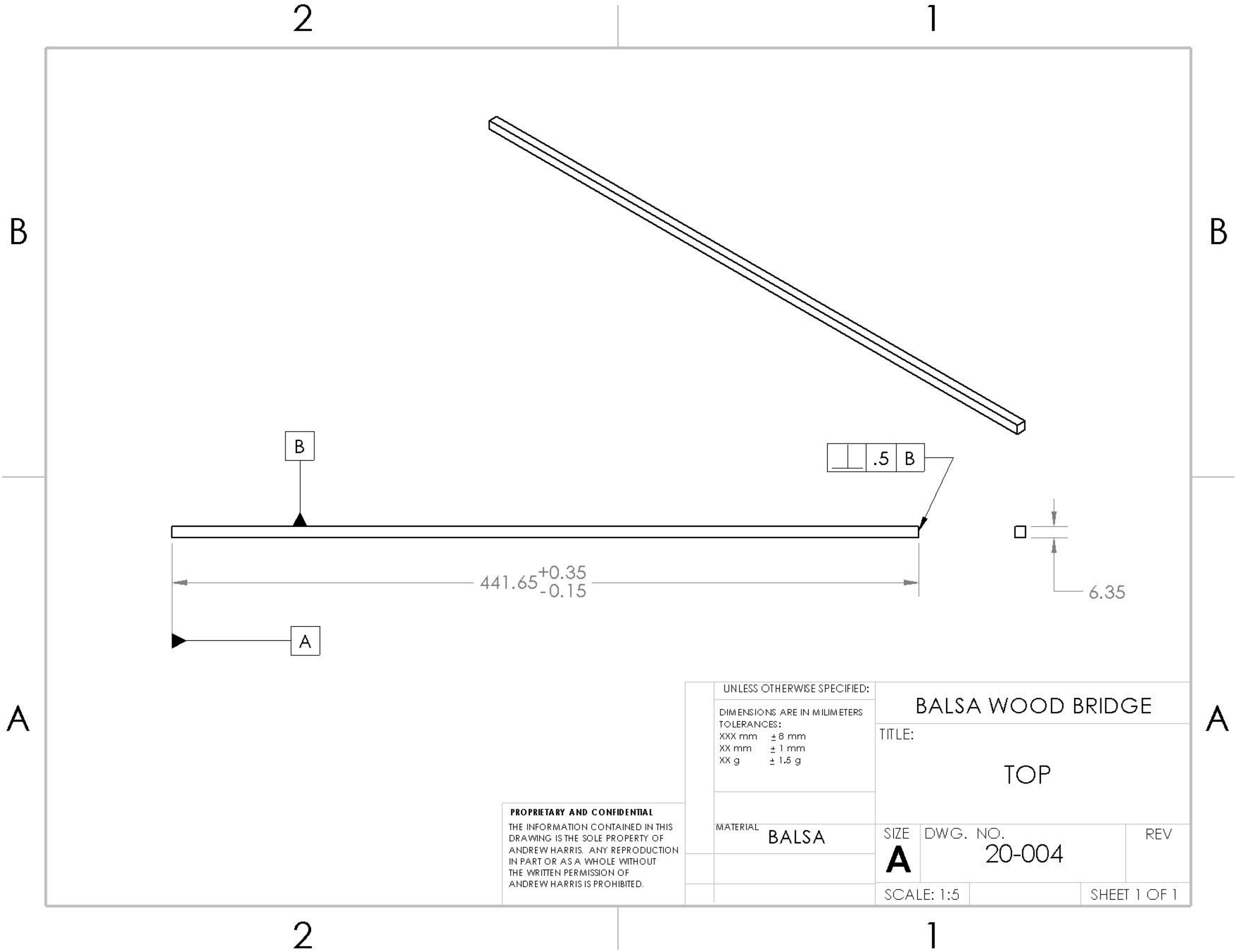
Appendix B – VERTICAL



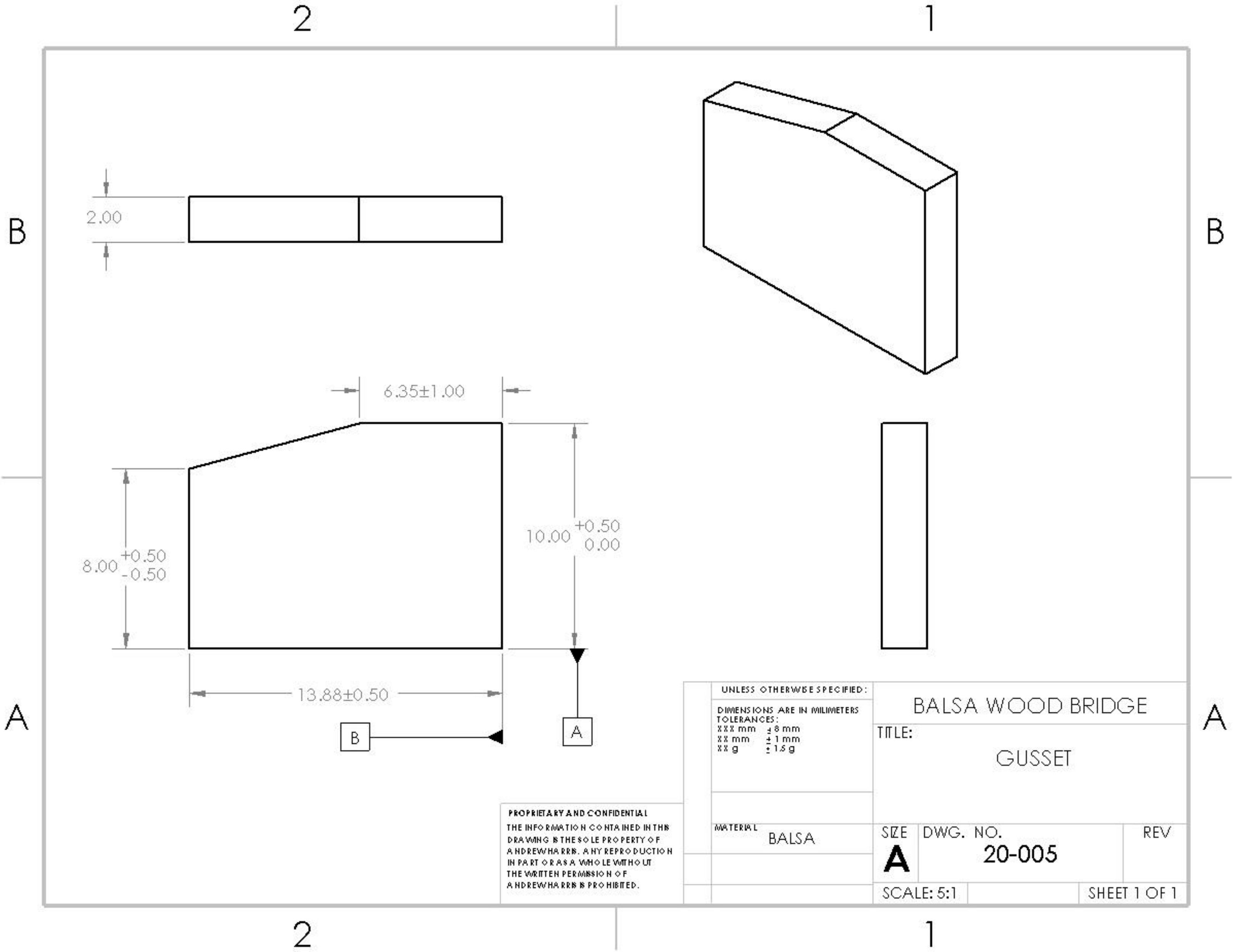
Appendix B – CROSS



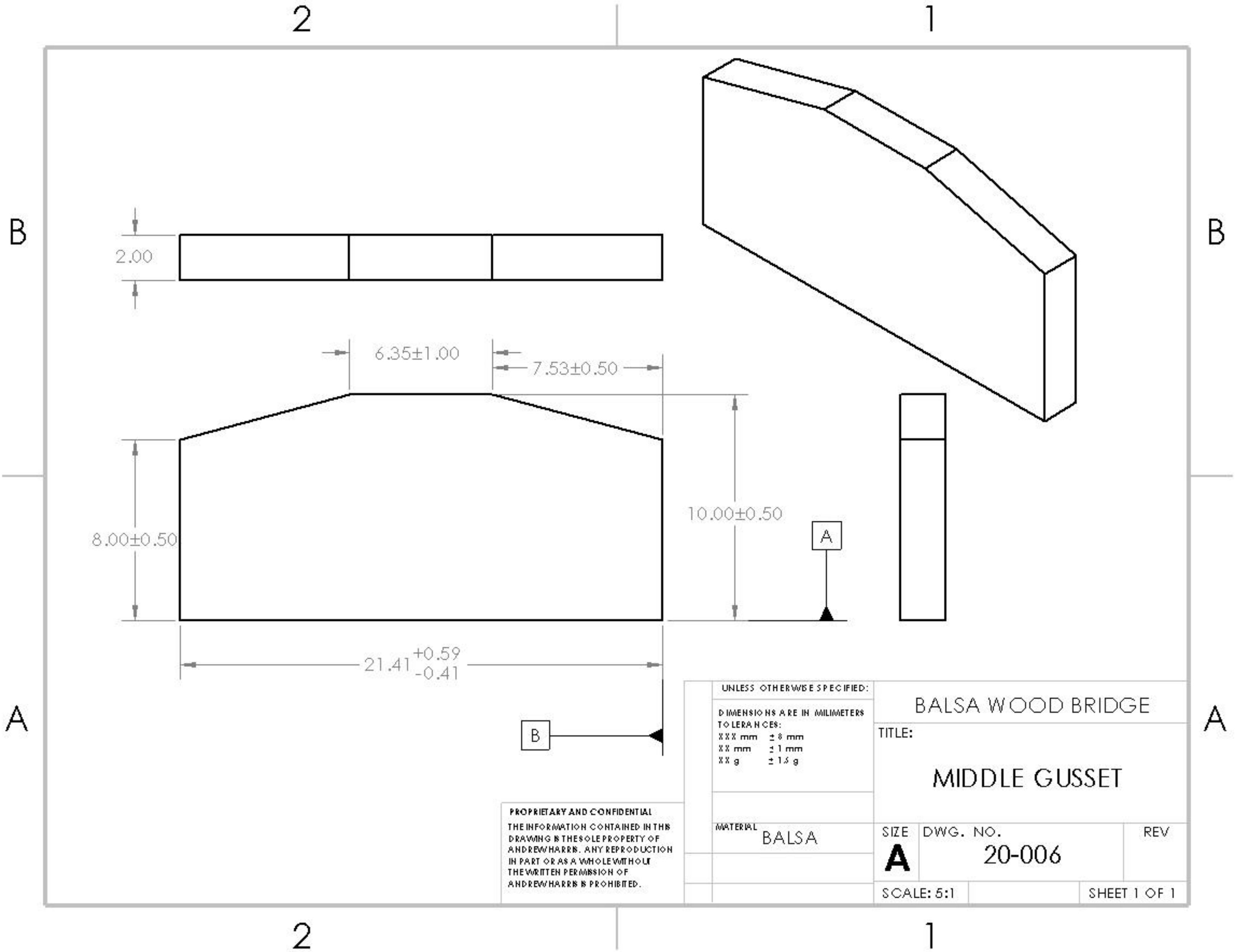
Appendix B – TOP



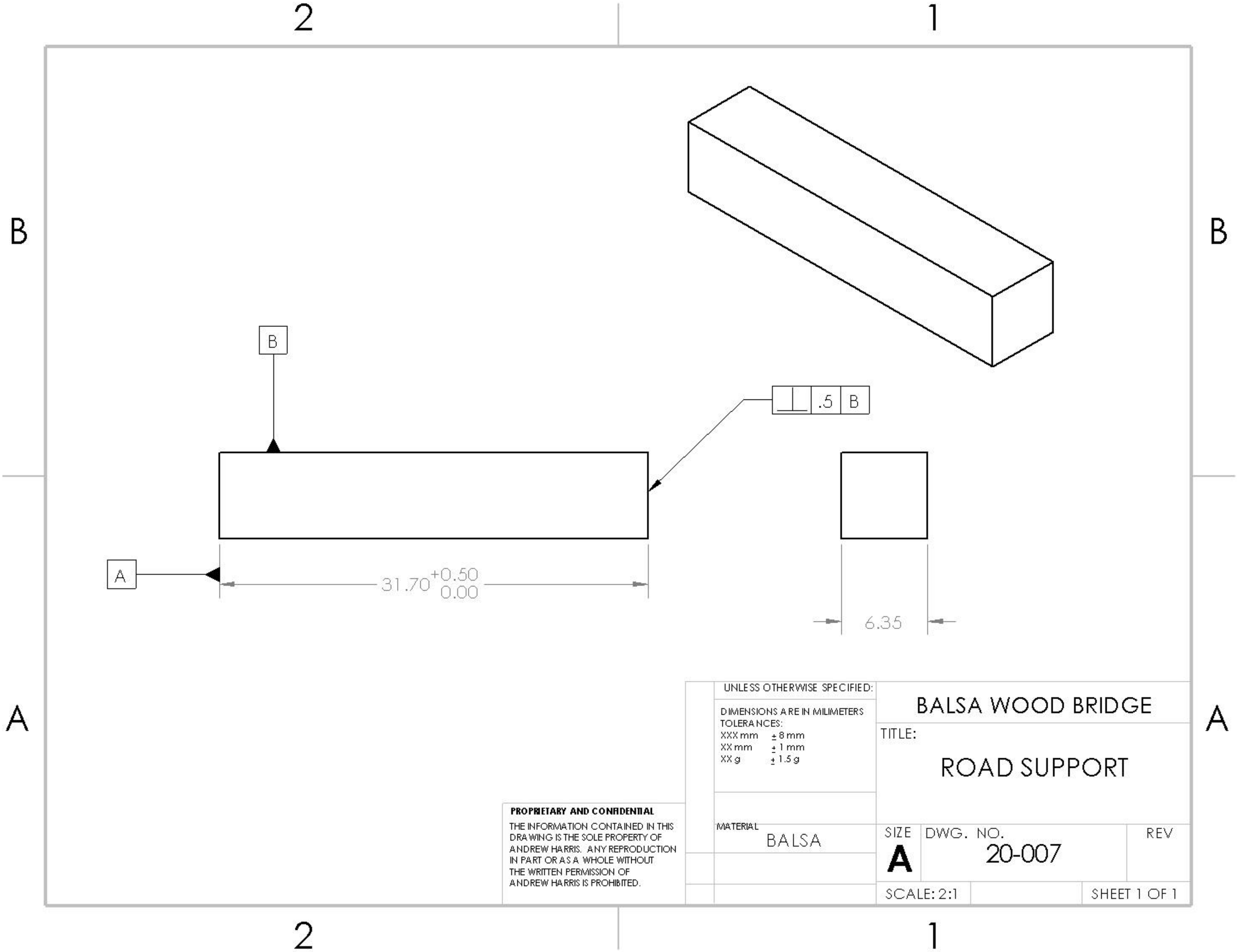
Appendix B – GUSSET



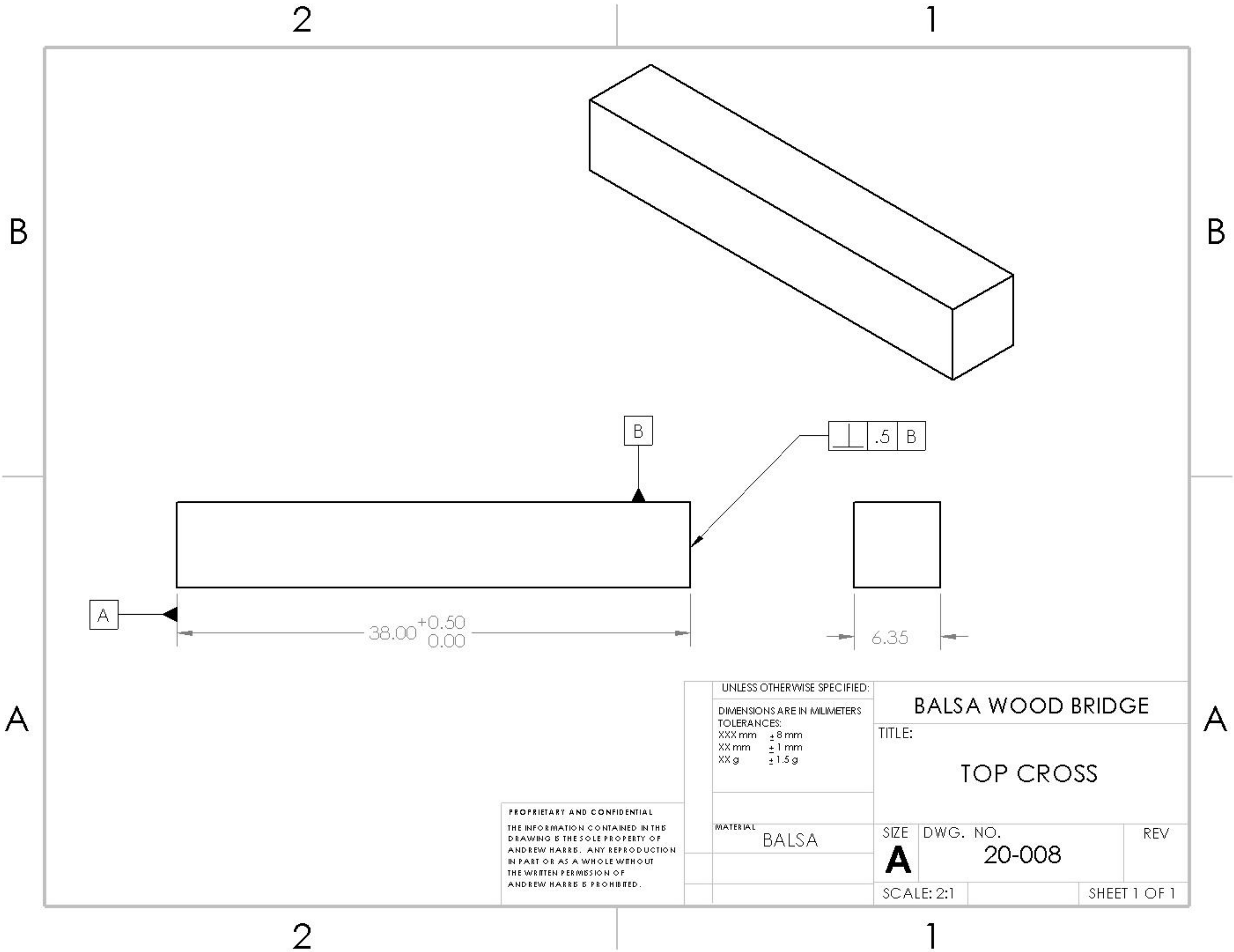
Appendix B – MIDDLE GUSSET



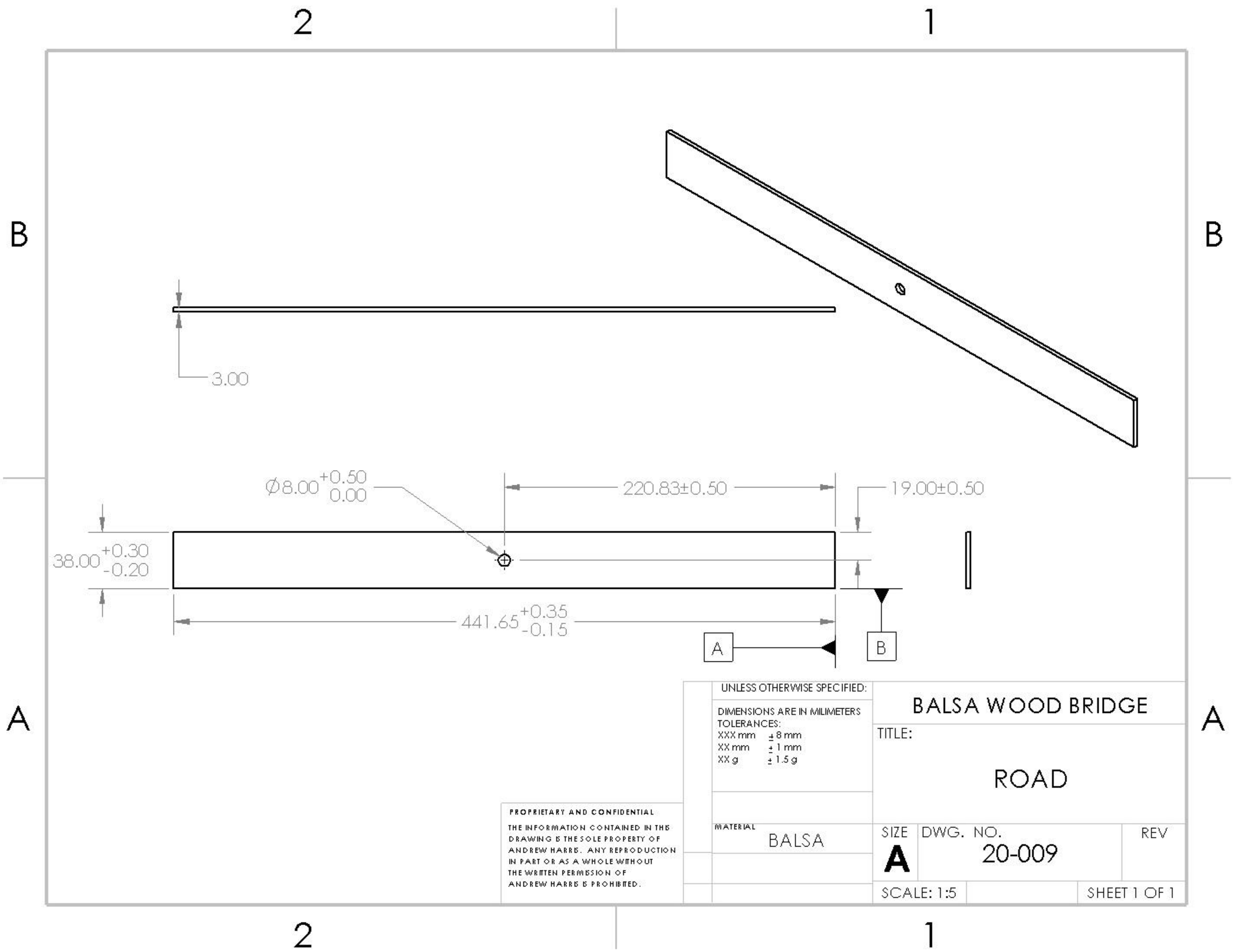
Appendix B – ROAD SUPPORT



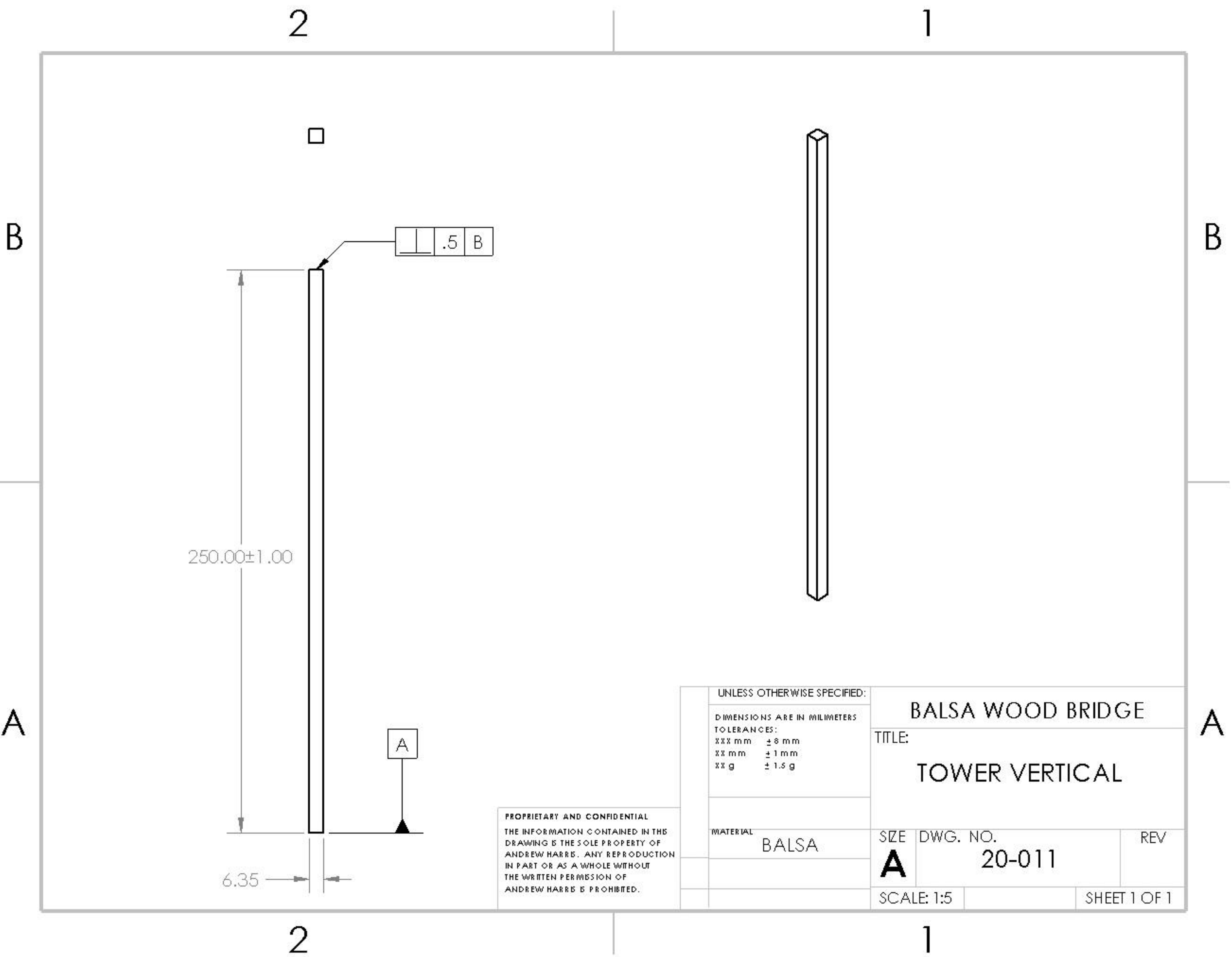
Appendix B – TOP CROSS



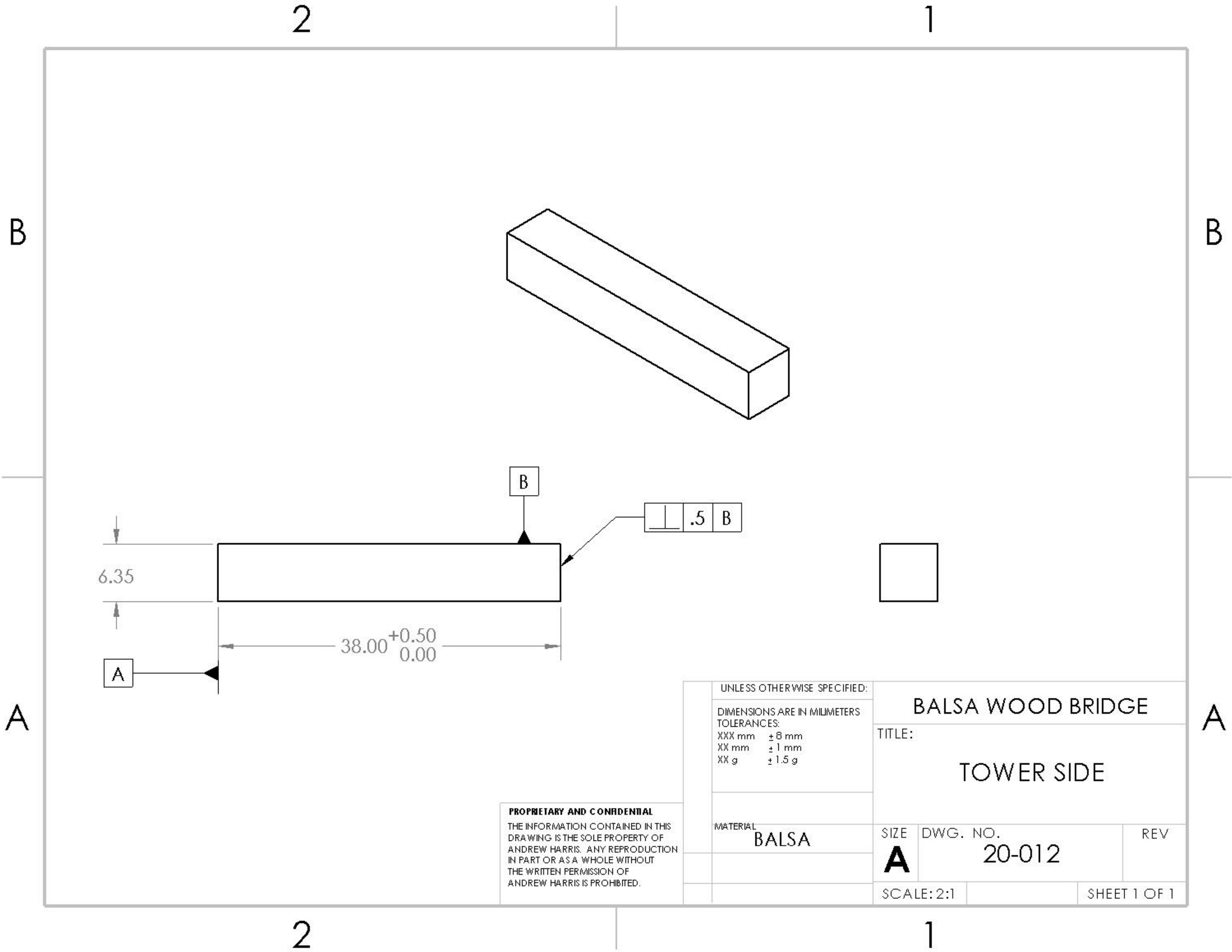
Appendix B – ROAD



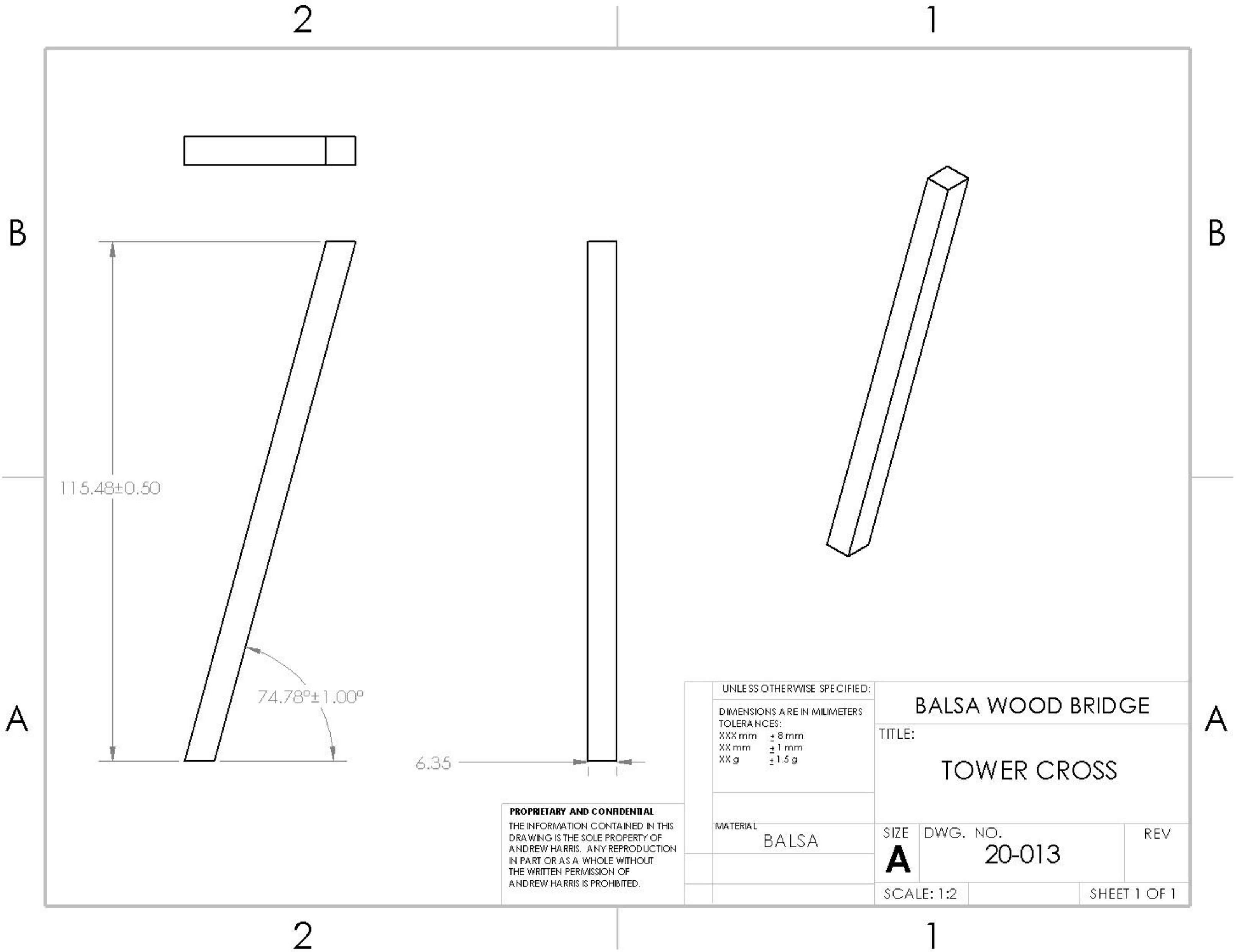
Appendix B – TOWER VERTICAL



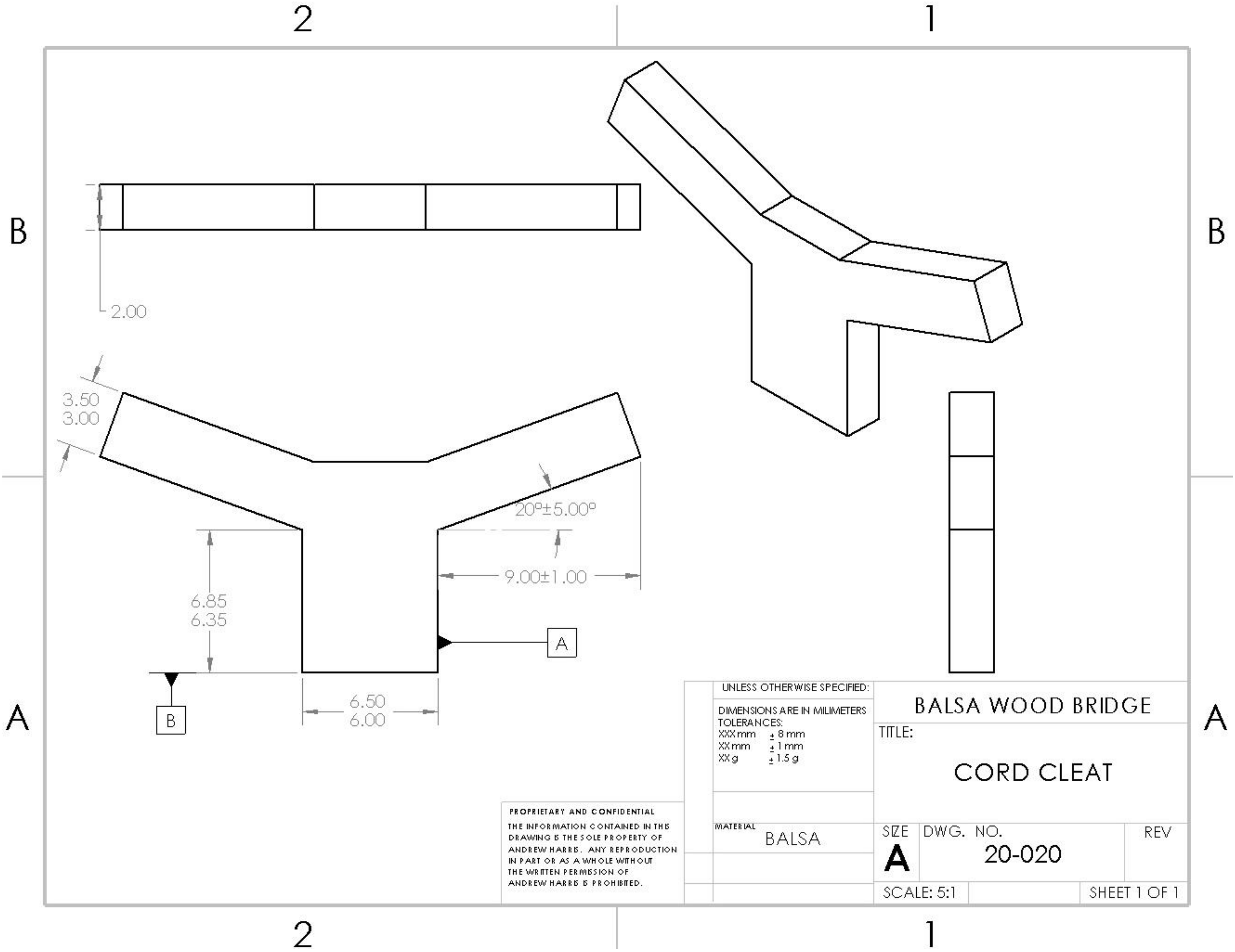
Appendix B – TOWER SIDE



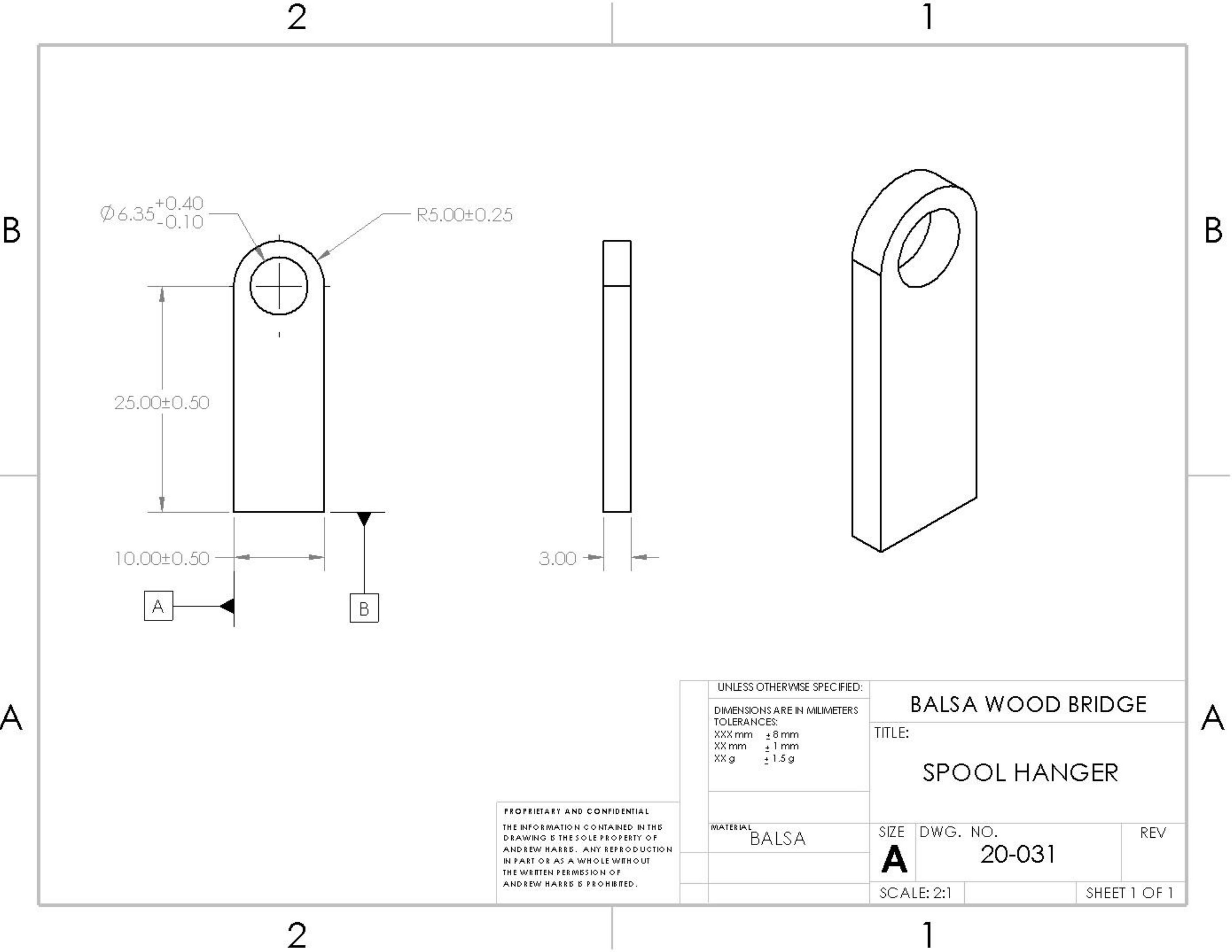
Appendix B – TOWER CROSS



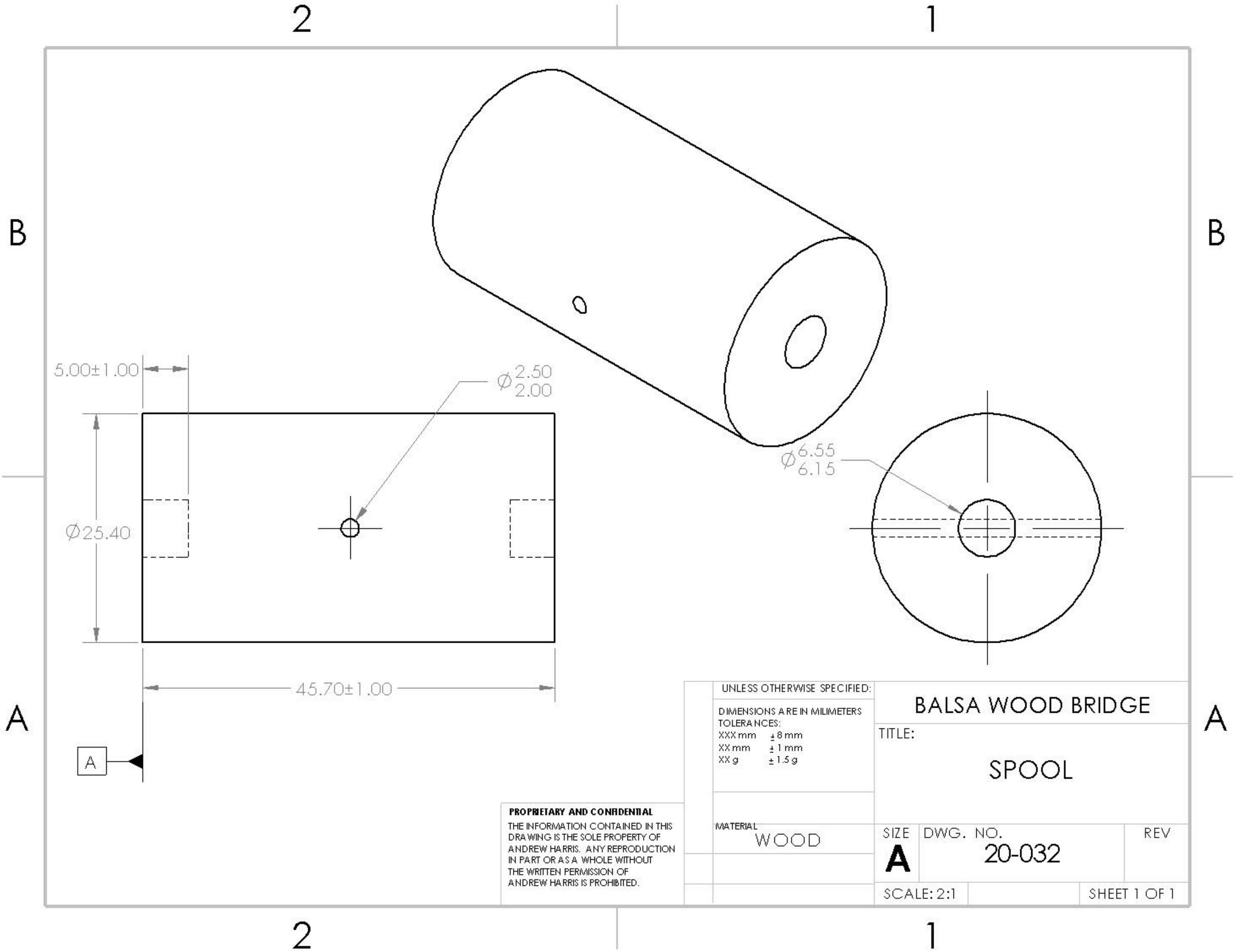
Appendix B – CORD CLEAT



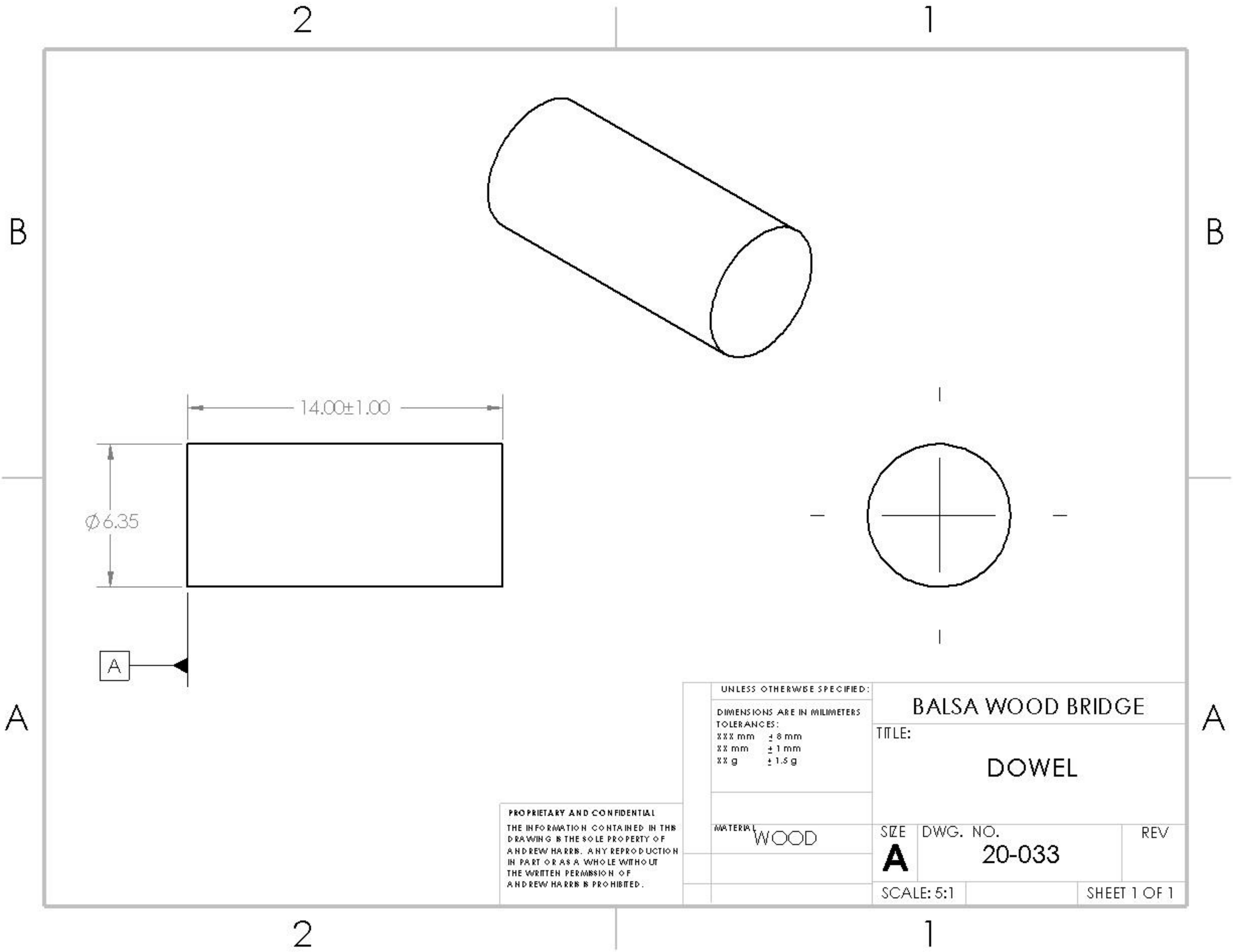
Appendix B – SPOOL HANGER



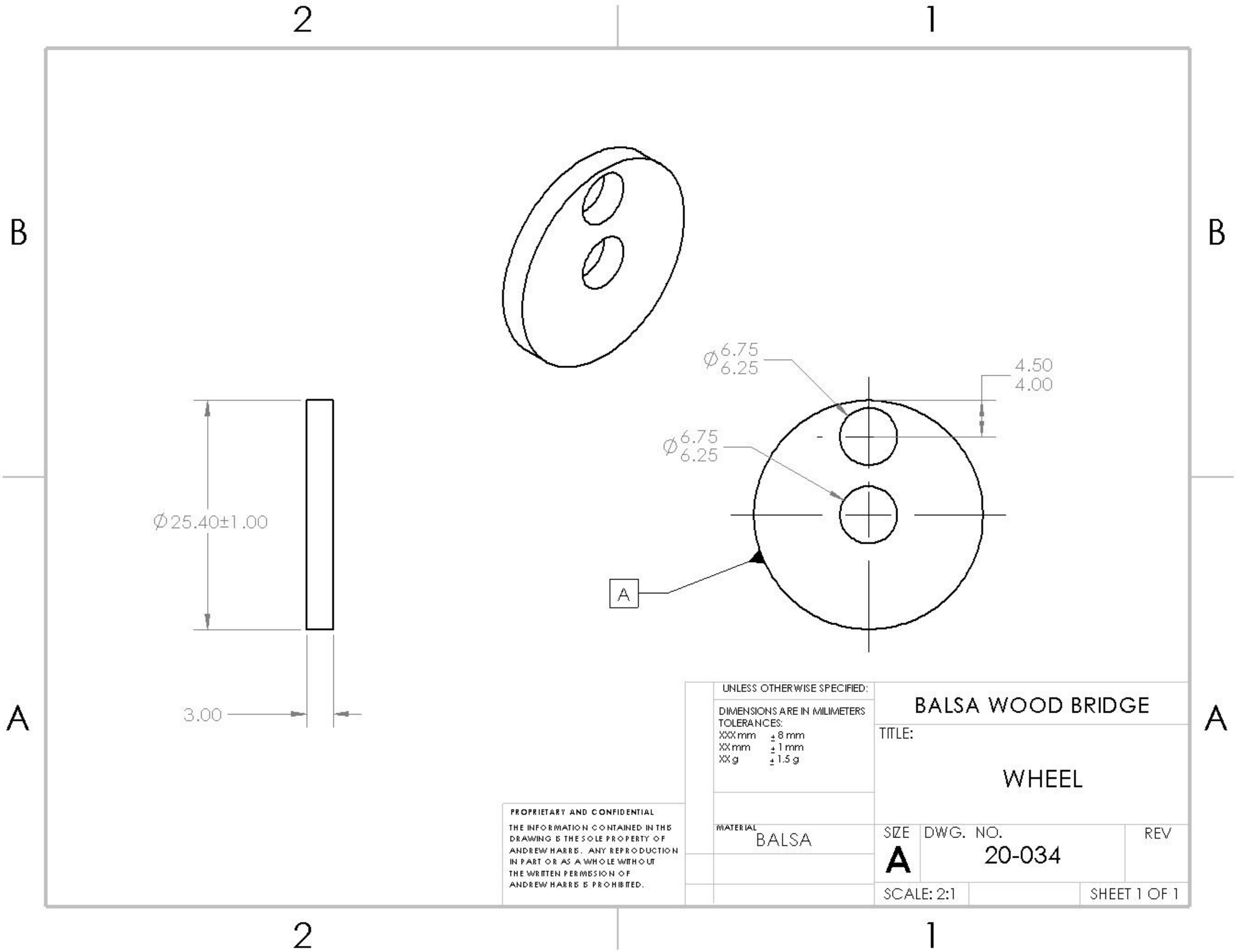
Appendix B – SPOOL



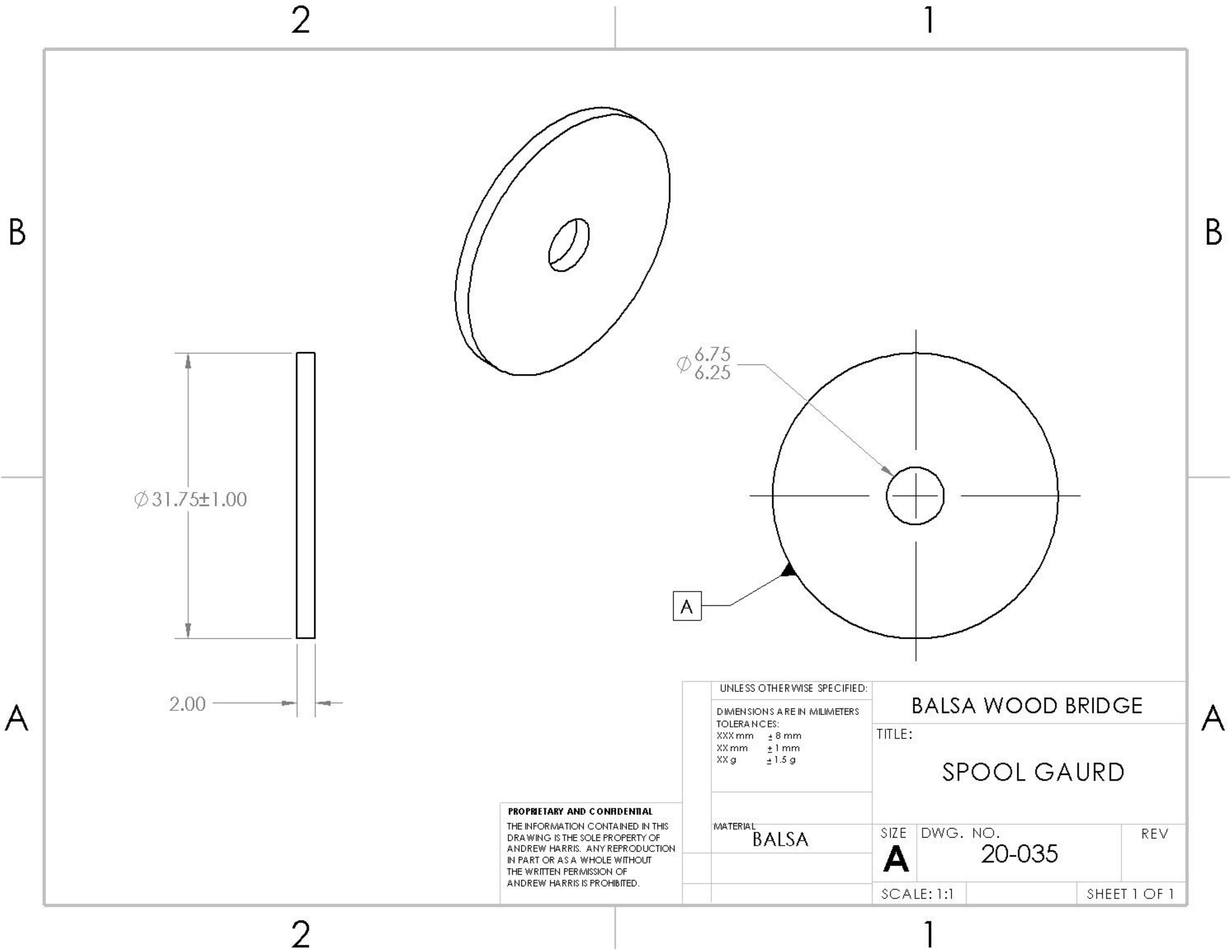
Appendix B –DOWEL



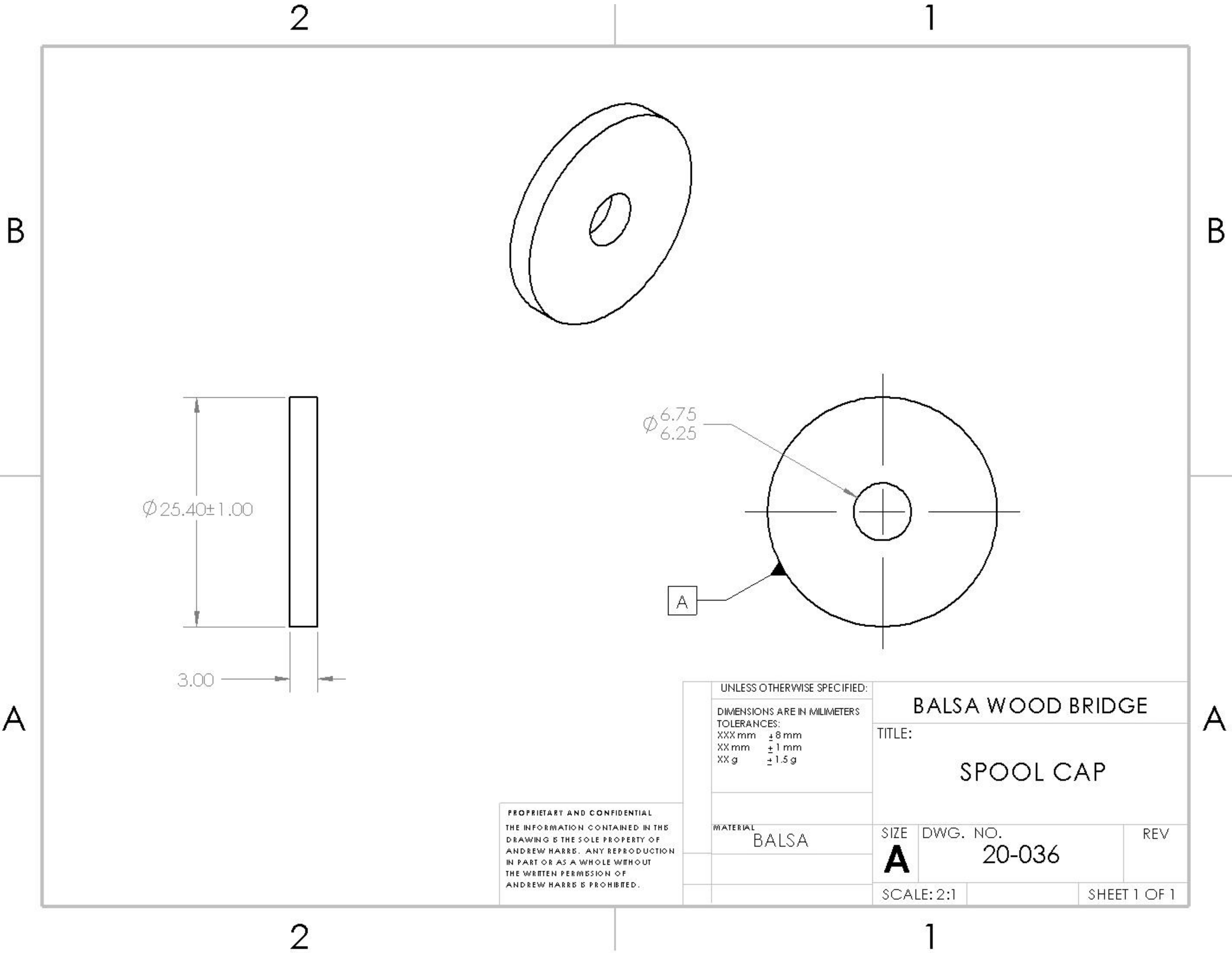
Appendix B – WHEEL



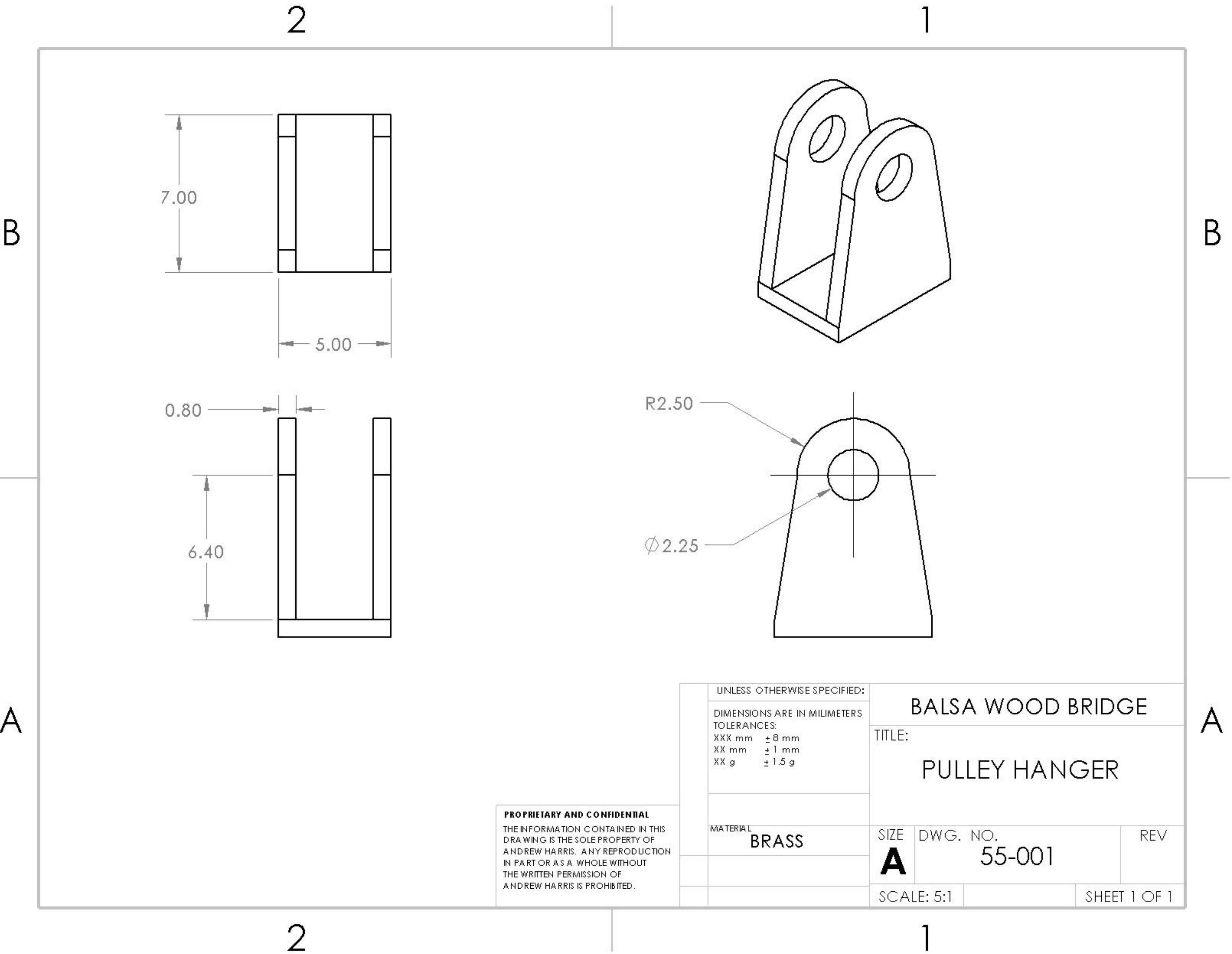
Appendix B – SPOOL GAURD



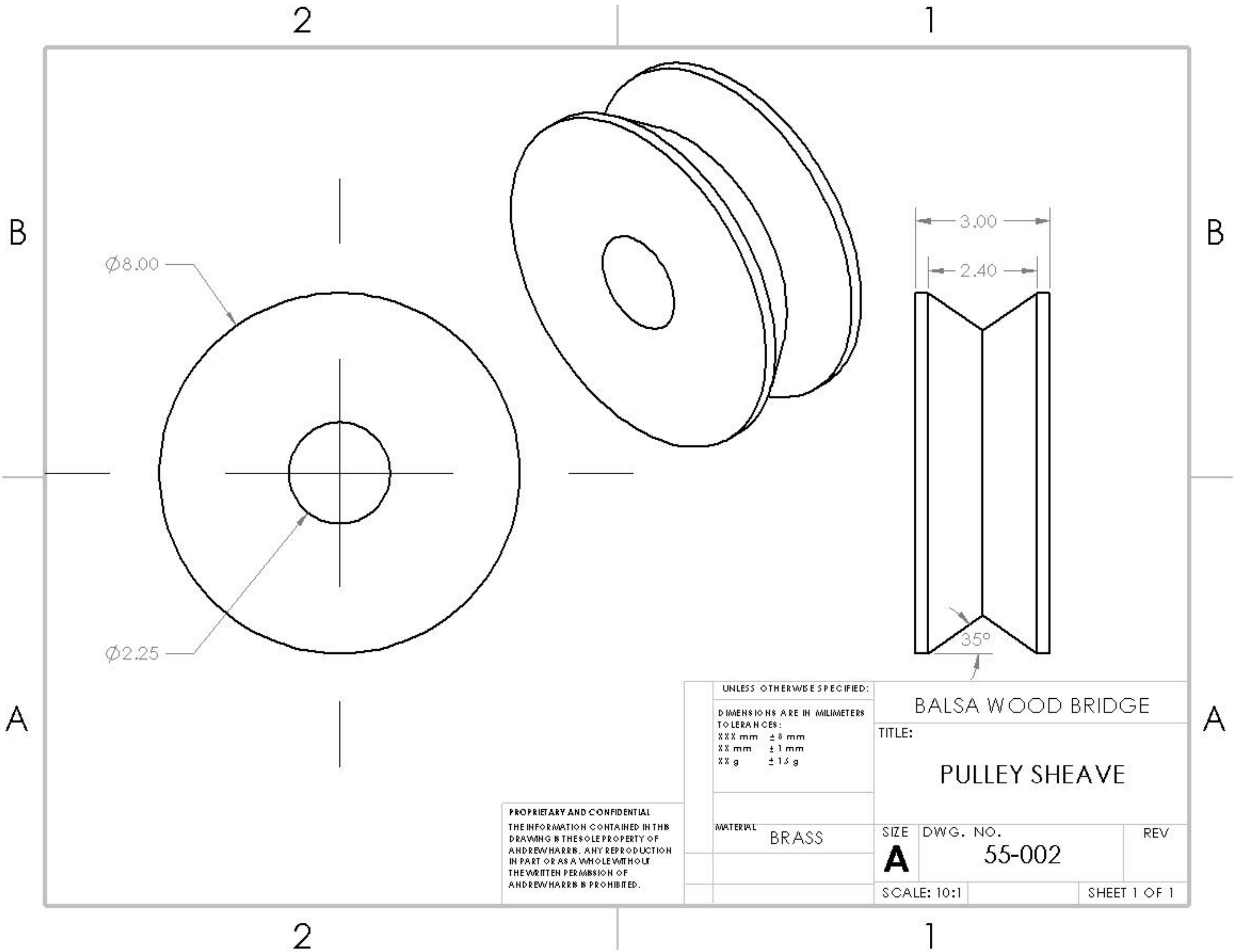
Appendix B – SPOOL CAP



Appendix B – PULLEY HANGER



Appendix B – PULLEY SHEAVE



APPENDIX C – Parts List and Costs

Appendix C - Parts List

Part Number	Qty	Part Description	Source	Cost	Disposition
50-001	1	Gorilla Wood Glue, 4 ounce Bottle,	Amazon.com	6.99	Glue Assemblies Together
55-003	8	Brass Pulleys	Etsy.com	$4.50	Brass Pulleys
20-003 20-002 20-007 20-008 20-012 20-011 20-013	2	Balsa Wood 1/4 X 1/4 X 36in (10)	Amazon.com	$16.50 $9.50 Shipping	¼” stock material
20-004 20-001	1	Balsa Wood 3/8 X 3/8 X 36 (6)	Amazon.com	$16.50 $9.00 Shipping	3/8” stock material
20-005 20-006 20-020 20-035	1	Balsa Wood Sheets, 15 Pcs (150x100x2mm)	Amazon.com	$14.00 Free shipping	2mm stock sheets
20-009 20-031 20-034 20-036	1	6pcs 3 X 100 X 500mm Balsa Wood Sheets	Amazon.com	$27.00 Free shipping	3mm stock sheets
55-004	1	PARACORD PLANET 95	Amazon.com	$7.50 Free shipping	1.8mm paracord
20-032	1	Wooden Dowel Rods – 1 x 36 Inch	Amazon.com	$13.90 Free Shipping	1in circular dowel
20-033	1	1/4-Inch x 12-Inch, 10-Pack Wooden Dowel Rods	Amazon.com	$6.11 Free Shipping	1/4in circular dowel

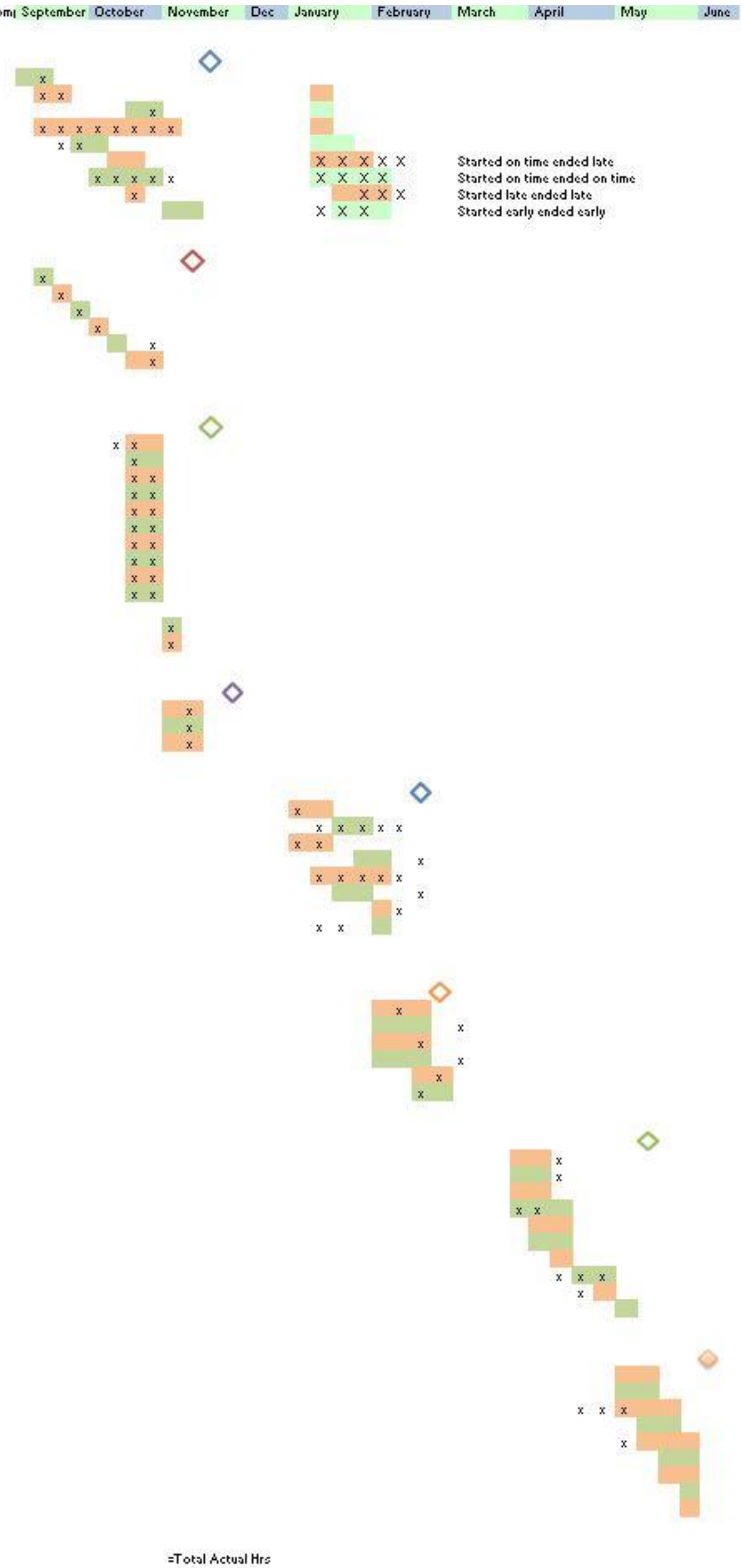
APPENDIX D – Budget

Appendix D - Project Budget

Item	Qty	Description	Cost
Parts Total	1	All parts needed for assembly	$165

APPENDIX E – Schedules

TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Comp
1	Proposal*			
1a	Outline	2	2	
1b	Intro	2	2	
1c	Methods	2	1	
1d	Analysis	8	15	
1e	Discussion	1	2	
1f	Parts and Budget			
1g	Drawings	5	10	
1h	Schedule	1	1	
1i	Summary & Appx			
	subtotal:	21	33	
2	Analyses			
2a	Static Equilibrium			
2b	Internal Forces			
2c	Internal Forces			
2d	Required member cross section			
2e	pulleys			
2f	Bridge lift tower			
	subtotal:	0	0	
3	Documentation			
3a	Truss Top and Bottom DWG	0.2	0.4	
3b	Vertical and Cross DWG	0.2	0.4	
3c	Truss Assembly DWG	0.2	0.4	
3d	Bridge Assembly DWG	0.2	0.4	
3e	Tower Vertical, Side, Cross	0.2	0.4	
3f	Tower Assembly DWG	0.2	0.4	
3g	Pulley DWG	0.2	0.4	
3h	Cord Cleat DWG	0.2	0.4	
3i	Gusset DWG	0.2	0.4	
3j	Road DWG	0.2	0.4	
3k				
3l	ANSIY14.5 Compl	0.1	0.2	
3m	Make Object Files	0.1	0.2	
	subtotal:	2.2	4.4	
4	Proposal Mods			
4a	Project Schedule	2	3	
4b	Project Parts Iventory	1	2	
4c	Crit Des Review*	5	5	
	subtotal:	8	10	
7	Part Construction			
7a	Buy Balsa Wood and Glue	0.1	0.2	
7b	Cut Wood to Dimensions	3	6	
7c	Buy Pulleys and Rope	0.1	0.1	
7d	Drill hole for bridge	0.5	0.1	
7e	Design fixtures for assembly	4	6	
7f	Cut out Gussets and Cleat	0.5	1	
7g	Take Part Pictures	0.1	0.1	
7h	Update Website	2	2	
7i	Manufacture Plan*	4		
	subtotal:	14.3	15.5	
9	Device Construct			
9a	Assemble Truss	2	1	
9b	Assemble Bridge	2	3	
9c	Assemble Towers	3	2	
9d	Assemble Pulley system	2	0.5	
9e	Take Dev Pictures	0.1	0.1	
9f	Update Website	1	2	
	subtotal:	10.1	8.6	
10	Device Evaluation			
10a	List Parameters	1	0.5	
10b	Design Test&Scope	1	1	
10c	Obtain resources	2		
10d	Make test sheets	1	2	
10e	Plan analyses	3		
10f	Instrument Bridge	1		
10g	Test Plan*	2		
10h	Perform Evaluation	1	1.5	
10i	Take Testing Pics	0.2	0.2	
10h	Update Website	1		
	subtotal:	13.2	5.2	
11	489 Deliverables			
11a	Get Report Guide	1		
11b	Make Rep Outline	2		
11c	Write Report	6	4	
11d	Make Slide Outline	2		
11e	Create Presentation	6	3	
11f	Make CD Deliv. List	2		
11e	Write 495 CD parts	2		
11f	Update Website	1		
11g	Project CD*	1		
	subtotal:	23	7	
	Total Est. Hours=	91.8	83.7	
Labor$	100	9180		



APPENDIX F – Expertise and Resources

APPENDIX G – Testing Report

MET489C TestProcedures.docx

APPENDIX H – Resume

Andrew Harris

Work Experience

Kitchen Lead - The Early Bird Eatery **May 2019 – Current**

- Responsible for inventory/ordering
- Ensuring prep is completed in a clean and timely manner
- Ability to produce high quality food using multiple techniques
- Close attention to detail in high pressure situations

Line Cook- The Roadhouse Bar and Grill **December 2017- March 2019**

- Proficient with group communication and task management
- Ability to perform and remain focused in high pressure situations
- Knowledge of basic knife skills and etiquette
- Manage a clean and organized work area

Grill & Pantry cook- Sip wine bar/ Dinner restaurant **June 2018 - August 2018**
December 2015 - August 2016

- Consistently completed tasks in a timely manner
- Maintained a clean and functioning work area
- Knowledgeable in proper cooking procedure
- Make and complete a daily prep list

General Laborer- Santa Trucking and Excavating **June 2017- August 2017**

- Preformed in multiple aspects of grading to achieve project and city specs
- Knowledgeable when determining the cut or fill in a landscape
- Learned basic operations of on-site equipment, including Roller, Backhoe, and excavator
- Used a shovel and rake daily
- Set catch basins and laid pipe

Basic Machinist- Handl Machine Shop **December 2016- January 2017**

- Ran CNC machines and changed out each part after each operation
- Examined finished parts and determined if each was in tolerance
- Deburred parts with any sharp edges or excess shavings

General Laborer- Twin Rivers Golf Course **September 2012- December 2015**

- Cleaned and maintained golf carts
- Manage driving range
- Collected garbage across course

Education and Athletics

- **CWU Mechanical Engineering Technology** — **September 2016- Current**
- **CWU Track and Field** — **September 2016- Current**

References

The Early Bird Eatery – Jeannie Bayles (509) 669-2211

The Roadhouse Grill - Chef Miguel (509) 910-3351

Sip at the wine bar and dinner restaurant – Chef Kim (206) 940-7361