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Balsa Wood Bridge

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By

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CWU MET 2021 Balsa Wood Bridge by Anndie Watterson

A model for a strong bridge that could span a set distance and rise up to allow for passage underneath was requested, and specifications for the design were given. The model bridge was designed out of balsa wood to meet all the requirements. Using structural and material analysis and simple mechanical designs, a bridge was designed and constructed out of balsa wood, wood glue, and metal components used for articulation that met all of the criteria set by the assigner. The bridge was tested to ensure all specifications were met. The resulting bridge can hold 20kg of weight suspended from the center and rise 1400mm above rest, while remaining locked in the raised position. It spans the 400mm distance between the two abutments it was designed to rest on and allows for a car to pass over the bridge without raising over 25mm at any point. The overall weight of the bridge did not exceed 85 grams, and the road deck rested within 12mm of the abutment, allowing for the model cars to access the bridge deck with ease. Aside from an 8mm hole in the road deck for testing, no other obstructions were present. The resulting product was a functional and effective model of a bridge that, when tested, successfully held the required weight and could also easily be raised, locked, and lowered for passage beneath the bridge.

Contents

Testing Report

Introduction

The testing for the balsa wood bridge was conducted in accordance with the required parameters set by the bridge assignment, which can be found in appendix G5.2. There were 4 tests completed on the bridge, which were done in the following order: road deck functionality, weight and length parameters, articulation functionality, and load support. Standard metric measuring devices were used to gather all data for the tests. The road deck functionality test was designed to measure the curvature of the road deck and ensure that an object with specific parameters could pass over the bridge with no interruptions from the road deck, both of which were sufficient. Weight and length were the 2 parameters of the bridge measured in the weight and length test, both of which were within the required values. The articulation test ensured that the bridge could be raised the required height and remain raised on its own for 10 seconds. The change in height of the road deck during the test was the parameter of interest, and it passed both parts of the articulation test. The final test, the load support, measured the deflection of the road deck while it supported an increasing load, up until it exceeded the required load. The bridge supported the load and did not deflect more than .10 inches. The test procedures for the 4 tests can be found in appendices G1-4. Between the 4 tests, all required specs of the bridge were tested, and results were recorded in the test report sheet. All testing was completed during the Spring 2021 quarter and a schedule breakdown can be found in the appendices.

Method

All resources required for testing were owned or accessible by the engineer previously, therefore no excess budget was needed for testing. Derek Lund provided all materials not owned by the engineer and provided a location for testing to take place. All tests were recorded so that the results and proper procedure proof could be provided to those interested in the project. Recording was done with personal cell phones and tablets and was edited and shared from there. Because of a lack of machinery and tools, some tests were not as in depth as possible, however all required specifications were tested sufficiently. A metric measuring tape accurate to 1mm, a caliper accurate to .01 inches, a scale accurate to .01 grams, and a bathroom scale accurate to .1 pounds were used and defined the accuracy of the tests. All measurements were converted to metric units before recording. Data was recorded on a physical report guide in pen, and the only data manipulation was converting units and rounding when necessary between conversions. The data was then typed into a document and presented numerically with the exception of the deflection of the road deck measured in the load test, which was presented graphically.

Test procedures

Road deck functionality test procedure

The test procedure for the car crossover functionality test:

1. Collect equipment
    a. 25mm x 32mm block of wood to represent the “car”
    b. Tablet with a functioning camera
    c. The bridge, not including the brace
    d. A ruler that will be used to push the car
    e. A printed test report sheet and a pen
2. Take all the equipment to the designated testing table in the mud room of the Lund residence.

3. Set up the tablet using the free-standing case on the South West corner of the table with the camera app open
4. Place the bridge on the table 24 inches directly in front of the camera from the tablet, parallel to the tablet
5. Set the block on the right end of the bridge, "right" being determined by standing behind the tablet and looking at the bridge. The layout should look similar to what is pictured below (North is up)

6. While holding the ruler, start recording on the tablet.
7. Use the ruler to push the block across the entire bridge at a rate close to one in which the entire crossing takes roughly 5 seconds. Do not push the block off the bridge.
8. Turn the bridge 90 degrees counter-clockwise and move it within 12 inches of the camera so that the short end of the bridge is clearly visible on to the camera, similar to below (North is up)

9. Use the ruler to measure the height of the road deck in millimeters from the table to the top of the deck, standing to the side of the video to ensure the measurement taken is visible on the video.
10. Stop recording
11. Record the bridge deck height on the test report sheet. Use the camera of the tablet to take a picture of the sheet
12. Edit the video so that walking to and from the bridge is cut out and ensure that the bridge is well visible and centered in the video.
13. Compress the video and send it from the tablet along with the picture of the test report sheet via email to wattersona@cwu.edu. Use the "send from photos" feature and select the Microsoft Outlook app. Include in the email any issues that occurred during the test, or any changes or variations from the test procedure.

Length and height test procedure

The test procedure for the dimensions:
The following is a guide for testing the dimensions of the bridge. The test should take no more than 30 minutes including the time required to gather materials, and will take place in the Lund residence.

1. Collect equipment
    a. Metric measuring tape
    b. Hornady scale
    c. Phone with a camera and video capabilities
2. Take all the equipment to the designated testing table in the mud room of the Lund residence.
3. Set up the metric tape in linear, flat manner. Ensure that at least 50 centimeters of the tape is flat and linear.
4. Turn on the scale and set it near the tape. Ensure it is set to measure in grams and reads "0"
5. Place the bridge just above the tape, so that the measurements can be read out. Place one end exactly at 20 centimeters. The setup should look as it does in the photo below.

6. Start the video and hold the phone to video.
7. Capture the length of the bridge in the video.
8. Place the bridge on the scale centered and in a direction such that the long side of the bridge is perpendicular to the long side of the scale.
9. Wait until the weight has steadied and capture the weight in the video.
10. Stop the video.
11. Compress the video and send it from the tablet along with the picture of the test report sheet via email to wattersona@cwu.edu. Use the "send from photos" feature and select the Microsoft Outlook app. Include in the email any issues that occurred during the test, or any changes or variations from the test procedure.
12. Record the weight and length of the bridge on the testing sheet. Note that the length will be the difference of the largest number minus the smallest number (20cm) and should be noted in millimeters.

Load test procedure

1. Collect required equipment

   a. Bridge
   b. Bathroom scale
   c. 2-foot section of mule tape pull rope
   d. Small washer
   e. Small section of hay twine
   f. 5-gallon bucket
   g. Two equal height sections of corrugated pipe, at least 42 inches long
   h. Two 4-foot pieces of wood
   i. Metric measuring tape
   j. Pocket knife
   k. Cell phone
2. Bring all equipment to the area near the water spigot and hose in front of the Lund residence
3. Set up the two pieces of pipe within reach of the hose, and ensure they are level
4. Place the two pieces of wood across the top of the pipe 400 millimeters apart parallel to each other
5. Place the bridge perpendicular to the direction of the wood
6. Tie the two ends of the rope together and thread the washer onto the rope
7. Feed the rope through the hole in the center of the road deck of the bridge
8. Tie the rope to the handle of the bucket using the hay twine section. Steps 3-8 should look as shown below

9. Set up the phone on the tool boxes to the west of the setup, using rocks to ensure the phone will capture the test in the video

10. Begin filing up the bucket with water from the hose

11. Fill the bucket up until less than half an inch from the top of the bucket. If any part of the bridge fails at any point, immediately stop filling the bucket.

12. Once the bucket has been filled entirely or the bridge has failed, cut the twine with the knife and weigh the bucket on the bathroom scale with the water in it.

13. Record the weight of the bucket on the report sheet.

14. Compress the video and send it from the tablet along with the picture of the test report sheet via email to wattersona@cwu.edu. Use the “send from photos” feature and select the Microsoft Outlook app. Include in the email any issues that occurred during the test, or any changes or variations from the test procedure.

Articulation test procedure

1. Gather the required materials and take them to the office of the Lund residence, on the flat table top
    a. Metric measuring tape
    b. Bridge and brace, assembled together
    c. IPad
    d. Cell phone with stop watch app
2. Set up the IPad on the north west corner of the table so that it will capture the test, with the brace and bridge set up on the south east corner
3. Ensure that at least 50cm of the tape are rolled out, so that the height can easily be measured
4. Begin videoing, and raise the bridge to its maximum height
5. Measure the height of the bottom of the road deck from the resting position to the maximum height
6. Record that height on the test report sheet
7. Start the stop watch on the cell phone and allow it to count on at least 10 seconds in view of the camera
8. Stop the video
9. Compress the video and send it from the tablet along with the picture of the test report sheet via email to wattersona@cwu.edu. Use the “send from photos” feature and select the Microsoft Outlook app. Include in the email any issues that occurred during the test, or any changes or variations from the test procedure.

Deliverables:
All anticipated values, individual test success criteria, and overall test conclusion can be found in the completed test report sheet below. The same sheet was used to collect data in all 4 tests. Because of the simplicity of the tests, no green sheets were required. The only data calculations completed were unit conversions, which were done via an online conversion calculator.

Testing Report

Weight of bridge:

Less than 83 grams? (Y/N): Yes

Weight: 75.315 grams

Length of bridge:

At least 400 mm? (Y/N): Yes

Length: 442 mm.

Object capable of passing through bridge on road deck? (Y/N): Yes

Road deck within 12 mm of abutment? (Y/N): Yes

Height of road deck: 11.5 mm.

Road deck curvature:

Less than 25 mm? (Y/N): Yes.

Curvature: 5 mm.

Bridge raised at least 120 mm and locked for 10 seconds? (Y/N): Yes

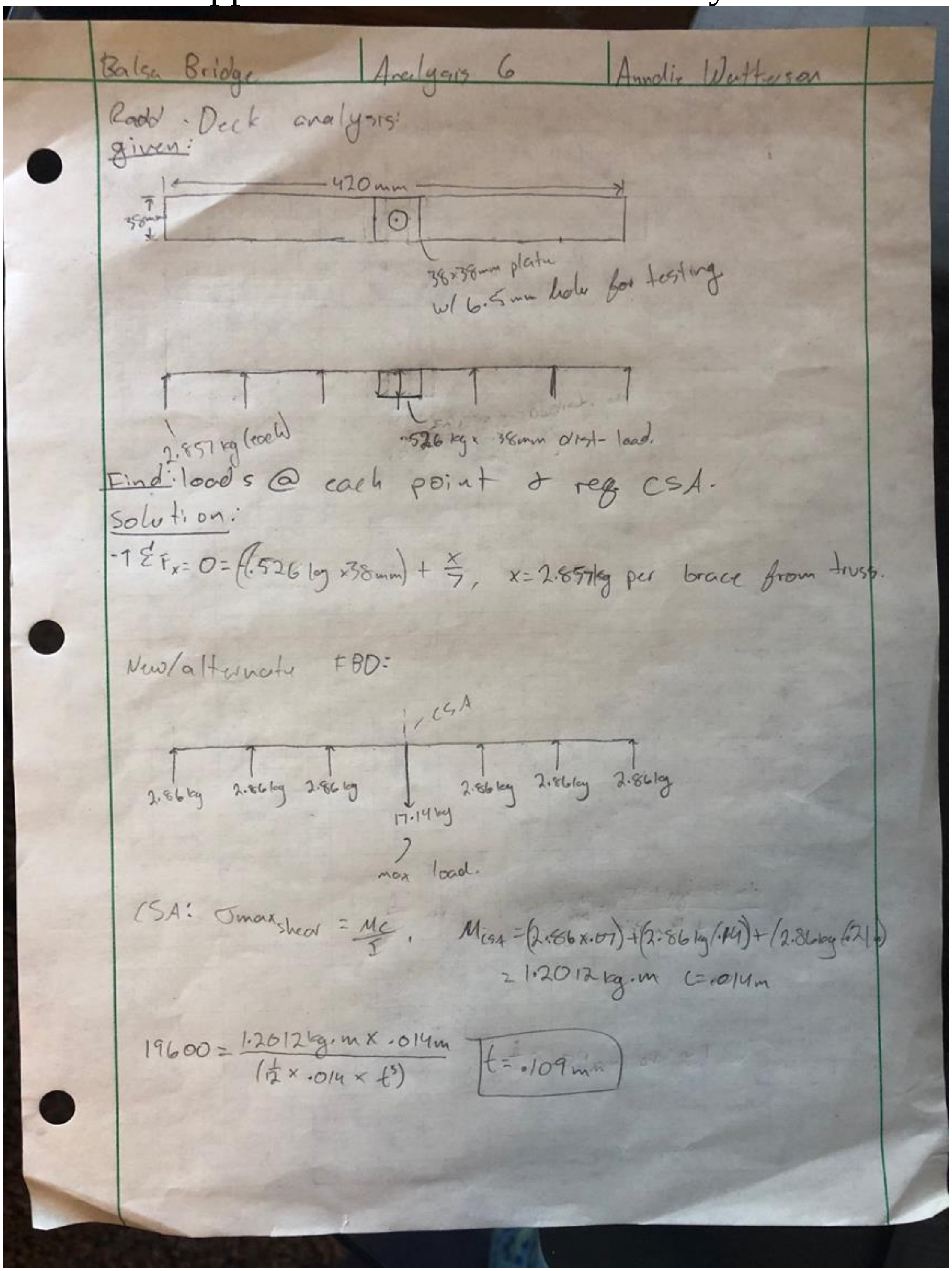
Height raised: 145 mm.

Bridge holds 18.9-20 kg of weight? (Y/N): Yes

Weight held: 20.4 kg.

Success criteria: if “yes” is answered to all questions above: Success

Appendix G1.1: Road deck analysis



Balsa Bridge | Analysis 6 | Annalie Wetterson

Road Deck analysis:

given:

420 mm

38mm

38x38mm plate w/ 6.5mm hole for testing

2.857 kg (each)

.526 kg x 38mm dist. load.

Find: loads @ each point & req CSA.

Solution:

$+\uparrow \sum F_y = 0 = (.526\text{ kg} \times 38\text{mm}) + \frac{x}{7}$, $x = 2.857$kg per brace from truss.

New/alternate FBD:

CSA

2.86kg 2.86kg 2.86kg 2.86kg 2.86kg 2.86kg

17.14kg

max load.

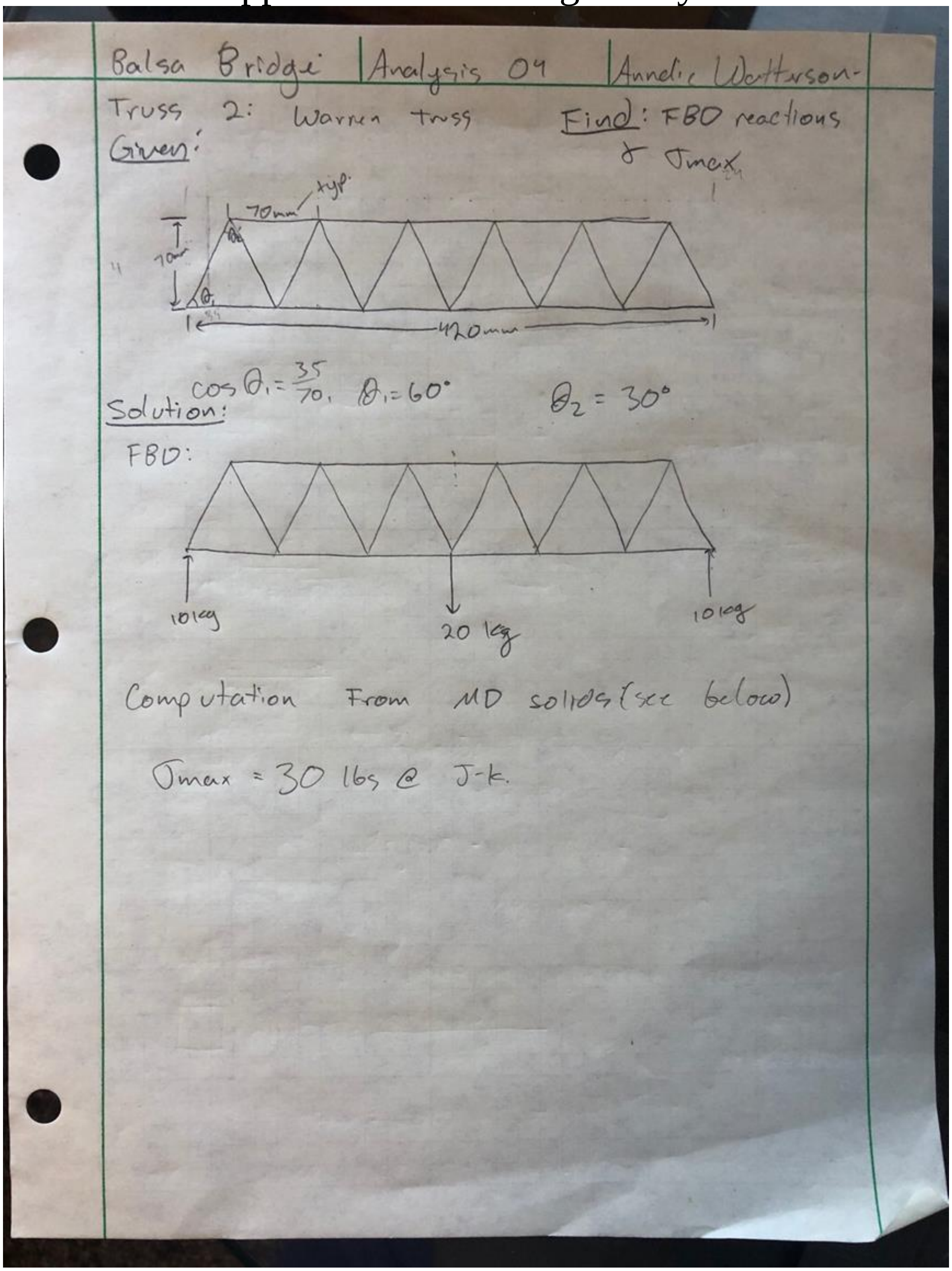
CSA: $\sigma_{max\,shear} = \frac{Mc}{I}$, $M_{CSA} = (2.86 \times .07) + (2.86\text{kg}(.14)) + (2.86\text{kg}(.21))$

$= 1.2012$ kg.m $c = .014$m

$$19600 = \frac{1.2012\text{ kg.m} \times .014\text{m}}{(\frac{1}{12} \times .014 \times t^3)}$$

$t = .109$ m

Appendix G1.2: Bridge analysis



Balsa Bridge | Analysis 04 | Annelie Watterson-

Truss 2: Warren truss

Find: FBD reactions & σ_{max}

Given:

$\cos\theta_1 = \frac{35}{70}$, $\theta_1 = 60°$ $\theta_2 = 30°$

Solution:

FBD:

Computation From MD solids (see below)

σ_{max} = 30 lbs @ J-k.

Appendix G2.1: Testing schedule

TASK: ID	Description	Est. (hrs)	Actual (hrs)	%Com	September	October	November	Dec	January	February	March	April
10	Device Evaluation											
10a	List Parameters	1	1									
10b	Design Test&Scope	1	3									
10c	Obtain resources	1	1									
10d	Make test sheets	1	1									
10e	Plan analyses		1									
10g	Test Plan		1									
10h	Perform Evaluation	1	3									
10i	Take Testing Pics	1	1									
10h	Update Website	1	1									

1. INTRODUCTION

a. Description

The structure will span a gap while supporting a load, and allow for moving structures to move across perpendicular to the gap, after the bridge is raised and held in the raised position.

b. Motivation

The project was motivated by a need for a bridge to span a gap and support a load, as well as rise up and allow for passage underneath.

c. Function Statement

The bridge will allow for an object to pass over a gap and support a load.

d. Requirements

The requirements for the bridge include mostly size and weight specifications, as well as some functional requirements. All requirements were given to the builder by the interested party, with specific numeric and function results outlined. These parameters are accountable in the testing process. They are as follows:

- The bridge itself must be built of only balsa wood and glue. The articulation device can be made from any material.
- The bridge without the articulation device must weigh less than 85 grams
- It must clear a 400 mm span between abutments and fit between 60 mm abutments
- A 38mm wide bridge deck is required to span the entire 400 mm distance.
- The bridge deck must be centered in the bridge, within 2mm.
- The 38 mm wide smooth centered bridge deck must come within 12 mm of the abutments
- The bridge deck must have an 8 mm hole in the center which will be used for testing
- At least 50% of the bridge must raise 280 mm above resting position.
- The bridge must support 18.9 to 20 kg of weight, supported by a. 38mmx38mmx6mm plate in the center of the bridge deck.
- The bridge must be able to maintain the raised position freely for 10 seconds

e. Engineering Merit:

The project was completed using engineering techniques acquired at Central Washington University, following standard MET code of conduct and ethics. The project is the best resulting design of the design and decision making process.

f. Scope of Effort

This project will deal with the bridge and articulation portion of the bridge only. All testing will be completed by the engineer. Parts will be manufactured from stock or purchased as completed. Purchasing of parts and construction materials necessary for the construction for the bridge was also done by the engineer.

g. Success Criteria

The bridge spans distance, supports a load, and articulates as specified. All requirements outlined above must be met in order for the bridge to be called successful. The two most important requirements are the weight and load support. A bridge that does not meet the weight requirements will not be tested further, and a bridge that does not hold at least the specified weight will be considered a failure. The other requirements are necessary in the best interest of the builder. Testing success criteria is outlined in the testing report in appendix G.

2. DESIGN & ANALYSIS

a. Approach:

Because of a lack of experience building bridges, the design process began with several truss designs that were analyzed to determine the best option. The first truss was a design that was drawn by the engineer with no reference, and the second was drawn based on a Warren style truss. Analyses of the two lead to the decision to go with the Warren truss.

b. Design Description

The Warren truss that the second design is based on can be described as a series of equilateral, or close to equilateral triangles

c. Benchmark

There have been many balsa wood bridge design assignments or competitions prior to this one. Those designs coupled with the given parameters set the benchmark for the project. The benchmark can be simply described as designing a bridge that can successfully hold a given weight and raise and lock at a certain height. Previous balsa bridges were referenced in the design process.

d. Performance Predictions

It was predicted that the bridge will hold at least 20 kilograms of weight. If the bridge does fail, it is likely to do so at the point connecting the top of the central-most triangles on the trusses. This point was found to be under the most strain in the entirety of the truss.

e. Description of Analysis

Analyses of different components of the bridge were completed and are shown below. The completed calculations were used to determine a design that meets all requirements specified with an optimal design for cost and performance. These analyses were used to determine several design parameters, such as the cross sectional area of components, and required materials for objects that do not have a specified material.

f. Scope of Testing and Evaluation

The bridge was tested to ensure all given parameters and requirements were met. The bridge was first weighed and measured, and then raised and locked to show the articulating component. It was then tested to hold the required weight. The results of testing were documented and provided in Appendix G

g. Analysis

The following analyses were determined using the RADD outline as exemplified in the CWU MET program.

Analysis 1

Appendix A-1 begins to illustrate how the bridge will withstand the weight test requirement. It is a cross-sectional area analysis for 2.4mmx2.4mm balsa wood, which can be purchased in that dimension, with an applied factor of safety to achieve a maximum shear stress allowable at any point on the bridge, as shown in the drawing. The free body diagram outlines how the bridge design will be analyzed at points of interest in the following appendices.

Analysis 2

Appendix A-2 demonstrates the pulley system that will be used to raise the bridge as required. The analysis of the system shows the mass of the bridge that needs to be lifted, and held by the pulleys and ropes. Both the pulleys and the ropes must withstand a force .266 Newtons, considering a factor of safety of 4.

Analysis 3

Appendix A-3 shows the brace that will be used to lift the truss with the pulley system analyzed in appendix A-2. The brace was sketched, and a free body diagram was completed and solved. A cross-sectional area analysis was also completed to determine the minimum thickness required to construct the brace with.

Analysis A-4

Appendix A-4 shows the second truss option. It is sketched, and a free body diagram is determined from that sketch. The truss is also added into MD solids and analyzed, with those results following the initial sketch in appendix A-4.

Analysis A-5

Appendix A-5 is a breakdown of the cross-sectional area for truss number 2. The analysis takes the maximum axial load shown in Appendix A-4a and A-4b and uses it to determine the required cross sectional area of the truss parts.

Analysis A-6

Appendix A-6 is an analysis of the road deck, assuming the weight that will be used for the test is applied. The bridge deck is sketched, and a free body diagram is solved, leaving a maximum load in the center of the deck. This load is then used in a cross sectional area analysis, with the hole in the deck taken into consideration, to calculate the required thickness of the road deck at that point.

Analysis A-7

Appendix A-7 covers the mass of the overall truss, including the glue, to ensure it meets the mass requirement given. The volume of the part is from the SolidWorks drawing, and the density of wood glue was pulled from a material safety data sheet of the glue.

Analysis A-8

Appendix A-8 is a torsional analysis of the high speed steel shaft that will be used in the lifting mechanism. The mass of the bridge from analysis A-7 is used to calculate the torque applied to the shaft in order to lift it. The results of the analysis show that the high speed steel shaft is sufficient.

Analysis A9
Appendix A-9 is a bending analysis of the vertical structures of the base. The analysis is a free body diagram of the base, solved for all the forces, which is used to calculate the moments at the points of interest. The larger of the two moments is used to solve for the stress at that point.

Analysis A-10
Appendix A-10 is an analysis of the pin used to hold the pulleys to the brace. The forces used in the pin analysis are from appendix A-3. It was determined that the pin would not break under the weight of the lifted bridge.

Analysis A-11
Appendix A-11 is a torsional analysis of the pin that will hold the lock in place to the locking gear. The analysis ensures that the pin will not fail when the lock is in place, supporting the maximum load it will need to support.

Analysis A-12
Appendix A-12 determines the required cross-sectional area for the piece of wood that will hold the crank mechanism in place. A free body diagram is drawn, and the maximum load that the piece will endure is calculated. This load is used to determine the required cross sectional area.

Analysis A-13
Appendix A-13 is an analysis that was completed during construction. After a design change request came about due to the extreme variation in the density of the actual wood used compared to the value used in prior analyses, it was determined that thicker truss members should be used. This analysis shows the new calculations compared to what was originally calculated.

h. Device: Parts, Shapes, and Conformation

The analyses listed above were used to determine the shape and size of the parts used in the project. Structural materials used in bridges typically have a safety factor between 4 and 6. Because the bridge is a model and no lives would be at risk in the case of a failure, a lower factor of safety was used. The factors of safety differed depending on the component, and can be seen in several analyses where applicable.

i. Device Assembly

The assembly of the device was outlined in the drawing tree. The assembly used only the specified allowed materials for the bridge portion, which was wood glue. The Brace was assembled using various fasteners and materials, as these were not specified and designed to perform well with various materials. The assembly took place in sections with the trusses and bridge being designed first, followed by the brace and the overall assembly of the completed project.

j. Technical Risk Analysis

The obvious risk of the produced solution was that it would not meet parameters. Thorough analyses and research was done during the design process to ensure that was not the case. Many parameters, such as size, weight, and the specific articulating specifications were met simply by building the device as outlined. The weight holding parameter, however, could not be tested until the bridge was completed, and therefore posed as a more serious challenge with higher risks.

k. Failure Mode Analysis

The points of interest of the bridge were found, and analyses were completed to determine the cross sectional area required to ensure that component would not fail under the given stresses. A factor of safety was applied to that analysis. All size and weight parameters were met in the design and assembly process, and were checked again after completing the bridge. Excess materials were tested to ensure that the numbers used in analyses were accurate and appropriate for the actual material used.

l. Operation Limits and Safety

There were no major safety concerns that were heightened during the construction and testing of this project. Personal protective equipment was used during testing in the case that the wood ruptured, eyes would be protected. The cutting of the balsa wood involved a box cutter, which offered potential risk of lacerations, however the handler met safety requirements outlined in the CWU handbook, despite being completed off campus, by having a competent person present to assist in the case of an accident.

3. METHODS & CONSTRUCTION

a. Methods

The truss portion of this device was designed using predominantly statics and strength of materials concepts. The material properties were used to determine stresses and, in turn, the dimensions of all parts. Static concepts were used to analyze the bridge and brace components as a whole, to ensure it would not fail. Truss analyses were assisted by the use of the online analysis program MDSolids. The resulting analyses from the program were shown and used for further analysis on points of interest. SolidWorks was used to estimate the weight of the bridge, by building the appropriate model and using the mass properties feature to get the volume. The volume was used in conjunction with the known properties of balsa wood and glue to estimate the end weight of the truss. After materials arrived, they were weighed to get an actual density. Previous analyses were based on online sources of balsa weight, which varies greatly, so a more accurate weight was desired due to weight being a critical specification for the project. The new weight was then applied to find the mass per unit. This mass was applied to the known accurate volume of the bridge, to ensure it was not nearing the weight limit.

Process Decisions: The projects was manufactured using wood glue and simple clamps to fasten pieces together. Metal pieces were also used in the articulating components, and were applied with pins. The material decision for the truss was reached by completed analyses and optimizing the design to meet the parameters. The two parameters that worked against each other were weight and strength. Designing a bridge that weighs less than 83 grams OR holds more than 20 kilograms each, but designing one that does both was much more challenging. The cross-sectional area of the truss pieces was optimized to a certain point use as much of the allowed weight as possible without coming too close to going over, given that the weight may vary due to the material density variations. After receiving the actual wood that would be used in construction, the true weight of the wood was determined to be much less than what was used in calculations. This value was used to change the design.

Decisions in materials were reached by listing the available materials, and considering how much manufacturing would be required to meet the required dimensions. Gluing multiple sheets together length-wise for the truss was not an option due to the added weight and unknown change of material properties, so finding material that was thicker than the required pieces was necessary. Using glue to fasten the truss pieces together was a specification of the bridge.

The design strength was optimized by coming up with several truss design options which were analyzed thoroughly, and determining which would be best. One design was a product of only the engineer. The other was a result of a commonly use, successful bridge truss design; the warren truss. The overall truss decision was based on the strength and size of the bridge and on how efficient it was to build and assemble into the articulating brace. The first bridge was extremely tall, and would have been difficult to make meet parameters of articulation without making a larger, and therefore more expensive brace. The truss also did not have any previous known uses, and therefore the overall strength could not be referenced. The combination of factors acting against the first bridge design made the decision easy.

The design of the brace did not have multiple options. Because of the few parameters given for the brace, the main focus was to ensure it was functional, so the focus of the design was on how well it would hold the bridge, while keeping the cost in mind.

b. Construction

i. Description:

The bridge was built in 2 major sections: the bridge and the brace. The bridge was constructed entirely of wood and glue, of fully manufactured parts. The brace was a composition of wood, metal, and glue, and of manufactured and purchased parts. The design and construction was completed by the builder, using resources that were already possessed or ordered online. The truss pieces were assembled from balsa wood sheets that were cut to size using a straight edge and a box cutter. The brace was composed of remaining materials to help reduce the cost of the materials. Materials were purchased in bulk, which was the cheapest option.

ii. Drawing Tree, Drawing ID's

The drawing tree in Appendix B outlines the order and manner in which items were constructed. This process was determined by considering which items had parameters that were more critical. Because a majority of the testing is done on the bridge itself, that was completed first. Some testing was scheduled to be completed on the truss during the construction process to allow time to make design changes if needed. Following the completion of the bridge, the brace construction was started. The brace has little parameters, and is only checked for functionality. If scheduling or budget became an issue, changes to the brace could be made without altering the overall success of the bridge. The drawing tree shows the two main subassemblies, as well as the subassemblies that occurred within those main subassemblies. Aside from one schedule change due to parts arriving late, the order of construction was followed closely.

iii. Parts:

The parts were grouped into 2 main categories; manufactured and purchased. Although all parts were purchased, those that did not require any additional manufacturing were considered to be purchased, while all that were manufactured from stock or needed additional modifications were considered to be manufactured. Of the manufactured parts, there was a group of wood parts and a group of metal parts. The wood parts were manufactured first, followed by the metal. All parts were manufactured prior to any construction. Some manufactured parts were on hand, and at no cost. Of the ordered bulk materials, about 75% was used in the construction of the bridge. Of that 75%, approximately 10% was scraped parts.

iv. Manufacturing Issues

The components of the truss and bridge were fairly small with tight tolerances. These were difficult to manufacture, and a few parts were tossed out due to not meeting specifications. One major issue was that the purchased wood was slightly over the needed dimension. The wood was difficult to successfully cut perfectly straight, and therefore thought was put into whether it was worth leaving the excess wood on one dimension. The obvious effect this would have on the project was the weight, as it would make it much heavier. The original design did allow for some wiggle room on the weight, which was based on a researched density of balsa wood. The actual weight of the wood used was significantly less than this calculated weight, so it was decided to leave the excess wood. This change in weight also lead to a re-design of the truss pieces, outlined in appendix A-13. The smaller pieces were easier to manufacture correctly, and there were significantly more small pieces than larger pieces, so the excess weight was not significant and did not affect the overall weight enough to put the assembly over the specified maximum weight. It was also difficult to ensure that excess glue did not get on any component where not required.

The excess glue would add extra weight if left on, and would damage the wood if it were to be removed. A box cutter was used to carefully remove the bulk of the excess glue that did not serve any structural purpose.

v. Discussion of Assembly

The bridge was composed first in 2 subassemblies; the road deck and the trusses. After both were done, the bridge was finished by constructing the subassemblies together. In addition to the truss and the road deck, support pieces were also designed to be used to construct the bridge portion. The brace is made up of 2 subassemblies; the brace structure and the crank mechanism. The crank mechanism was made first, followed by the brace structure, and the overall assembly of the brace. The brace and bridge can be assembled and disassembled freely, as it is required for testing that the bridge be removed from the brace. Because of a delay in parts, the crank mechanism of the brace was started first, but not finished, as the wood arrived shortly after and the truss and brace construction was started from the top, as planned. This kept the project on schedule despite the unexpected delays in shipping.

4. TESTING

a. Introduction:

The testing of the bridge was completed as outlined in the specifications for the project. Functionality checks were performed, as well as numerical measurements recorded. A weight was added to the center of the road deck via rope, and the bridge was tested to hold 20 kilograms. The size and weight of the bridge itself were also measured, as specifications for these aspects were given. The bridge was also lifted by the mechanism to a height of at least 140 millimeters. All of the aspects that were tested were requirements of the bridge as given to the engineer. Each specification was confirmed in some way throughout the testing process. No additional component of the bridge were recommended to be tested by the engineer.

b. Method/Approach:

The size and weight specifications were checked by simply measuring the bridge. The articulation requirement was checked beforehand by raising the bridge to its maximum height and measuring the change of height in the bridge deck. Road deck functionality was checked using a single test session that focused on the height and ability to cross over. Testing the load requirement was done separately and following all other tests. The required load was applied to the center of the road deck with a metal plate and a bolt. All measuring devices used measured in the correct units, aside from the scale used to measure the load that the bridge supported. That scale measured in pounds, and the resulting value was converted to kilograms and recorded. A rope was used to complete the load test, which was rated as 1200-pound test. This exceeded the load it would be under and therefore failure of the rope during the test was not a concern.

c. Test Procedure:

The only major requirement for testing the bridge is the abutments on which it will sit to be tested, and the weights and parts that need to be added. All other aspects of testing/measuring the bridge require standard measurement devices. The road deck functionality test required an object of specific dimensions to be used. A roll of tape that was the correct width and height was used, because it was able to roll and was easy to demonstrate the successful function of the road deck. The weight and functionality of all components including the lifting mechanism were tested first. The weight test was conducted last, in the case that the bridge failed, to ensure that a failure of the bridge during that test would not prevent other components from being tested. Tests were completed in the following order: road deck functionality, weight and length, articulation height and functionality, and strength testing. No issues occurred during testing that impacted the bridged ability to continue to be tested.

d. Deliverables:

The results of the testing and measuring of the bridge were recorded in the testing report sheet in Appendix G, which outlines all requirements of the bridge. All test results were recorded on the same test sheet. Some results are simply pass/fail, such as holding the required weight and the car passing over, but others are a numerical result, like the size and height lifted by the mechanism. This numerical value was converted into a pass/fail system by determining if the parameter was over or under the specified maximum or minimum.

The first test that was conducted was a functionality check of the road deck, ensuring an object could pass over the entire bridge without obstruction, and a numerical measurement of the road deck at the end, ensuring it was less than 12 millimeters above the level surface it rested on. The object successfully crossed the bridge, and the road deck was less than 12 millimeters on the end. Both objectives were passed in this test. The weight and length of the bridge were tested following the road deck functionality test. The bridge was simply measured and weighed in millimeters and grams, respectively, and the results were recorded. Because the bridge was longer than the required 420 millimeters and lighter than the required 83 grams, both aspects of the test were passed.

5. BUDGET

a. Parts

The overall cost of the project, outlined in appendix D, was initially $45. Because of availability issues for the required amount of balsa wood, the budget was increased to $50 to allow for a bulk amount of wood to be purchased at a lower price-per-unit. The actual cost of the project was $45.27, including taxes and shipping. Aside from balsa wood, wood glue, and a few metal components, all other required materials and tools were on hand and did not cost money. Manufacturing was also done by the designer at no cost, which allowed for the budget to be accurately calculated based on the cost of materials, with little room for error should the construction process change, either in schedule or materials, as extra materials were available from the bulk order.

The bulk of this cost was attributed to the balsa wood. To save money, sheets of balsa wood were purchased and cut to the required dimensions. The additional portion of the budget was spent on glue and the metal materials used for the brace and locking mechanism. Some of the materials and the required tools were used in the project were owned by the manufacturer already, so therefore did not affect the budget. Excess balsa wood was used to construct the majority of the base, in order to use as much of the wood as possible. After the entire project was completed, approximately 35% of the balsa wood ordered was left over. To make a more accurate budget, given that balsa wood is not commonly used by the manufacturer and the excess will likely sit for some time, a more precise calculation could have been completed on how much was needed. While it was handy to have extra on hand, and some money was likely saved in buying a pre-determined package amount versus an exact order, more research could have been done to see if it was possible to cut down on costs and order balsa wood differently. All metal parts required were within budget, and the manufacturing required to make them work was at no cost.

The balsa wood was the only material that did not arrive on time. It was about a week later than anticipated, and therefore the schedule was edited to continue the construction process on other items until it arrived to stay on schedule.

b. Outsourcing

There will be no outsourcing for the production of the bridge. Materials were purchased as close to the final parameters as possible, while still being in budget, but no pieces were sent out to be manufactured after purchasing.

C. Labor

All labor will be completed by the designer at no cost. A limited amount of time was allotted for the project by the manufacturer which was more than adequate to complete the project, however time was considered.

d. Estimated Total Project Cost

The overall cost of the project as outlined in appendix C is $37.27. An additional $12.73 is granted to the project for any un-estimated costs, making the overall budget $50.

e. Funding Source

This project is funded by the designer. The process for achieving additional funds included showing research on where the funds were needed, and a risk analysis for said funds. No additional funds were needed, so this process was not needed.

6. Schedule

The overall schedule is outlined in the Gantt chart in appendix E. The schedule was subject to change if needed. Excess time was allotted for some processes to give the overall project schedule some breathing room. About 80%of this excess time was used up during all three portions of the project listed below. There was also a small amount of overlap in the three sections as some components needed to be tested which resulted in design changes during the construction process.

a. Design: the design portion of the project included designing, drawing, and analyzing the bridge. The analyses took a considerable amount of time, and the analyses that were completed during the construction process had the potential to delay the project. Enough spare time was allowed during this period that it would be completed on time, even if a delay were to happen. The design portion of the project was completed on schedule.

b. Construction: this portion includes the ordering of all parts and the construction of all components of the bridge. The ordering of parts was completed on time, however longer-than-expected shipping times were experienced for some parts. This slight delay led to a small change in the order in which parts were constructed. Because there was no specific set of parts that needed to be completed before others, this did not affect the end completion date. Another scheduling issue occurred when a new part drawing was needed, which was noticed during the construction process. This drawing took little time but did indeed eat into some of the excess time allotted for the entirety of the project. A small design change that applied to some of the parts of the trusses was also noticed. A minimal amount of time was spent considering the change, and a quick analysis was completed to assist in the decision-making process. Aside from these few small changes, no major delays to the schedule were encountered.

c. Testing: the testing portion required more time than just the time needed to complete the testing report. Tests were completed during the construction portion to ensure certain properties were met. This also ate into the excess time allotted in the construction process but did not exceed the amount set aside for these measurements. Time was also allotted to prepare for testing, which included gathering necessary materials for testing and preparing the test sheet. Procedures were written for each test to ensure that the test could be repeated and yield reasonably similar results. Time was also spent collecting resources and setting up materials needed for the test. After the actual test was completed, videos were edited and the report sheet was filled out and compiled into an entire testing report, which included all testing procedures, schedule, and overall test results. These tasks all made up the entire testing procedure, which was completed on time as predicted.

7. Project Management

The design and construction of the bridge was completed with the results of risk analyses in mind. Some of the major risks of the project were the cost, and the consequences of not finishing the bridge on time. Thorough planning and consideration was completed to ensure that risks were mitigated and the project would be a success. Prior planning was completed to ensure that if certain issues did arise, the project could continue on without falling behind schedule or going completely over budget. Some examples of this were being within a reasonable driving distance to the university in the case that remote access to software failed, and ensuring that parts and material could be delivered in a timely matter and returned if necessary.

a. Human Resources

The principle engineer designed and constructed the bridge with the assistance and guidance of mentors and a few third party sources. Employees of the material provider were relied on to deliver the materials in a timely matter, and the delivery personnel was expected to not damage the materials in the process. Both cases would result in delays in the process, and putting the project off schedule. The professor mentors offered assistance and guidance throughout the entire process via insight and helpful suggestions, as well as answering questions that arose from the engineer.

b. Physical Resources

The design and construction required a few physical resources which were already available to the engineer. A work area with a table and some simple clamps was required to construct the bridge. A box cutter and a straight edge were necessary to cut all the pieces to size for construction. Paper, pencils, and a calculator were necessary for the analyses and other calculations. Towels, chisels, and a vacuum were all necessary to both clean up the project after gluing to maintain quality, and to clean up areas following construction. There was no issue with a limit to physical resources for the project, but a limit would have resulted in a delay in schedule or an unplanned financial cost.

c. Soft Resources

Access to the internet, Microsoft Word, Microsoft Teams, Solidworks, and google were all used to complete the project. There were several instances of Solidworks being inaccessible, which resulted in time crunches to meet certain deadlines and travel to the campus, but overall there was no major delay in schedule or financial risk associated with issues with soft resources.

d. Financial Resources

There was no outside sponsor for the project. All funds were provided by the engineer. Financial risks included material damage, the necessity to drive to the University to use software, and unplanned purchases of necessities. In several instances, a lack of remote access did require that the engineer travel to the campus. Funds for miscellaneous costs were allotted in the budget, which were used for travel. This allowed for the project to remain within the budget. Going over budget would result in the engineer spending more personal money on the project.

8. DISCUSSION

a. Design:

The project evolved from a simple idea based on the given requirements to a bridge in construction, and finally to a functional bridge that raises and supports the required loads. A simple initial design and decision-making process was completed prior to any in-depth analyses being completed. This process was followed to come up with two rough truss designs, which were analyzed to make a decision on which to use. Following that decision, analyses were completed to specify and ensure that design requirements would be met by the end results for both the bridge and the brace. No further analyses were completed on the truss design that was not chosen.

The design of the bridge was completed first using structural analysis techniques and calculations, in addition to simple material analyses. An online structural analysis program, MD solids, was used to determine the weak spot in the design. This weak spot was used to determine the required dimensions for all components of the bridge. An additional analysis was conducted after materials were received to ensure the values used were accurately reflected in the analysis of the truss components. This showed that the wood ordered was much less dense than the estimated density used in analyses of the bridge up to that point. Because of this, the truss components were doubled up to maximize the amount of material used while still meeting the weight requirement. The density of the wood was less more than one half of the estimated density, but the amount of wood that was used was double the calculated amount. Because this lessoned the concern for failure of the bridge, no additional analyses were conducted using the new dimensions for bridge components.

The brace design followed, which included the articulation device. Structural analyses were also completed for the brace, and torsional and weight analyses for the crank. The design of the brace and articulating crank had a few changes due to parameters being clarified after the design process had begun, but the overall design process was completed on time and met all requirements. Some metal components that were originally included in the design were excluded and replaced with wood parts to save money. A simple test of the wood that would be used for the components aided in the design process and ensured they would not fail during use.

Time for changes to designs was taken into account and allotted during the construction process if needed. Much of this time was consumed by the decision to double up the trusses, however the project was still completed on time despite the decision being made later in the construction process.

b. Construction

The construction process has been outlined in the drawing tree and construction discussion portion of this proposal. This process was designed to organize and outline how the bridge was built. Delivery schedule, additional testing and design changes, allotted time for glue to dry, and access to the required tools were all things that were taken into consideration when determining the construction schedule.

The truss was completed first so that testing could be completed in enough time to make changes to the design and rebuild if necessary. If the testing were completed later on in the process, potential risks such as delivery time and lack of time are much more threatening to the on-time completion of the process compared to being noticed early on in the construction process. Simple material tests were also completed early on, making sure that the properties of the material were similar to the values used in analyses so that design changes could be made if needed before construction began. After completing all components of the trusses, the parts were weighed to ensure that the weight requirement was not being surpasses. The bridge weighed much less than half of the required maximum weight. Because of this, and because there is no maximum load requirement, the engineer decided to double up all the components of the bridge. This change essentially maximized the load that the bridge could take without changing materials or design, by maximizing the amount of material used.

The construction of the brace followed the truss construction. The parts had little to no tolerances or requirements from the specifications or the designer aside form functionality checks, so much less time was needed to manufacture the parts used for the brace. After all components were manufactured, the brace was constructed and tested for functionality.

While the schedule was set, it was flexible and allowed for minor changes to be made if needed. If one portion of the project was delayed in delivery, other parts were worked on while waiting. The components did not need to be completed in any particular order to complete the process, but priority of certain parts was considered when making the drawing tree and construction process, and therefore those processes were followed as closely as possible. Potential changes to scheduling and budget had been accounted for during the construction process

c. Testing

The project testing process has also been outlined in this report. This includes the order in which parameters will be checked or tested, the success criteria for each test, and the overall success criteria of the bridge. This order was determined by looking at the necessity of each parameter being met, and by the effect of failure on future tests. If the load support was tested first and the bridge failed, other parameters would not be able to be tested. The parameters that were tested were determined by specifications that were given to the engineer. Overall weight, height, functionality, and articulation are some of the areas that are dealt with in testing. A testing report sheet has been made to assist with organization for the testing process. The sheet also exhibits the results of each individual test and the overall passing or failing of the bridge as a whole, and can be found in appendix G. The only component that would disqualify a bridge from being tested was weight. If the bridge were over-weight, it would be disqualified from continuing testing.

Materials required for testing included standard measuring devices such as a scale, metric tape, stopwatch, and a micrometer. A roll of tape that represents a car and a push stick were needed for the road deck functionality test. The load support test required a 5-gallon bucket that could be filled with water, as it was advised that this weight would be just over the required 18.9-20kg load specified. A bolt, a washer, and a piece of rope to attach the bucket to the bolt were also needed for the load test. During the load test, a micrometer was used to measure the deflection in the road deck. The bucket of water was weighed after the test on a standard bathroom scale. Everything needed for the articulation functionality check was included in the brace, aside from the stopwatch.

The testing procedures, which outline materials needed and step-by-step instructions for completing tests, can be found in appendix G. As tests were completed, the testing report sheet was filled out and after all tests were completed, the sheet was analyzed to determine if the project passed or failed. Each test was passed, and therefore the entire bridge passed all aspects of the testing process. Methods were put in place to gather information in the event of a failure, so that an accurate and useful re-design could be completed if needed. They were not necessary, however, due to all tests being passed.

9. CONCLUSION

The resulting bridge was conceived and designed to meet all requirements given for the project. The requirements were designed to be checked during the construction process to ensure that all specifications regarding weight, size, functionality (excluding strength) and articulation can be ensured while constructing or upon completion of construction of the parts in question. The analyses completed to ensure the bridge would pass the load test were adequate, as it did indeed support the required amount of weight without failing. Additional tests of material used were completed to ensure that strength calculations were accurate within a reasonable tolerance, and that the analyses were sufficient for the estimations used.

The design of the project meets all function requirements listed in this proposal. Analyses, as taught by the CWU MET program, have been completed to outline and accurately predict the success of this project. Requirements of a successful senior project, outlined by CWU, have also been met. Structural analysis, project management, budget and scheduling, and many other aspects taught in the program are exemplified by this project and the process outlined for successful completion. The successful completion of the project was defined by a functional, complete project, a project which meets all requirements, and a report and website that support the project and outline the process followed. All three of these components were satisfied by the end result, and a presentation was completed to display the project to any audience.

10. ACKNOWLEDGEMENTS

Thank you to the following people for their assistance and knowledge lended to the engineer to help with this project:

Professor Charles Pringle acted as the mentor to the engineer for this project, offering advice and assistance to the engineer, assistant greatly in the design process and the overall project management and organization of the proposal.

Derek Lund provided tools and resources necessary for the construction process, as well as a space to work.

Central Washington University provided many resources for this project, including access to texts and software programs.

References

Project Management Body of Knowledge, 3th ed., Project Management Institute, Inc., 2004.

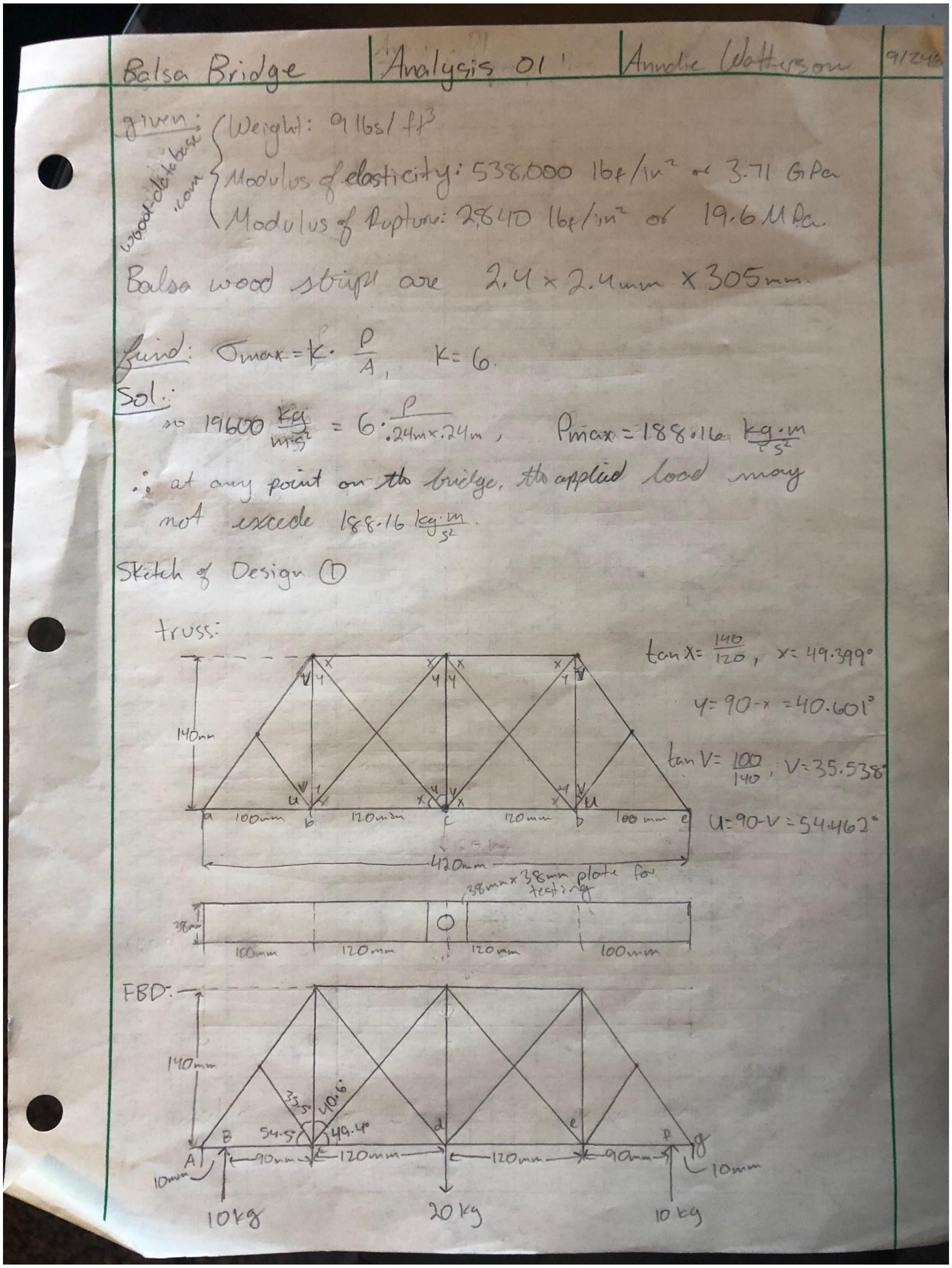
Machine Elements in Mechanical Design, 6th ed., by Mott; Prentice Hall Publ., 2018.

Engineering Mechanics Dynamics, 14th ed., by Hibbeler; Prentice Hall Publ., 2016.

https://www.wood-database.com/balsa/

APPENDIX A – Analysis

Appendix A-1 – Free Body Diagram of material



Balsa Bridge | Analysis 01 | Annalie Watterson

given: (wood-database.com)
Weight: 9 lbs/ft³
Modulus of elasticity: 538,000 lbf/in² or 3.71 GPa
Modulus of Rupture: 2,840 lbf/in² or 19.6 MPa

Balsa wood strips are 2.4 × 2.4 mm × 305 mm.

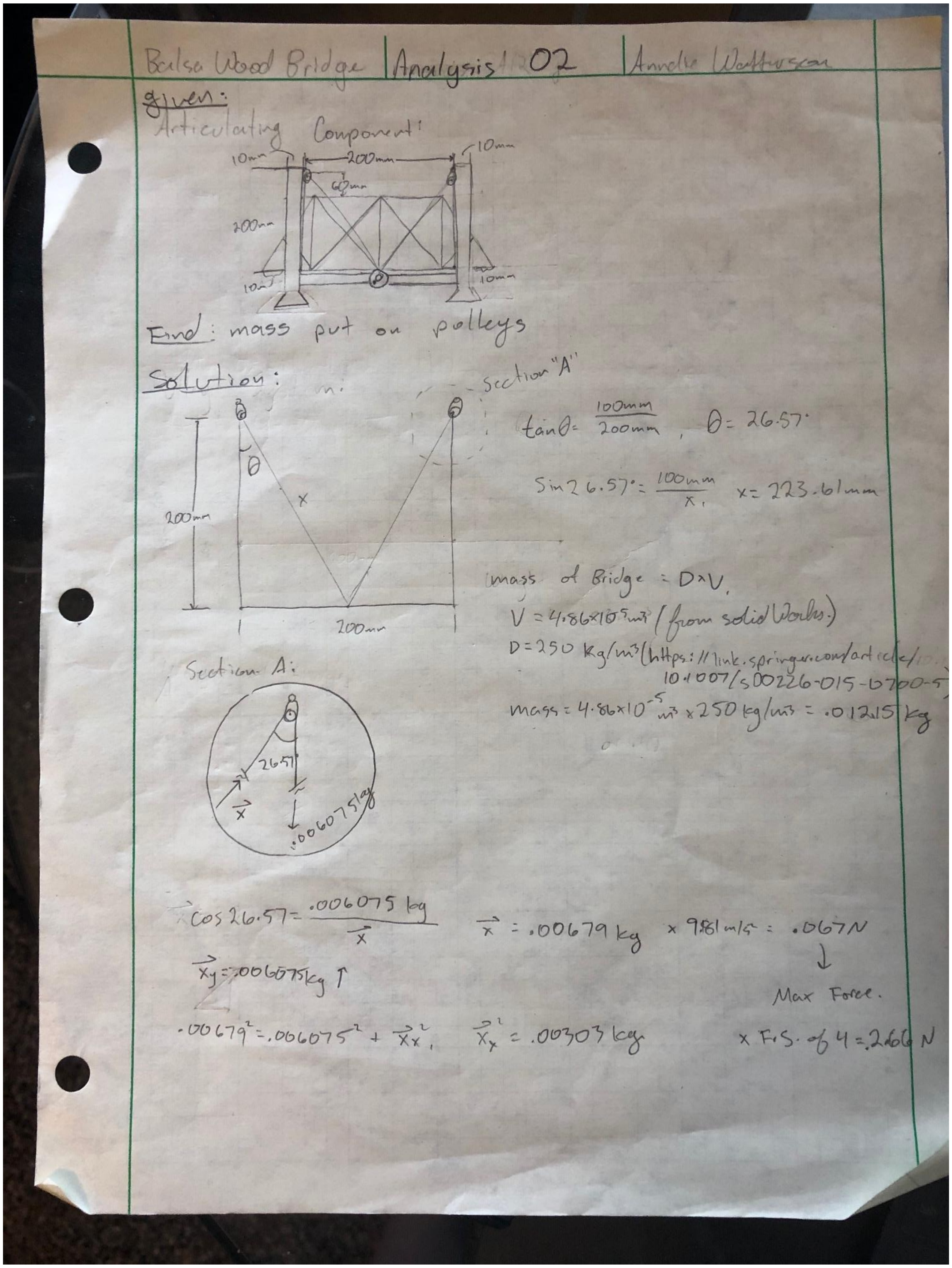
find: $\sigma_{max} = K \cdot \frac{P}{A}$, K = 6.

Sol.:
$19600 \frac{kg}{ms^2} = 6 \cdot \frac{P}{.24m \times .24m}$, $P_{max} = 188.16 \frac{kg \cdot m}{s^2}$

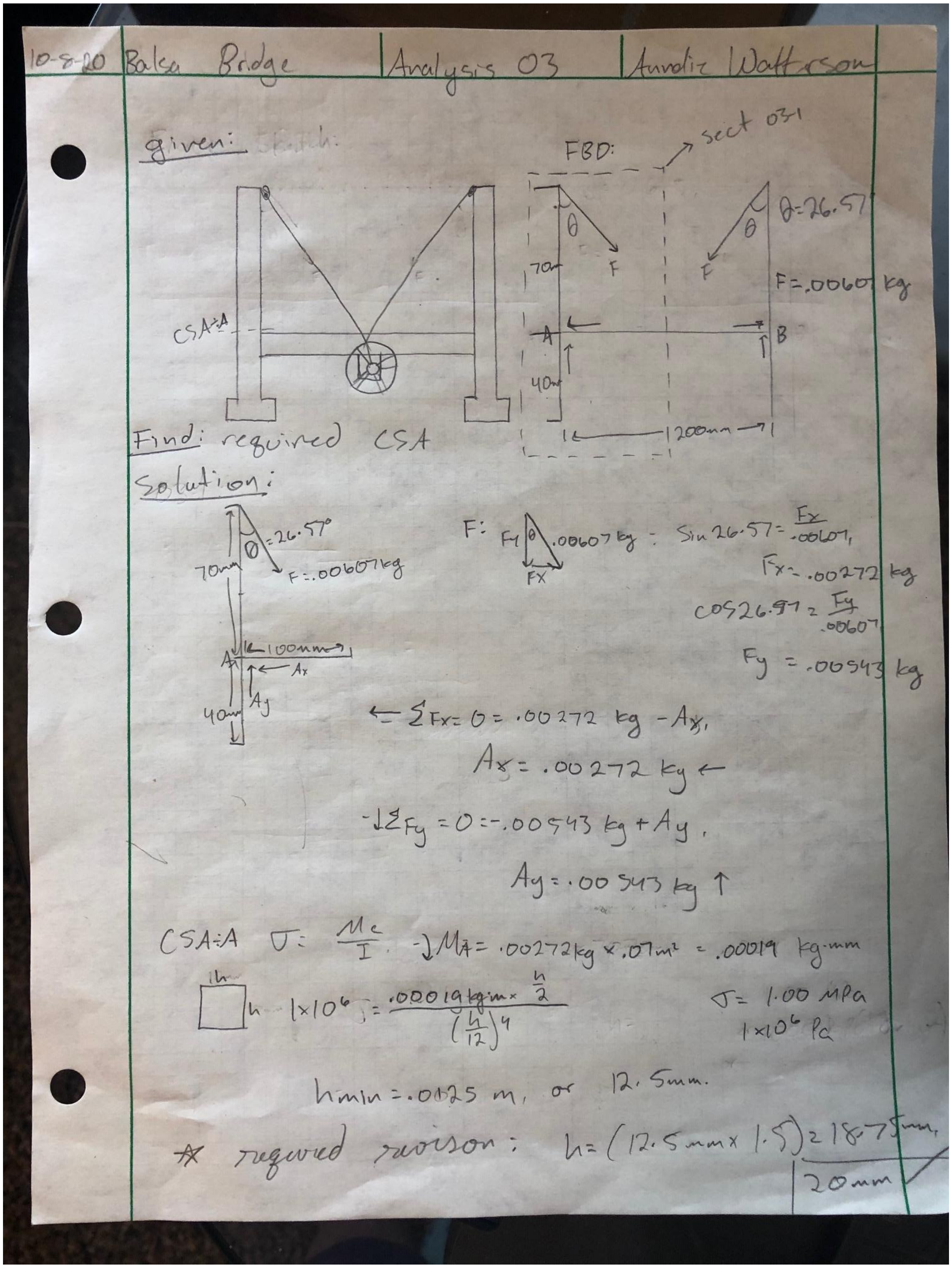
∴ at any point on the bridge, the applied load may not excede $188.16 \frac{kg \cdot m}{s^2}$.

Sketch of Design ①

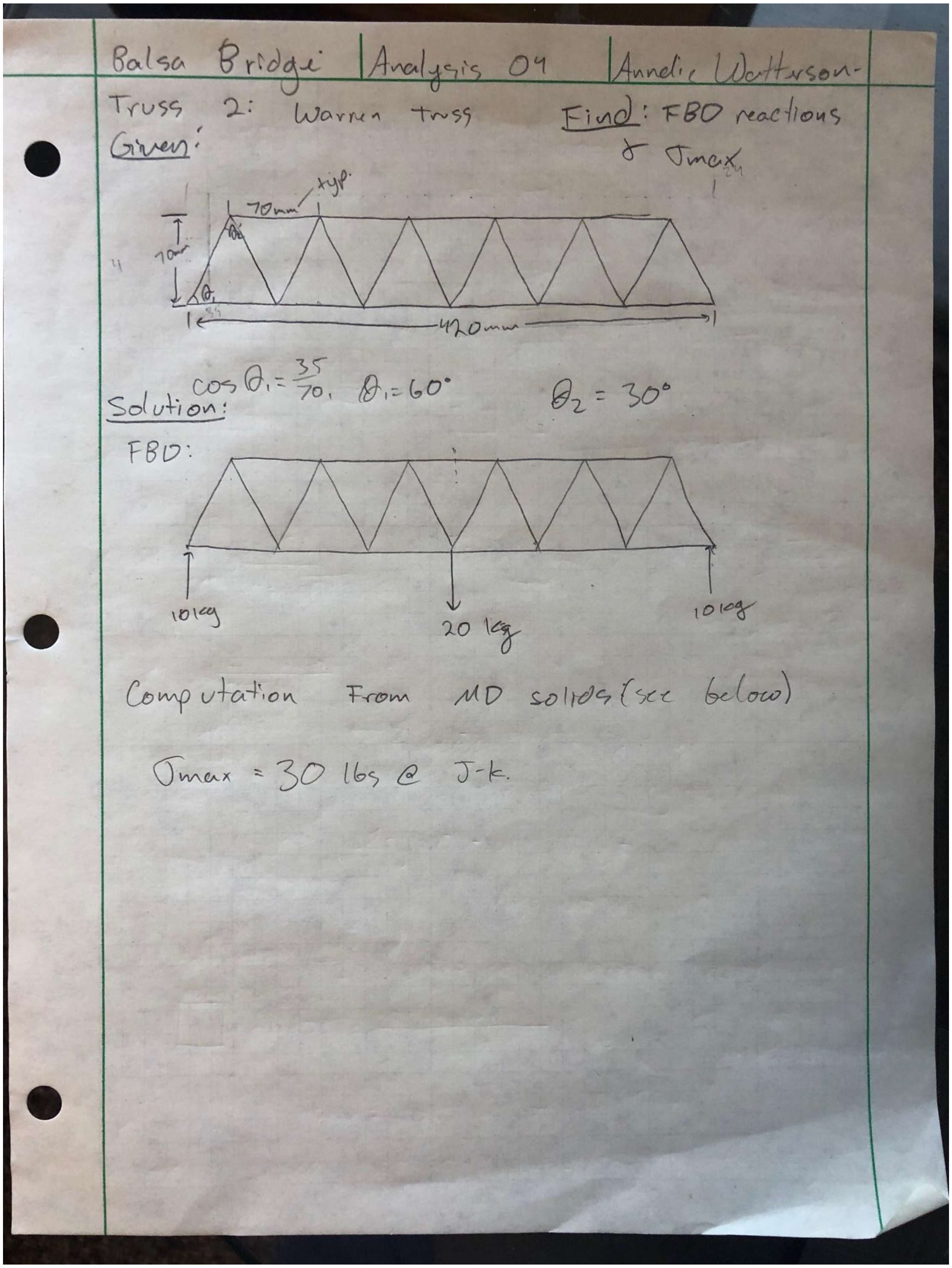
Appendix A-2 – Pulley System Analysis



Appendix A-3: brace analysis



Appendix A-4a: truss 2 analysis



Balsa Bridge | Analysis 04 | Annelie Watterson-

Truss 2: Warren truss

Given:

Find: FBD reactions & σ_{max}

70mm typ.

70mm

θ_1

420mm

Solution:

$\cos\theta_1 = \frac{35}{70}$, $\theta_1 = 60°$ $\theta_2 = 30°$

FBD:

10kg

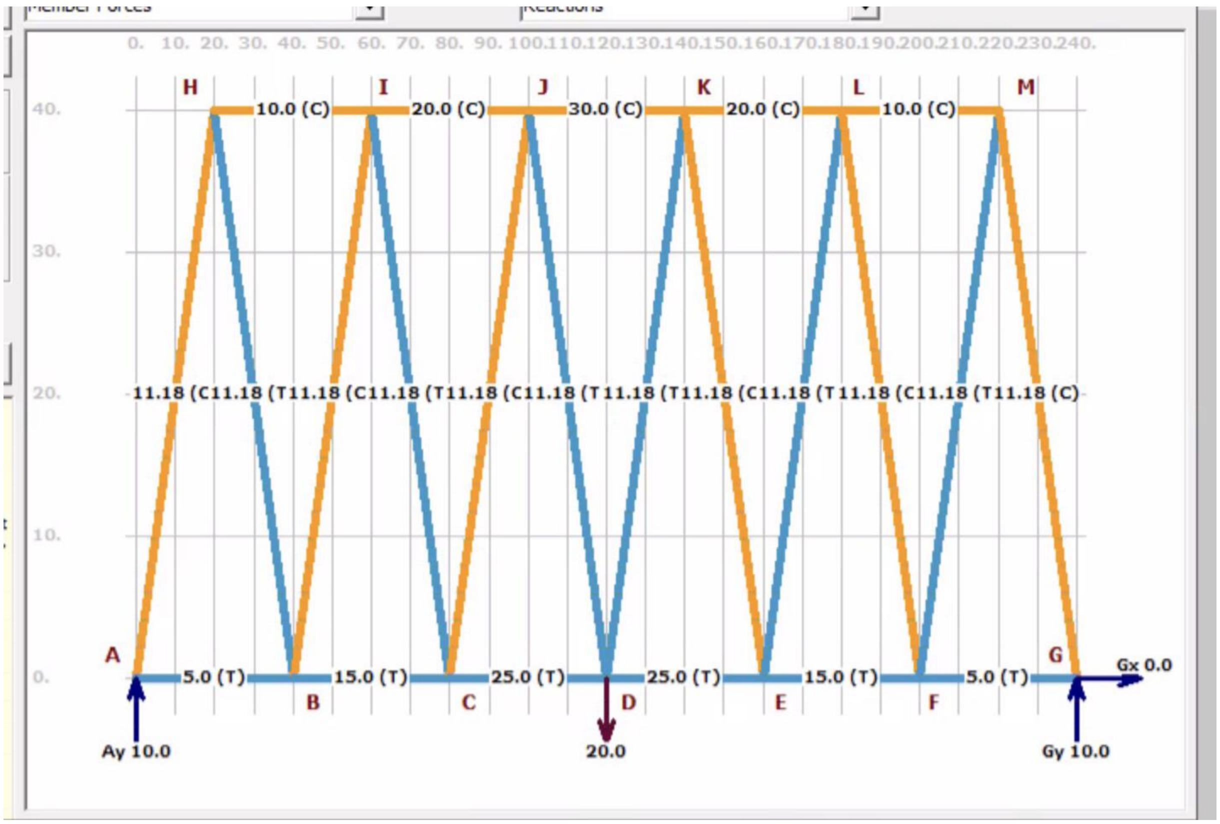
20 kg

10kg

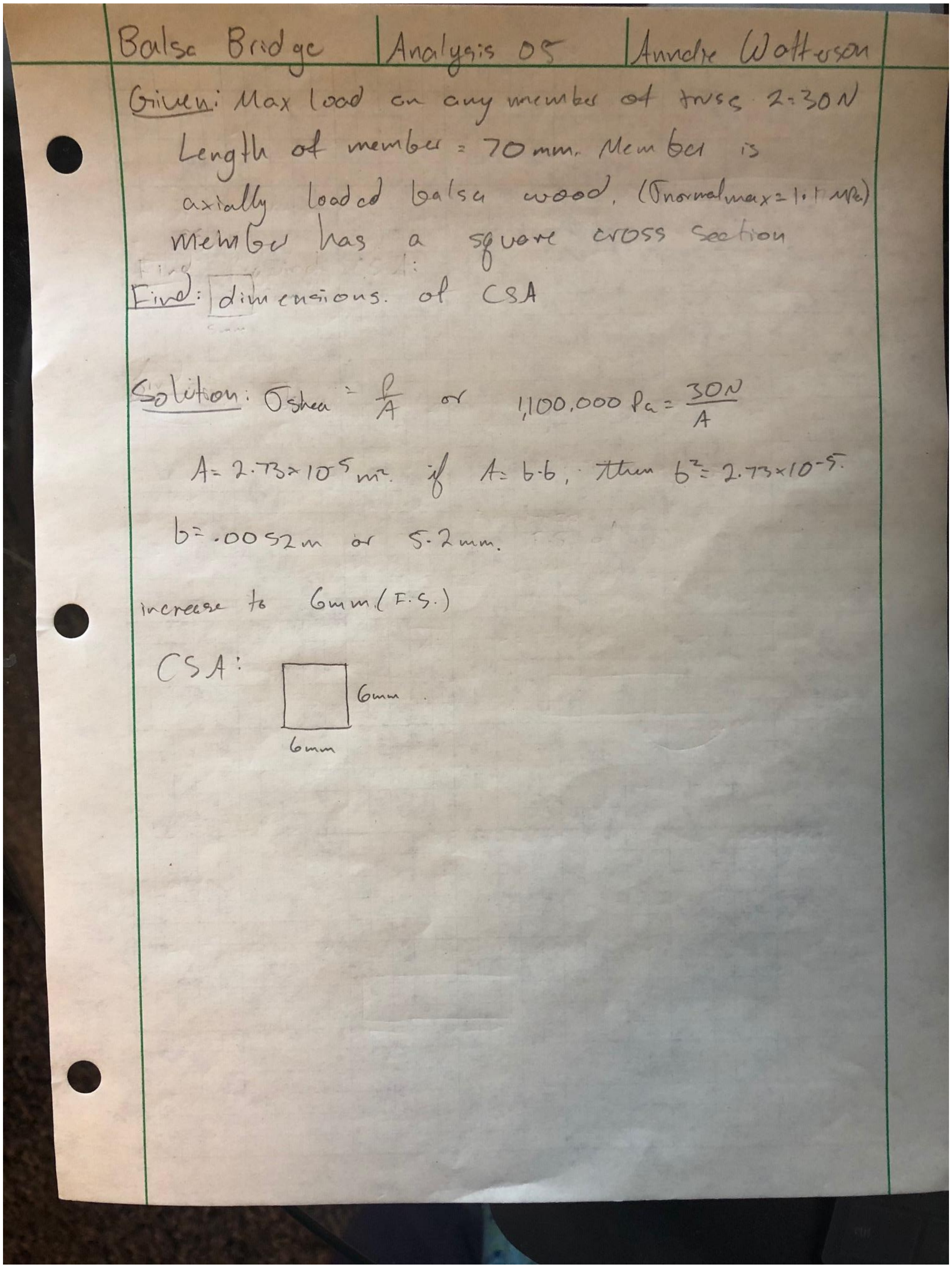
Computation From MD solids (see below)

σ_{max} = 30 lbs @ J-k.

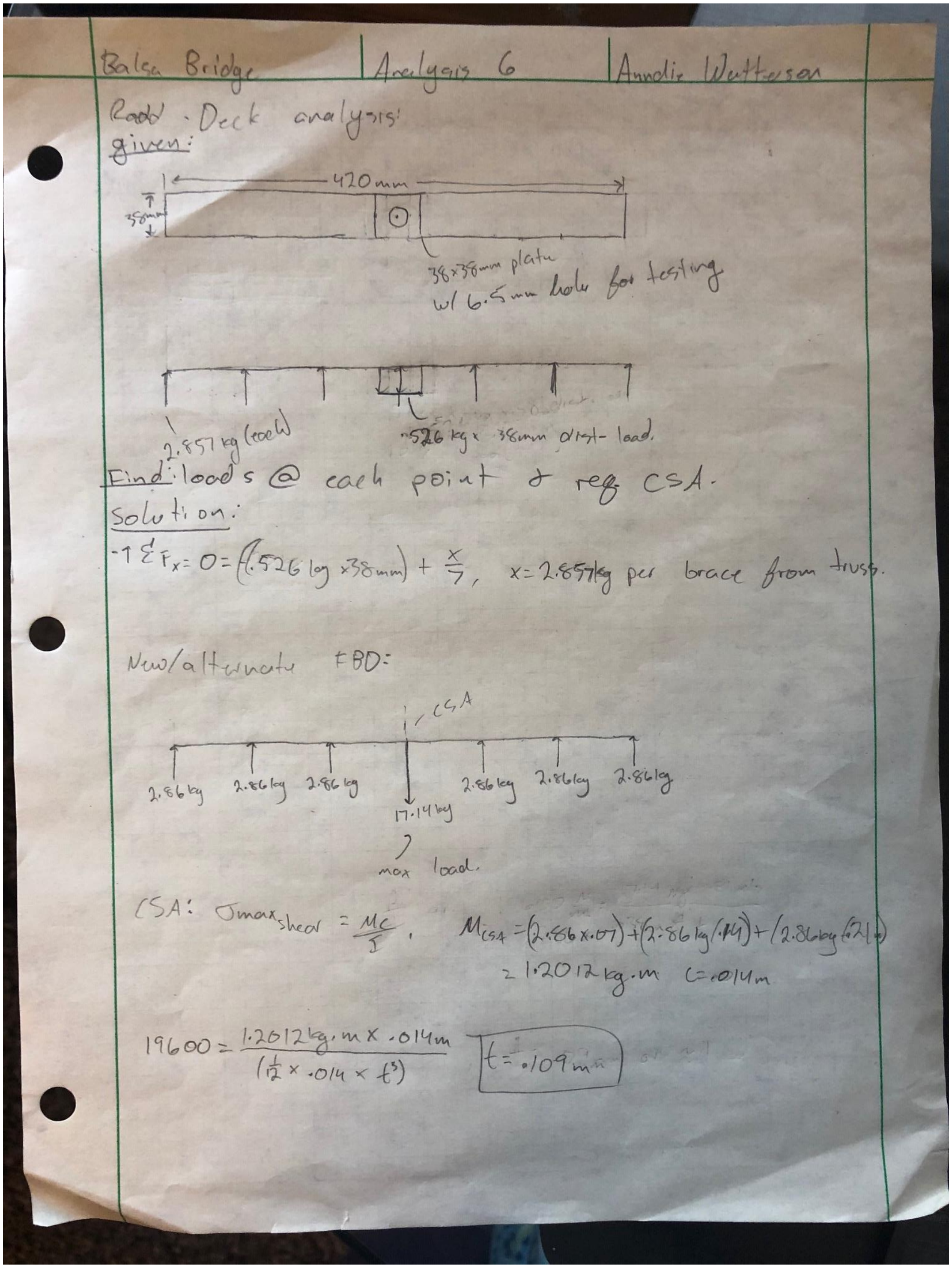
Appendix A-4b: MD solids analysis truss 2



Appendix A-5: cross-sectional area truss 2



Analysis A-6: bridge deck analysis



Balsa Bridge | Analysis 6 | Anndie Wattersen

Road Deck analysis:

given:

420 mm

38mm

38x38mm plate w/ 6.5mm hole for testing

2.857 kg (each)

.526 kg x 38mm dist. load.

Find: loads @ each point & req CSA.

Solution:

$+\uparrow \sum F_x = 0 = (.526\ kg \times 38mm) + \frac{x}{7}$, $x = 2.857kg$ per brace from truss.

New/alternate FBD:

CSA

2.86 kg 2.86 kg 2.86 kg 2.86 kg 2.86 kg 2.86 kg

17.14 kg

max load.

CSA: $\sigma_{max\,shear} = \frac{Mc}{I}$, $M_{CSA} = (2.86 \times .07) + (2.86kg(.14)) + (2.86kg(.21))$

$= 1.2012\ kg \cdot m$ $c = .014m$

$19600 = \frac{1.2012\ kg \cdot m \times .014m}{(\frac{1}{12} \times .014 \times t^3)}$ $t = .109m$

Appendix A-7: mass of truss 2

Balsa Bridge | Analysis 07 | Anndie Watterson

Mass of truss 2:

<u>given</u>:

Volume, from solidWorks model, = 897.16 mm³ or $8.9716\times10^{-5}\,m^3$

Density = 250 kg/m³

Volume of road deck: 420mm × 38mm × 5mm = 79800mm³ or $7.98\times10^{-5}\,m^3$

mass = D×V = 250 kg/m³ × ($7.98\times10^{-5}\,m^3$ + $8.9716\times10^{-5}\,m^3$) = .042244 kg

or 42.244 grams.

Required bridge mass = < 85 grams.

Glue Density: 9.3 g/cm³ or .0093 g/mm³

<u>Find</u>: weight of truss

<u>Solution</u>:

Volume used: Assume 2mm³/Joint + 5 mm³/Road deck & Brace joint.

# of joints: 48

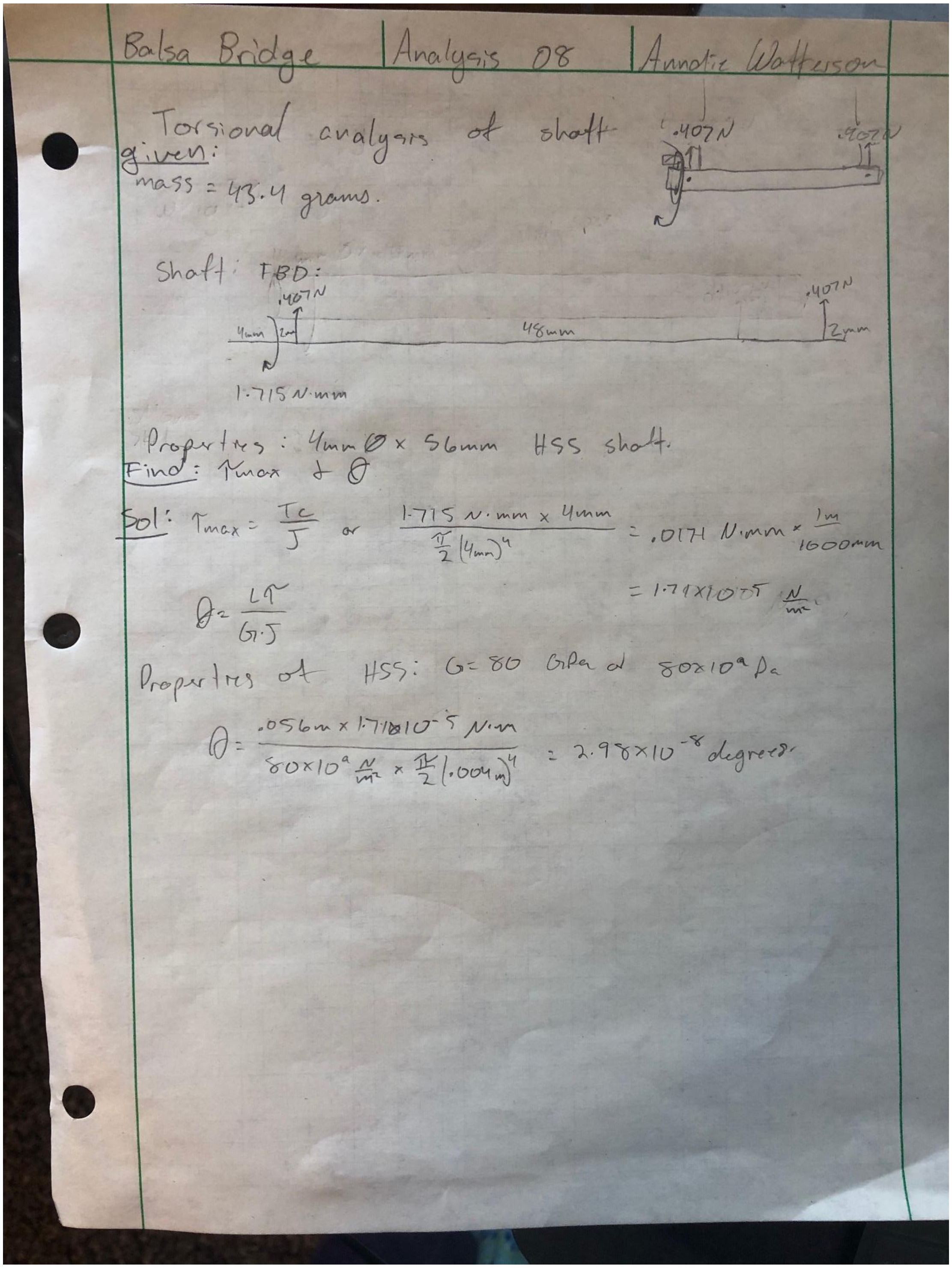
# of Road deck & Brace joints: 5

So Volume of glue = (2mm³ × 48) + (5 mm³ × 5) = 121 mm³

m = d × V or .0093 g/mm³ × 121 mm³ = 1.1253 grams

so 42.244g + 1.1253g = 43.369g, < 83 g ✓

Appendix A-8: torsional analysis of shaft


Balsa Bridge | Analysis 08 | Annette Watterson

Torsional analysis of shaft

given:

mass = 43.4 grams.

.407N .407N

Shaft: FBD:

.407N .407N

4mm 2mm 48mm 2mm

1.715 N·mm

Properties: 4mm Ø × 56mm HSS shaft.

Find: τ_{max} & θ

Sol: $\tau_{max} = \frac{Tc}{J}$ or $\frac{1.715\ N\cdot mm \times 4mm}{\frac{\pi}{2}(4mm)^4} = .0171\ N\cdot mm \times \frac{1m}{1000mm}$

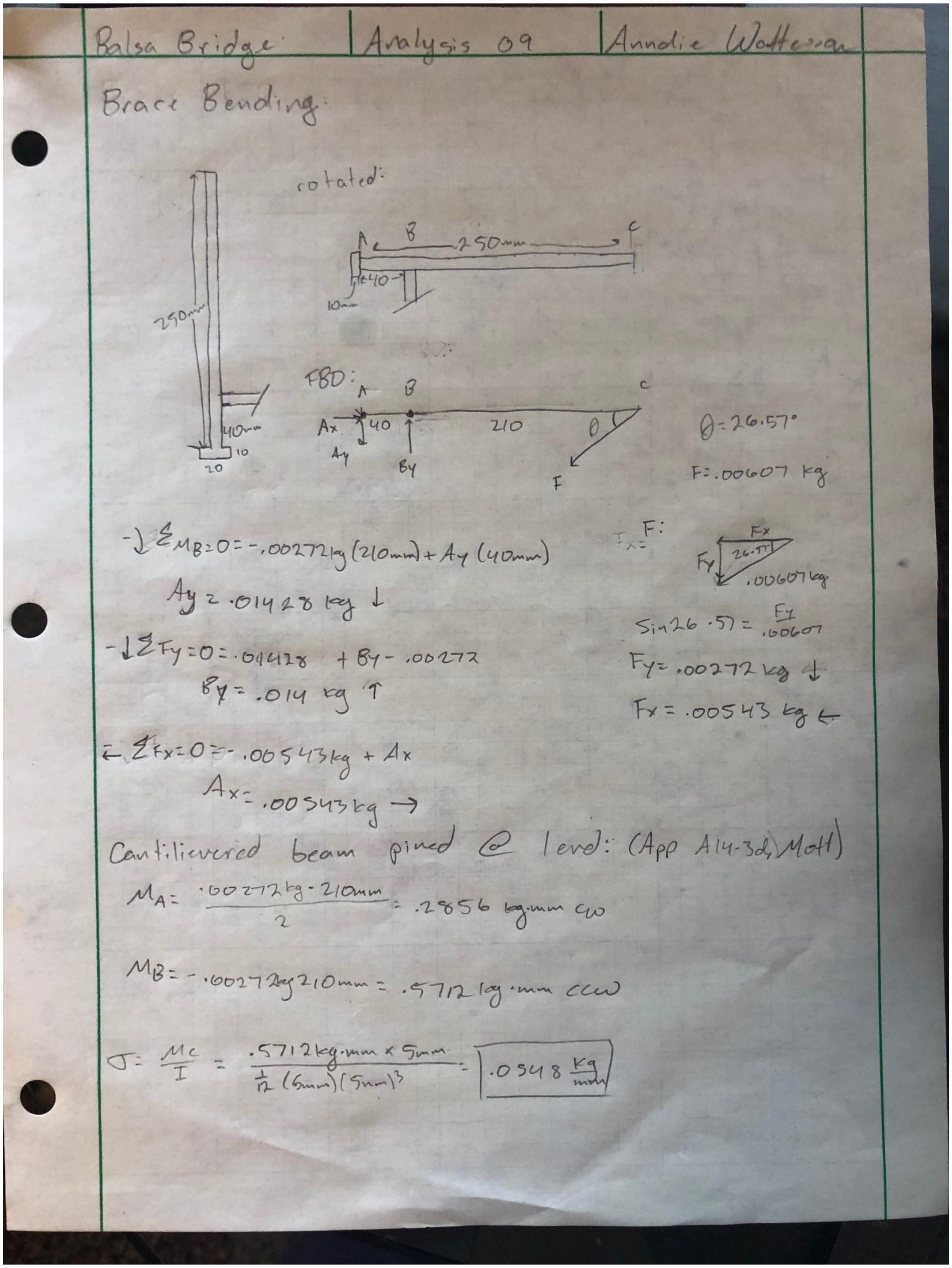
$= 1.71 \times 10^{-5}\ \frac{N}{m^2}$

$\theta = \frac{L\tau}{G\cdot J}$

Properties of HSS: G = 80 GPa or 80×10^9 Pa

$\theta = \frac{.056m \times 1.71 \times 10^{-5}\ N\cdot m}{80 \times 10^9 \frac{N}{m^2} \times \frac{\pi}{2}(.004m)^4} = 2.98 \times 10^{-8}$ degrees.

Appendix A-9: Bending of Brace Sides



Balsa Bridge | Analysis 09 | Anndie Watterson

Brace Bending:

$\theta = 26.57°$

$F = .00607$ kg

$-\circlearrowleft \Sigma M_B = 0 = -.00272kg(210mm) + A_y(40mm)$

$A_y = .01428$ kg ↓

$-\downarrow \Sigma F_y = 0 = .01428 + B_y - .00272$

$B_y = .014$ kg ↑

$\leftarrow \Sigma F_x = 0 = -.00543kg + A_x$

$A_x = .00543$ kg →

F:

$\sin 26.57 = \frac{F_y}{.00607}$

$F_y = .00272$ kg ↓

$F_x = .00543$ kg ←

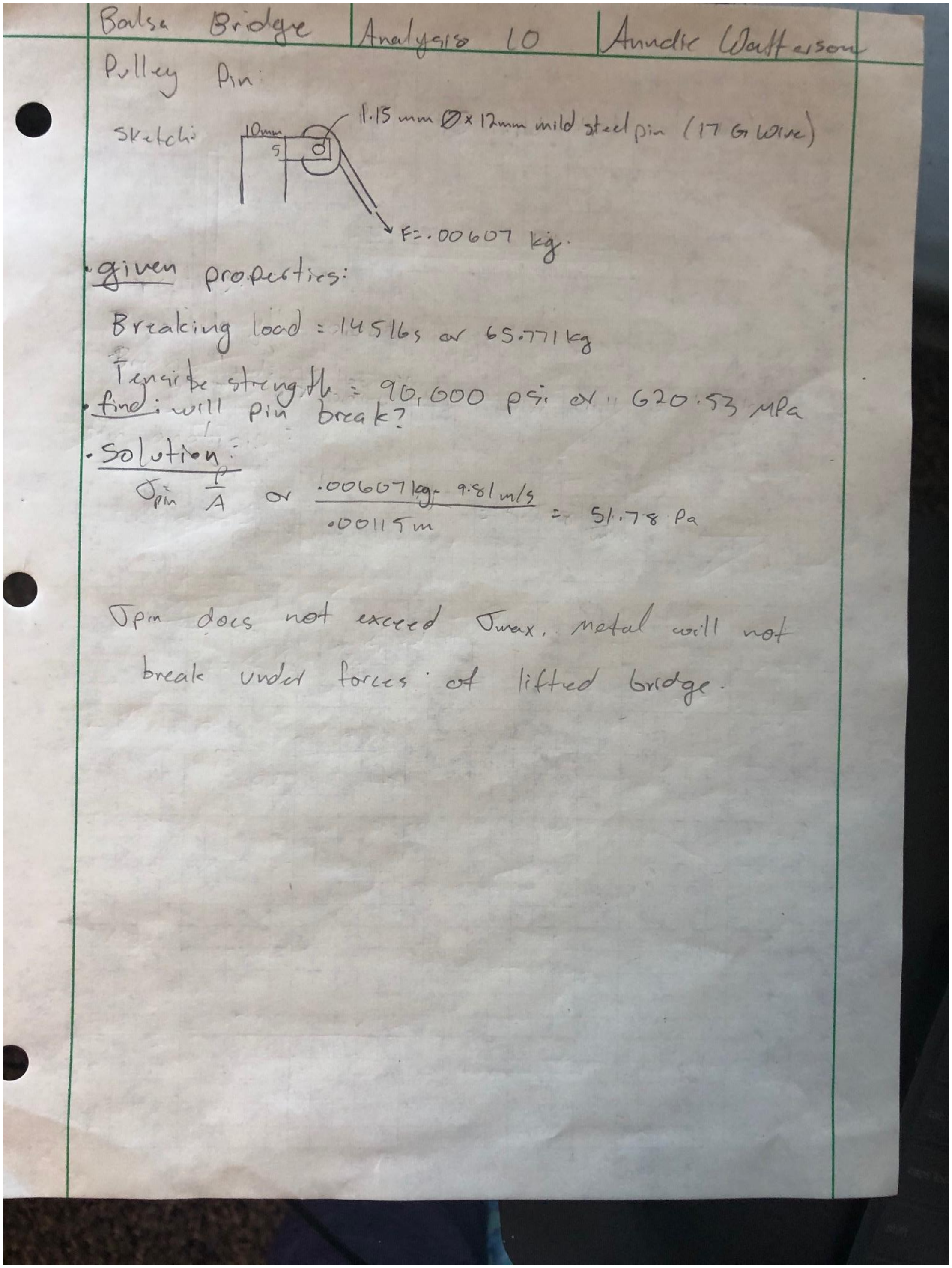
Cantilievered beam pined @ 1 end: (App A14-3d, Mott)

$M_A = \frac{.00272kg \cdot 210mm}{2} = .2856$ kg·mm CW

$M_B = -.00272kg \cdot 210mm = .5712$ kg·mm CCW

$\sigma = \frac{Mc}{I} = \frac{.5712kg \cdot mm \times 5mm}{\frac{1}{12}(5mm)(5mm)^3} = \boxed{.0548 \frac{kg}{mm^2}}$

Appendix A-10: Pulley Pin analysis



Balsa Bridge | Analysis 10 | Annalie Waltersen

Pulley Pin:

Sketch:

· given properties:

Breaking load = 145 lbs or 65.771 kg

Tensile strength = 90,000 psi or 620.53 MPa

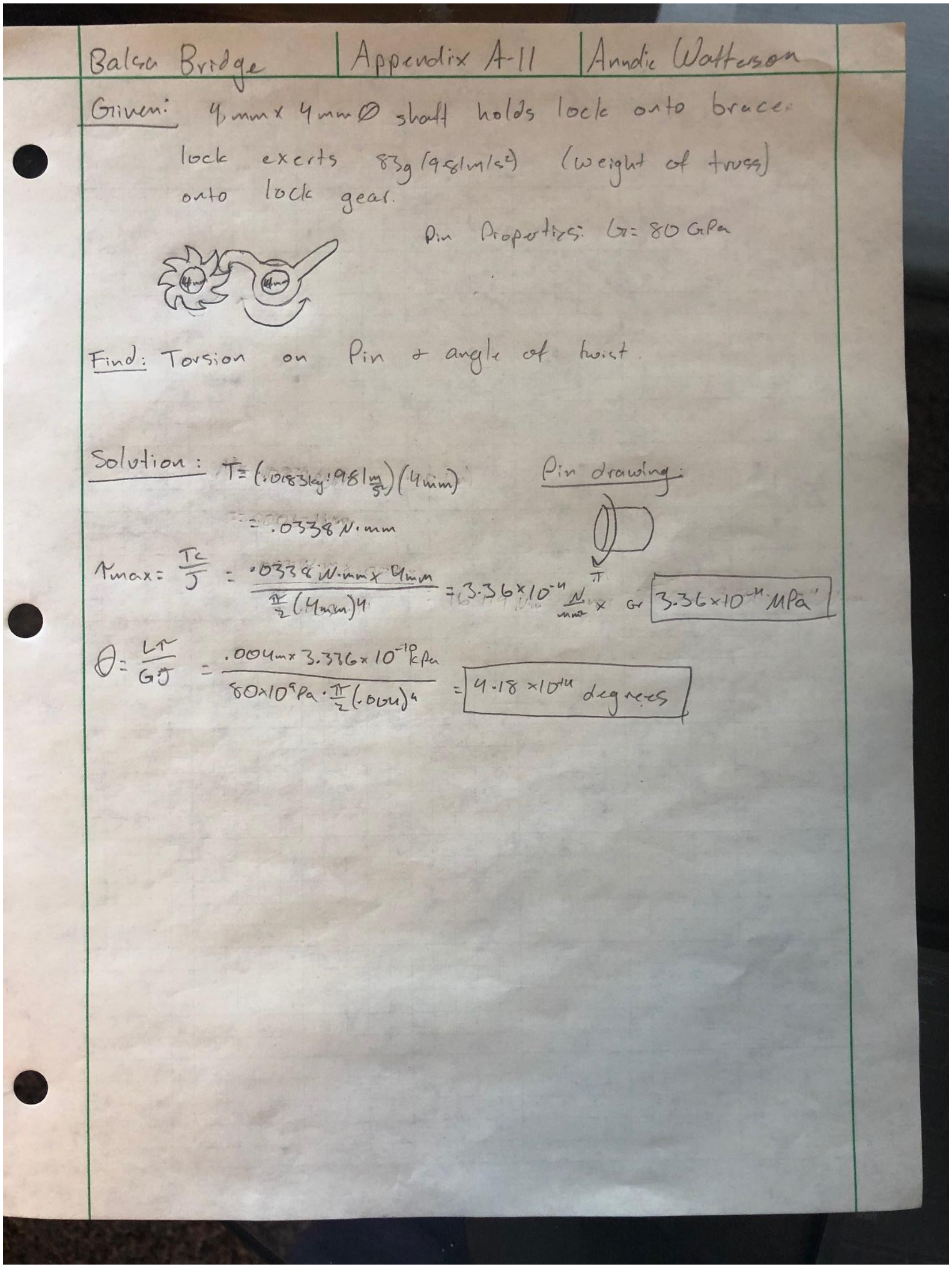
· find: will pin break?

· Solution:

$\sigma_{pin} = \frac{F}{A}$ or $\frac{.00607 \text{ kg} \cdot 9.81 \text{ m/s}}{.00115 \text{ m}} = 51.78 \text{ Pa}$

σ_{pin} does not exceed σ_{max}, metal will not break under forces of lifted bridge.

Appendix A-11: Gear lock pin torsion



Balsa Bridge | Appendix A-11 | Anndie Watterson

Given: 4 mm x 4 mm Ø shaft holds lock onto brace. lock exerts 83g (9.81 m/s²) (weight of truss) onto lock gear.

Pin Properties: G = 80 GPa

Find: Torsion on Pin & angle of twist.

Solution: $T = (.0083 kg \cdot 9.81 \frac{m}{s^2})(4 mm)$

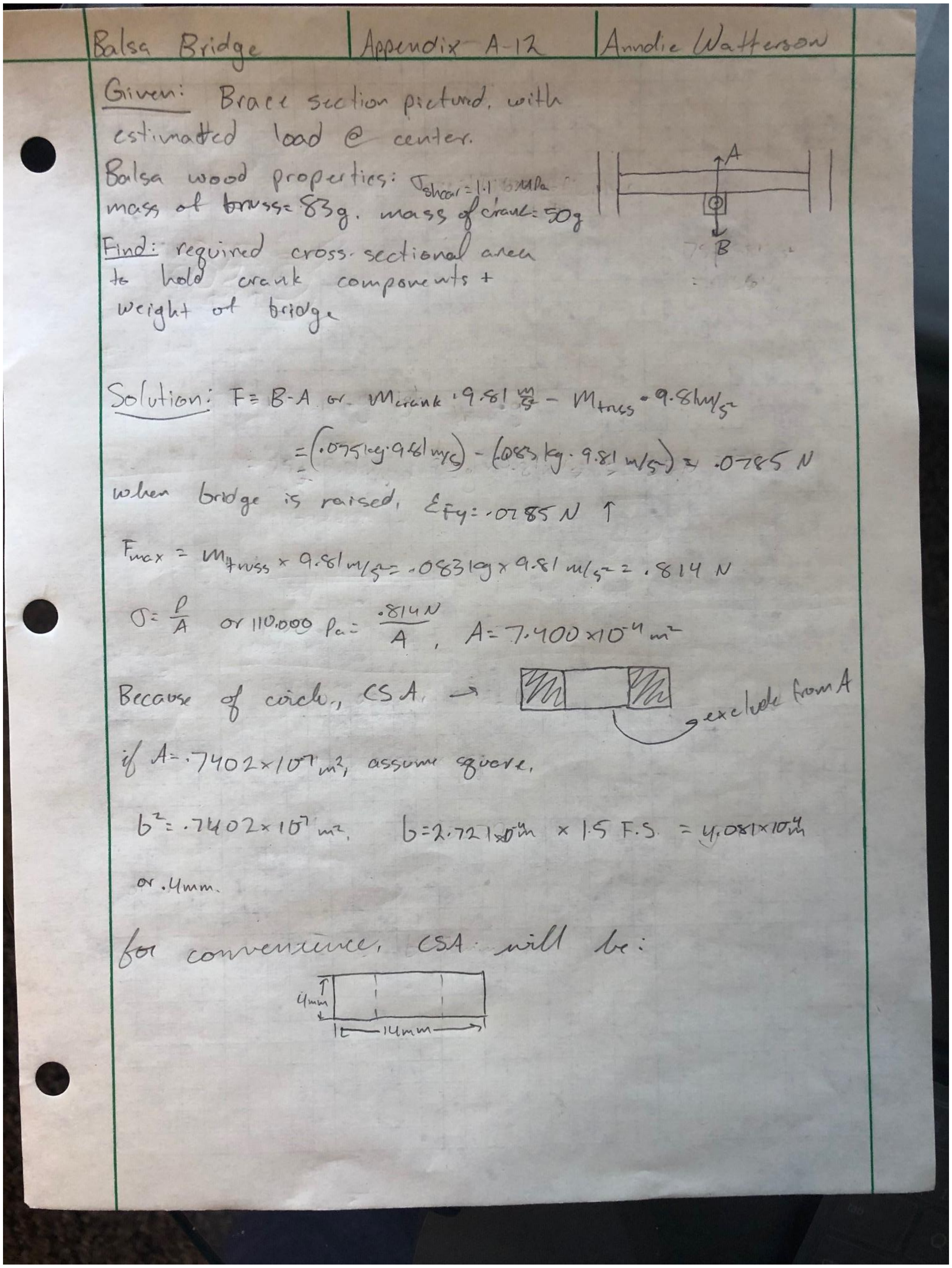
$= .0338\ N \cdot mm$

Pin drawing:

$\tau_{max} = \frac{Tc}{J} = \frac{.0338\ N \cdot mm \times 4mm}{\frac{\pi}{2}(4mm)^4} = 3.36 \times 10^{-4} \frac{N}{mm^2}$ or $3.36 \times 10^{-4}\ MPa$

$\theta = \frac{L\tau}{GJ} = \frac{.004m \times 3.336 \times 10^{-10} kPa}{80 \times 10^9 Pa \cdot \frac{\pi}{2}(.004)^4} = 4.18 \times 10^{-14}$ degrees

Appendix A-12: Crank holder CSA



Balsa Bridge | Appendix A-12 | Annalie Watterson

Given: Brace section pictured, with estimated load @ center.

Balsa wood properties: $\tau_{shear} = 1.1$ MPa

mass of truss = 83g. mass of crank = 50g

Find: required cross-sectional area to hold crank components + weight of bridge

Solution: $F = B - A$ or $m_{crank} \cdot 9.81\ \frac{m}{s^2} - m_{truss} \cdot 9.81\ m/s^2$

$= (.075\,kg \cdot 9.81\ m/s^2) - (.083\,kg \cdot 9.81\ m/s^2) \approx .0785\ N$

when bridge is raised, $\Sigma F_y = .0785\ N \uparrow$

$F_{max} = m_{truss} \times 9.81\ m/s^2 = .083\,kg \times 9.81\ m/s^2 = .814\ N$

$\sigma = \frac{P}{A}$ or $110{,}000\ Pa = \frac{.814\ N}{A}$, $A = 7.400 \times 10^{-4}\ m^2$

Because of circle, CSA → exclude from A

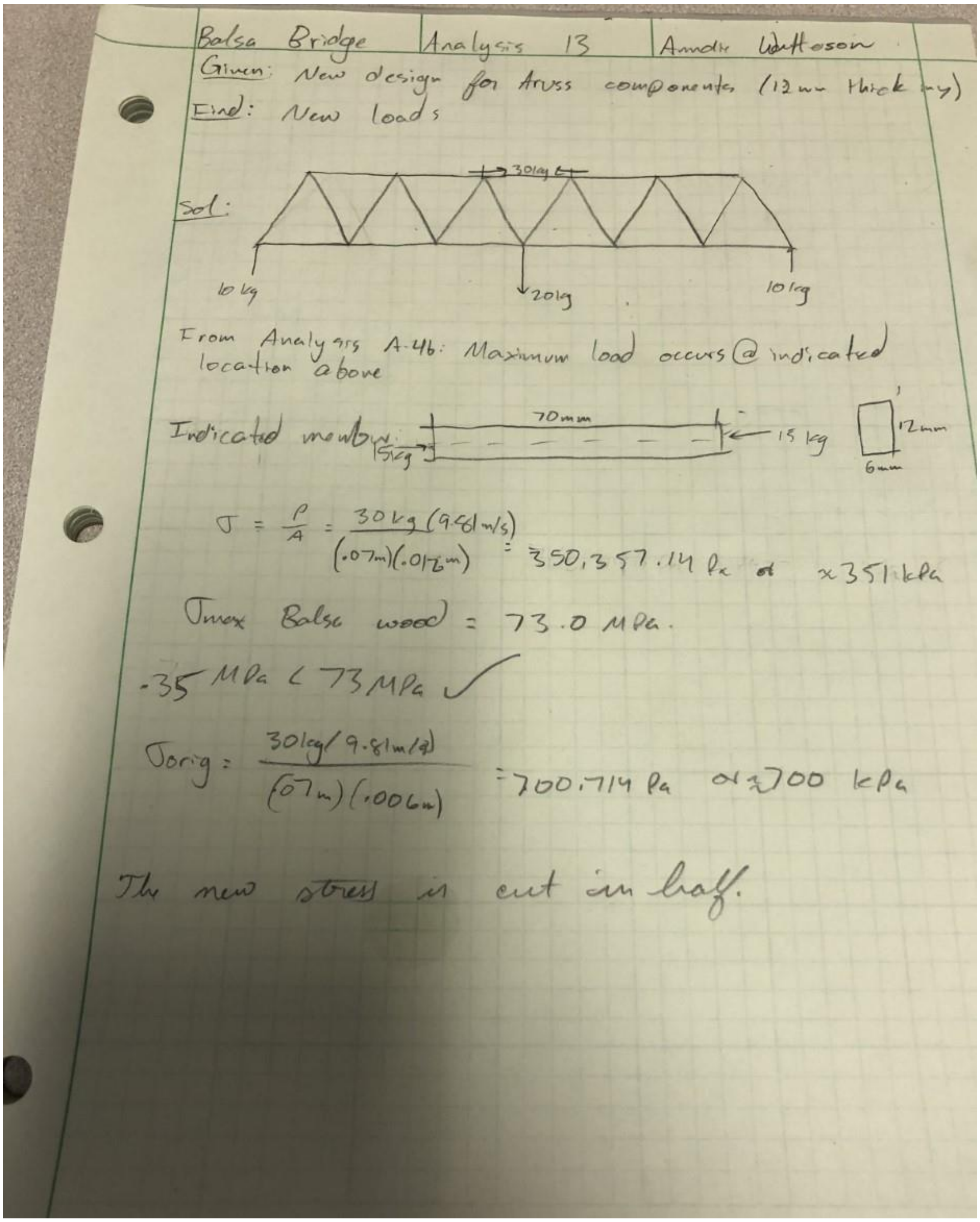
if $A = .7402 \times 10^{-7}\ m^2$, assume square.

$b^2 = .7402 \times 10^{-7}\ m^2$, $b = 2.721 \times 10^{-4}\ m \times 1.5$ F.S. $= 4.081 \times 10^{-4}\ m$

or .4mm.

for convenience, CSA will be:

Appendix A-13



Balsa Bridge | Analysis 13 | Andre Watteson

Given: New design for truss components (12 mm thick)
Find: New loads

Sol:

From Analysis A-4b: Maximum load occurs @ indicated location above

Indicated member:

$\sigma = \frac{P}{A} = \frac{30\,kg\,(9.81\,m/s)}{(.07m)(.012m)} = 350{,}357.14\ Pa$ or $\approx 351\ kPa$

σ_{max} Balsa wood = 73.0 MPa.

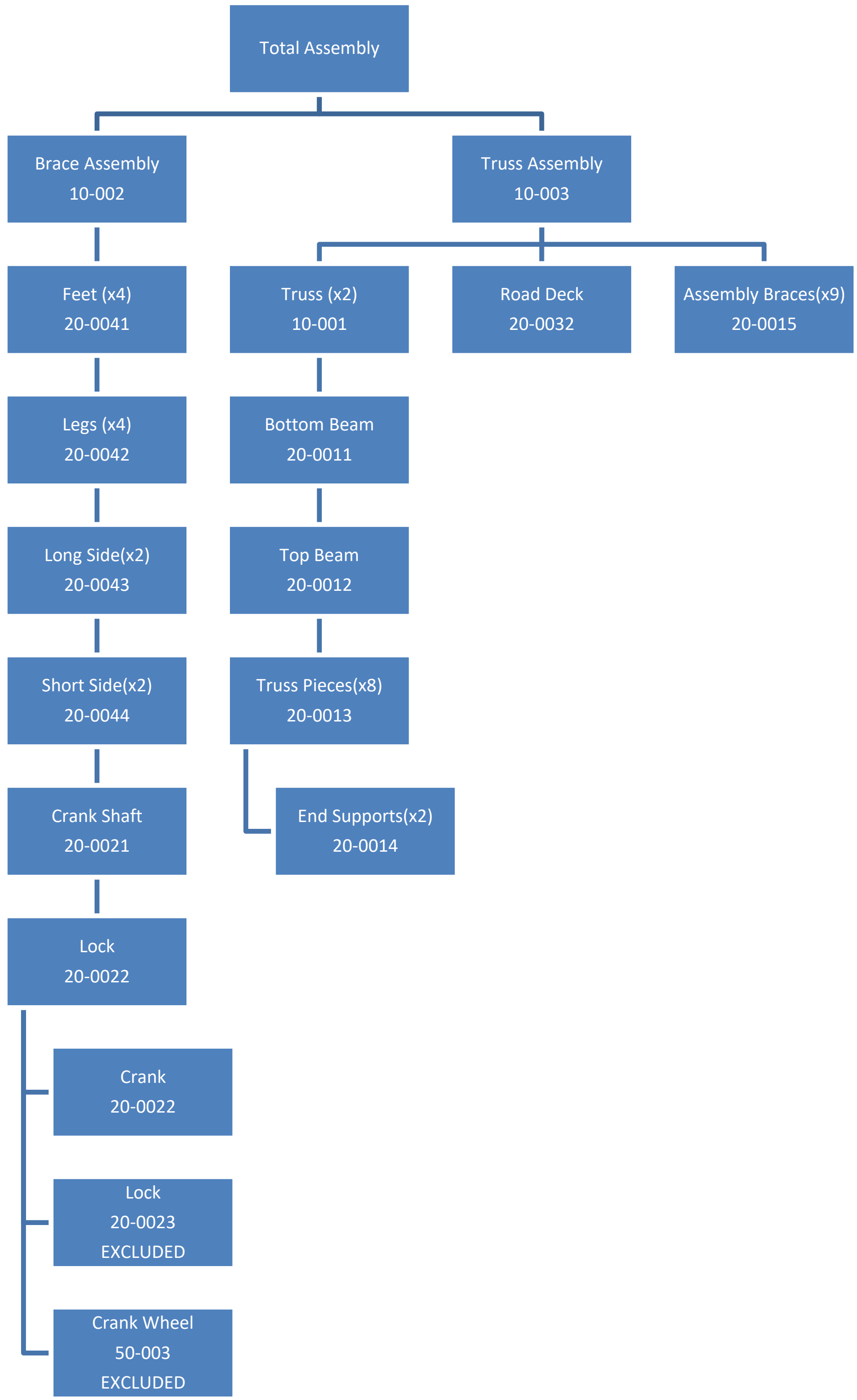
.35 MPa < 73 MPa ✓

$\sigma_{orig} = \frac{30\,kg\,/\,9.81\,m/s)}{(.07m)(.006m)} = 700.714\ Pa$ or $\approx 700\ kPa$

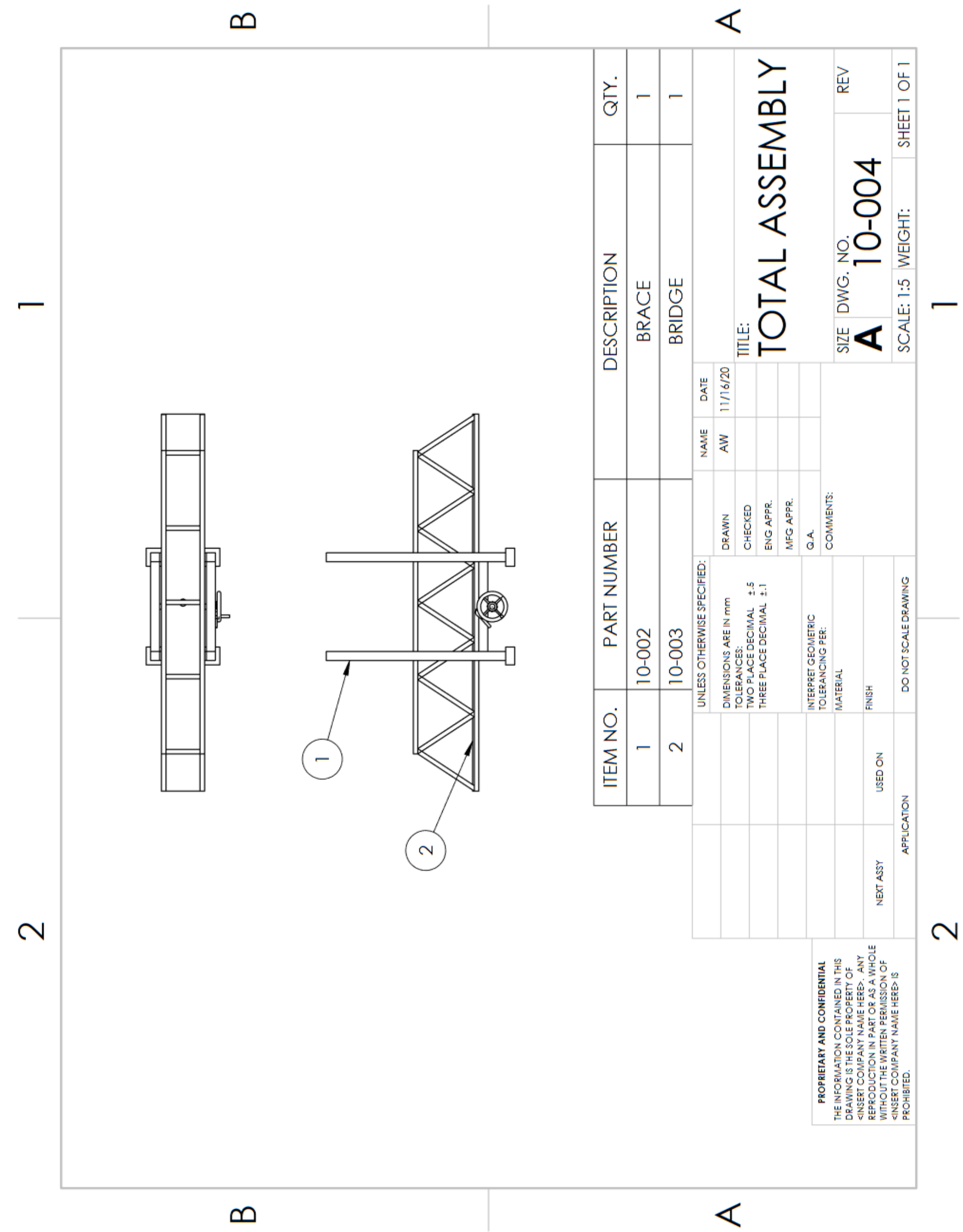
The new stress is cut in half.

APPENDIX B – Drawings

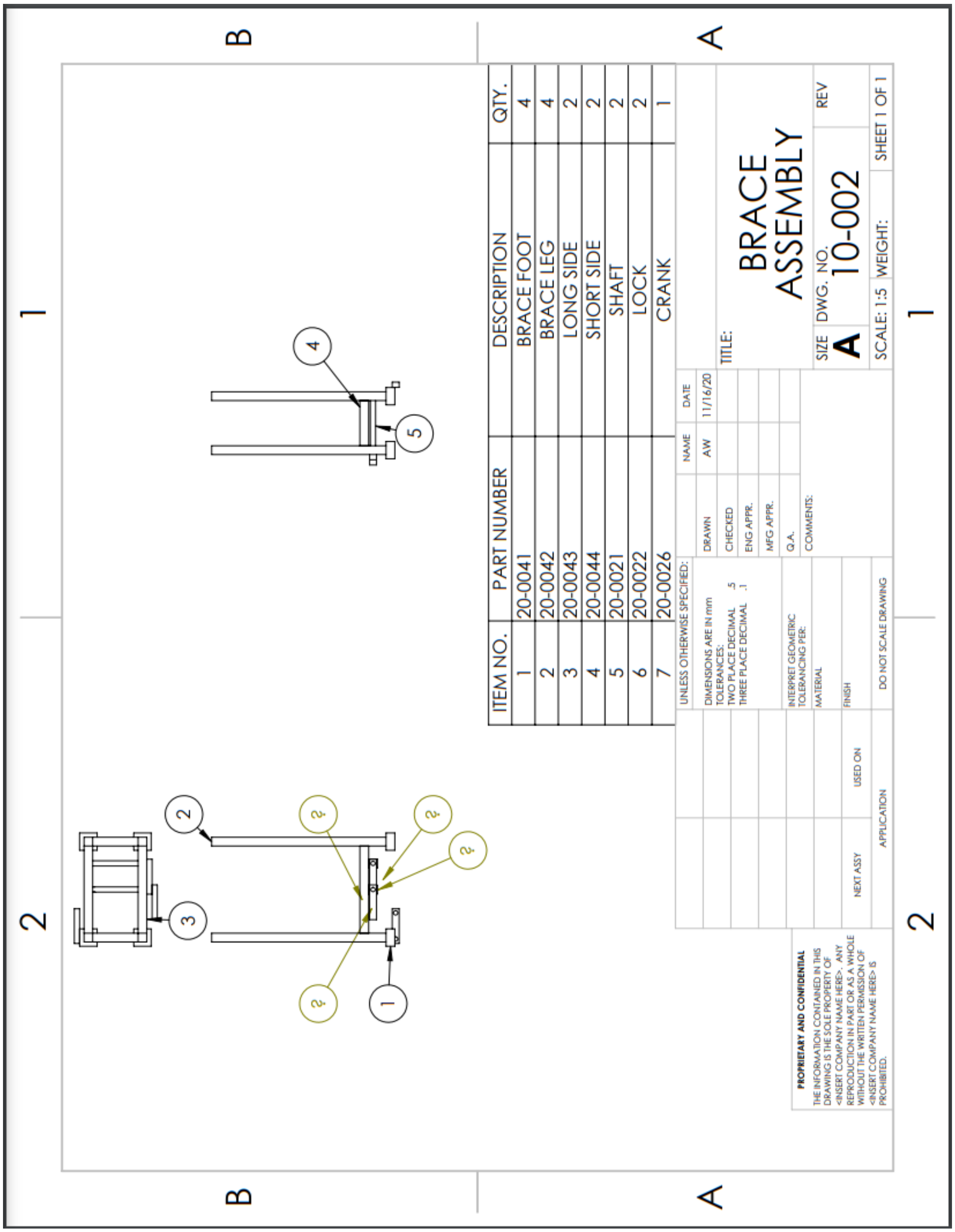
Appendix B – Drawing Tree



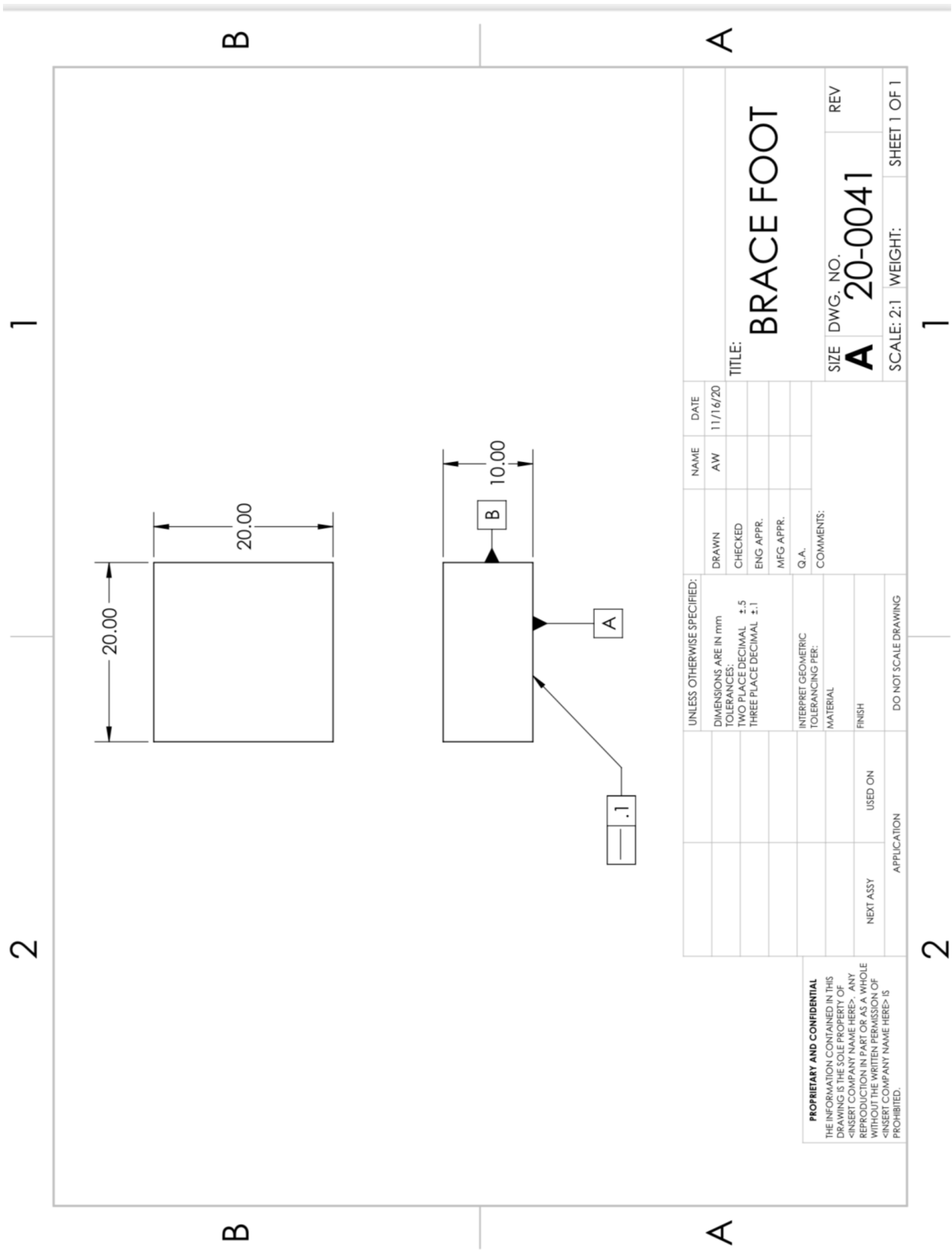
Appendix B-1– Total Assembly



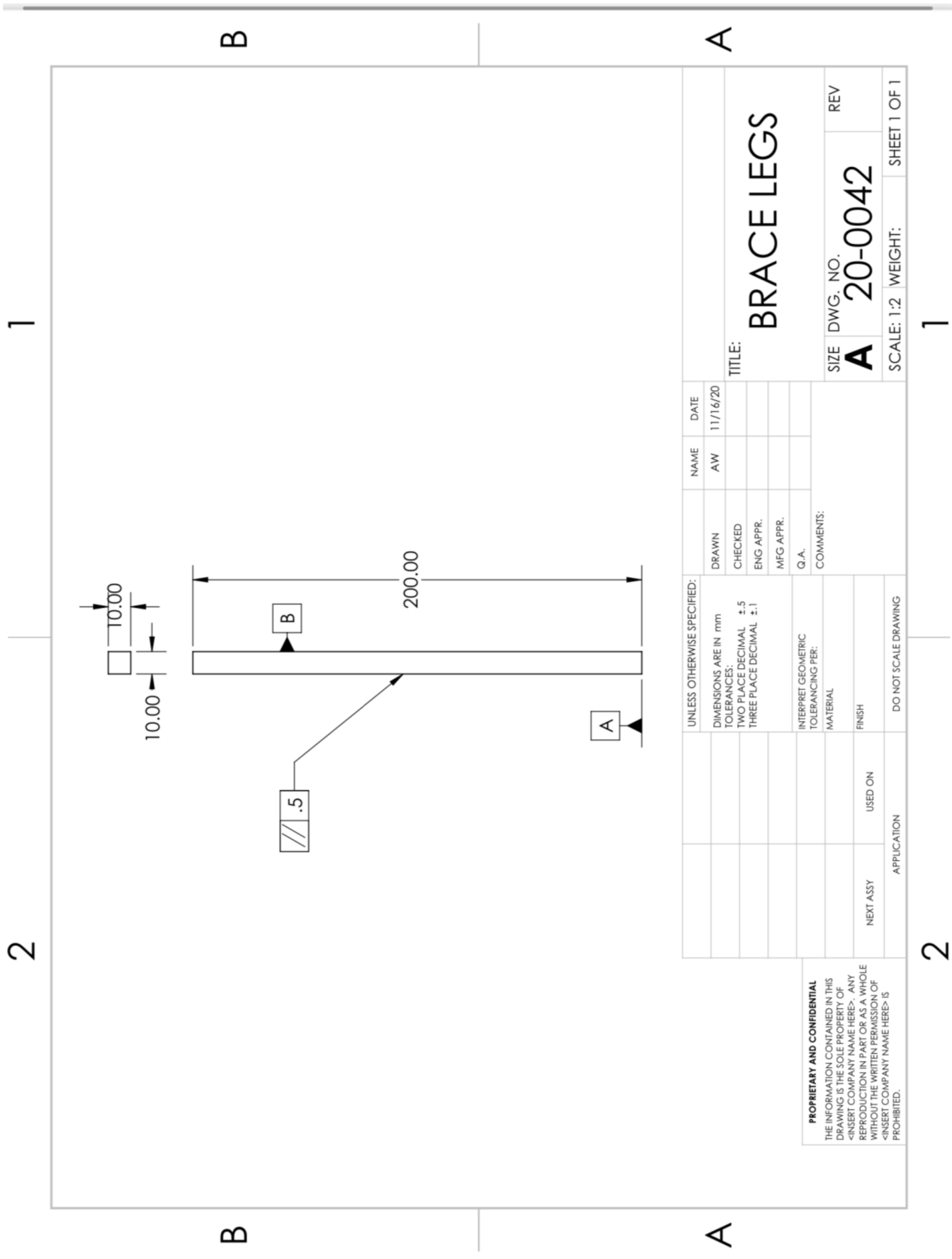
Appendix B-2: Brace Assembly



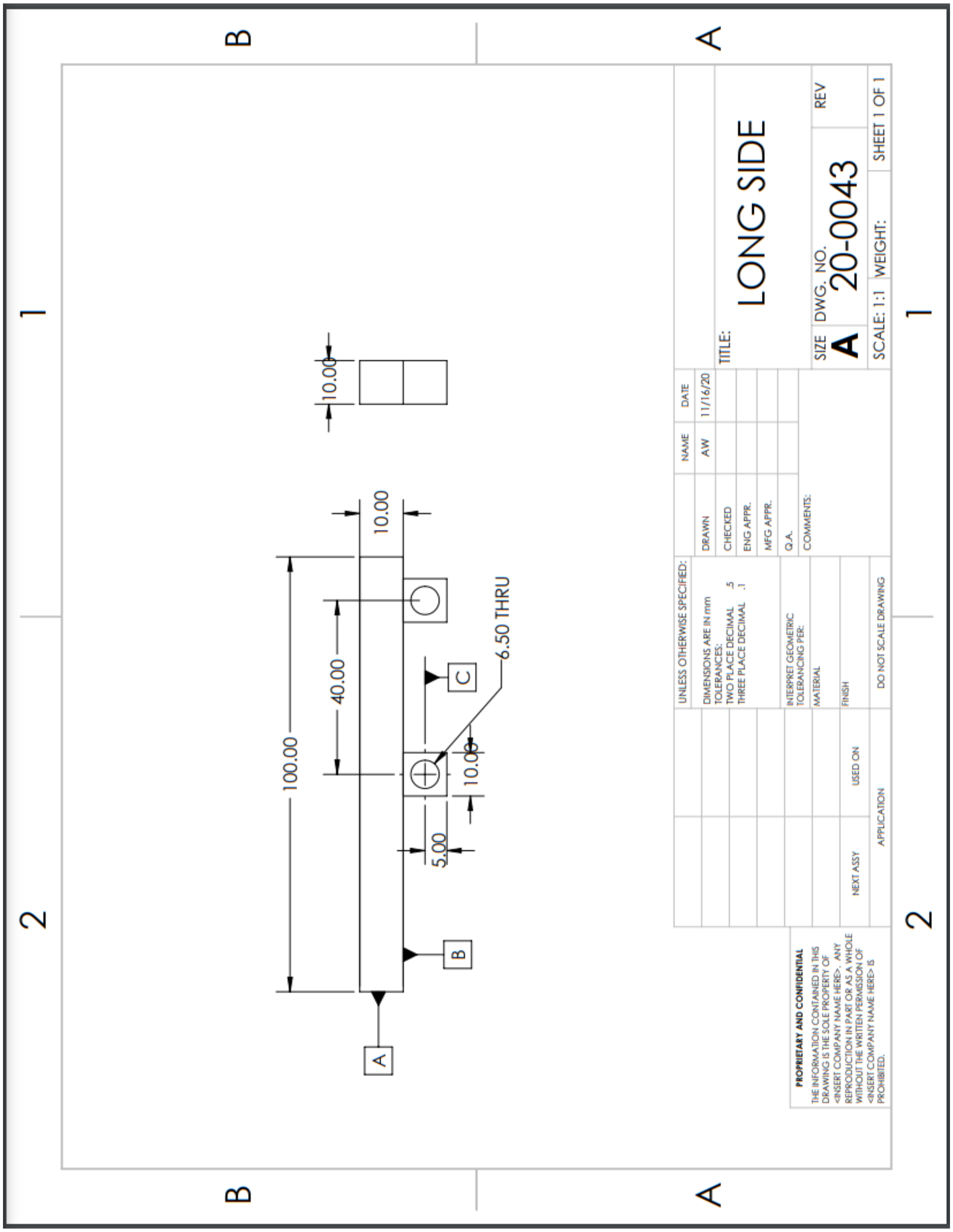
Appendix B-3 –Brace Foot



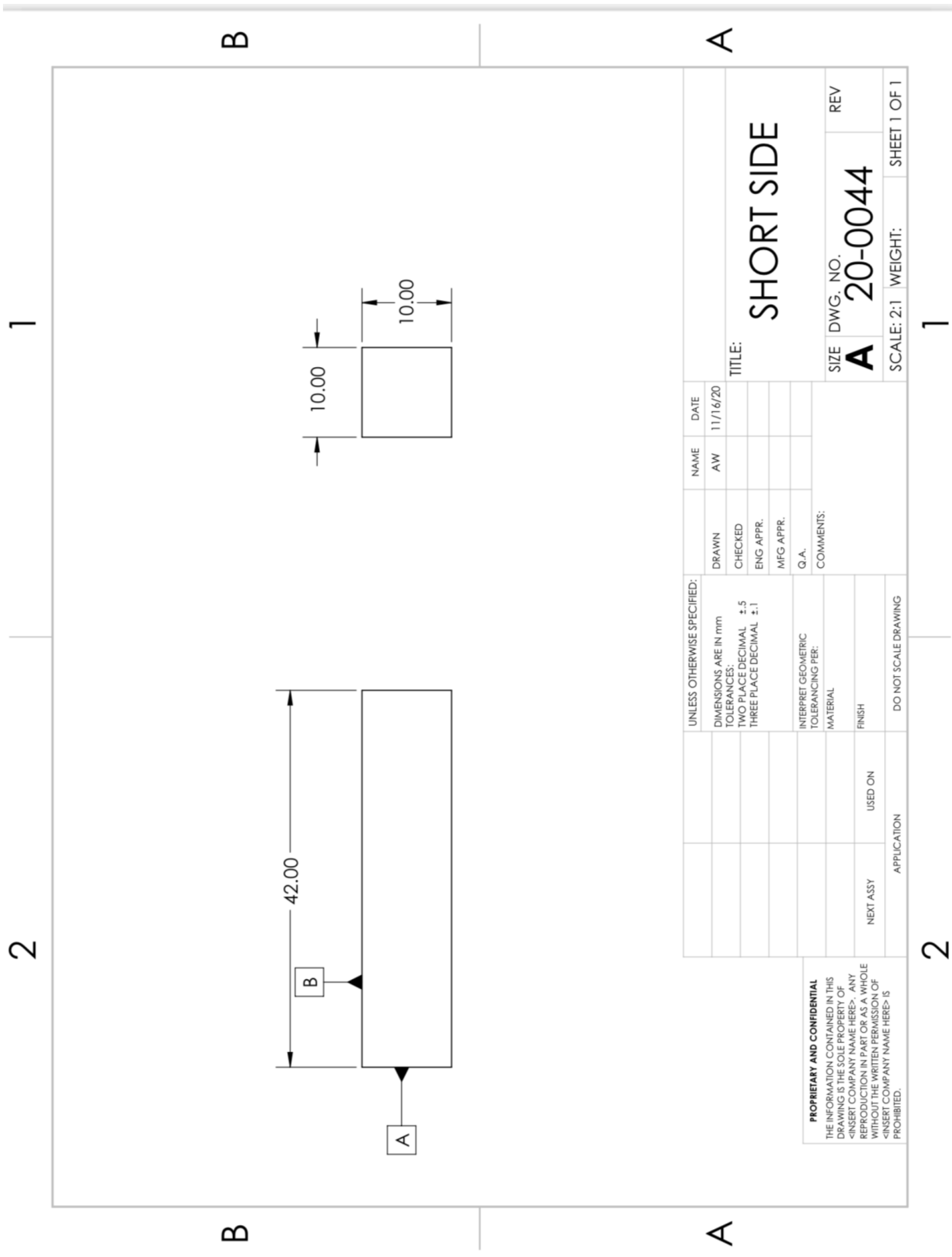
Appendix B-4: Brace Legs



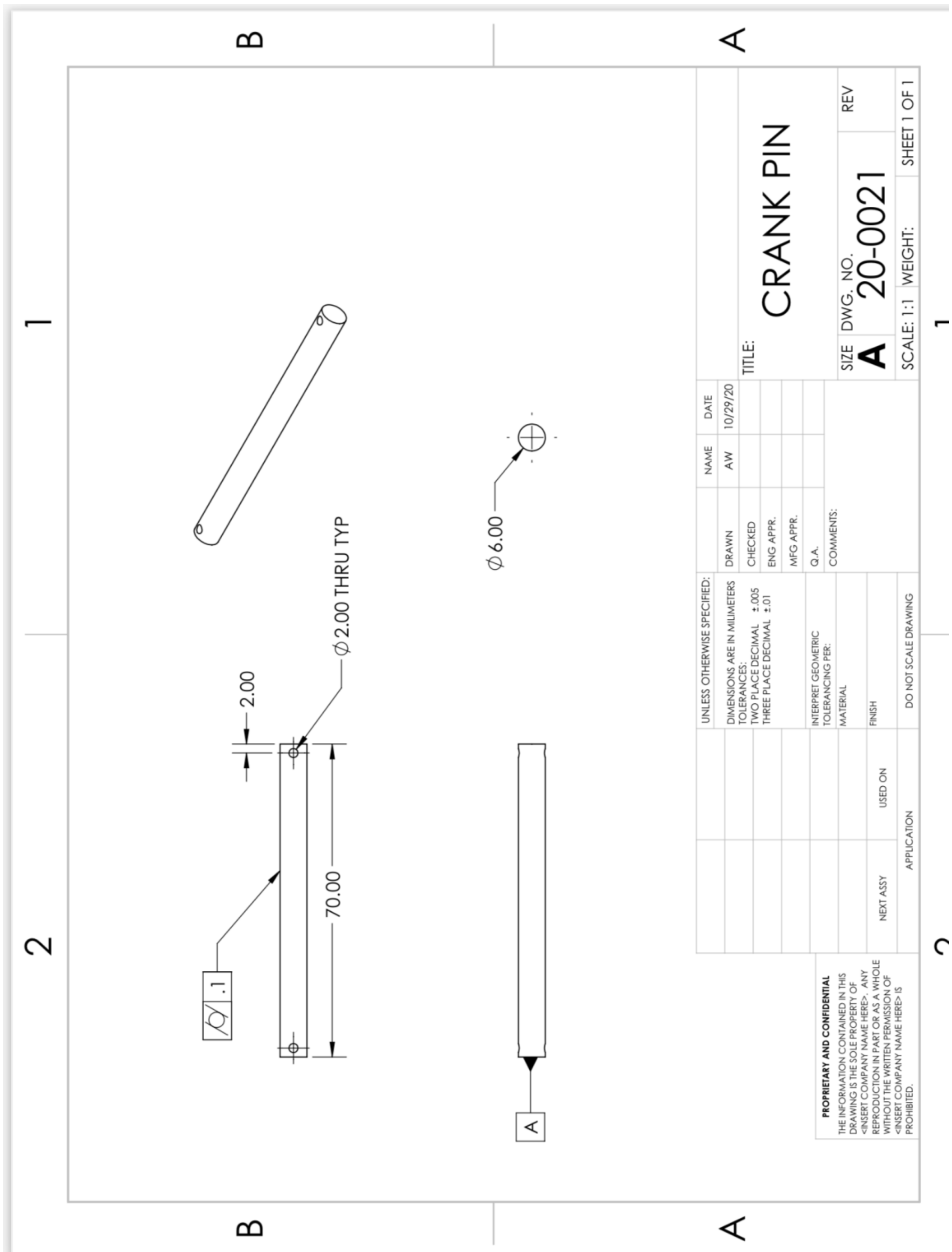
Appendix B-5: Long Side



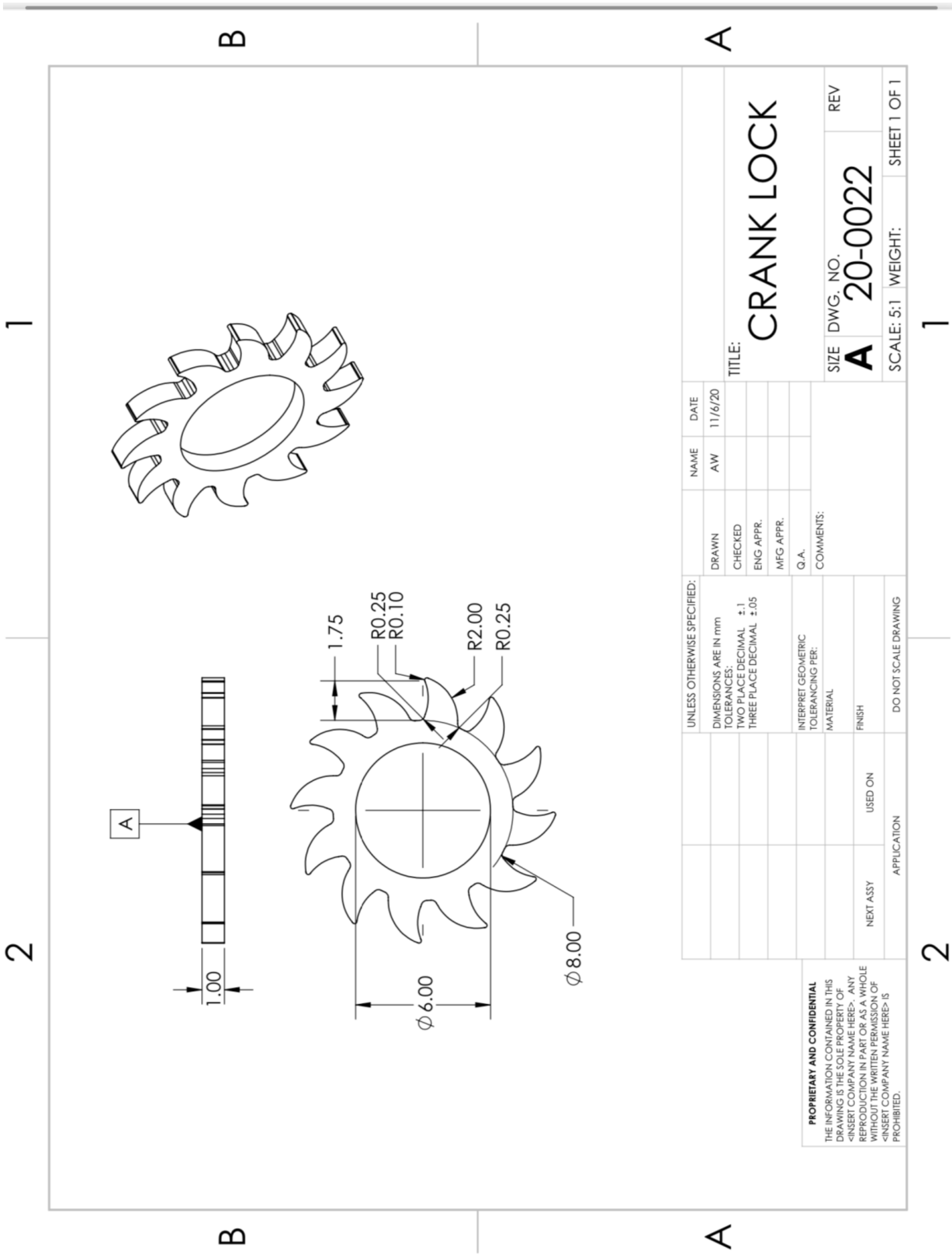
Appendix B-6: Short Side



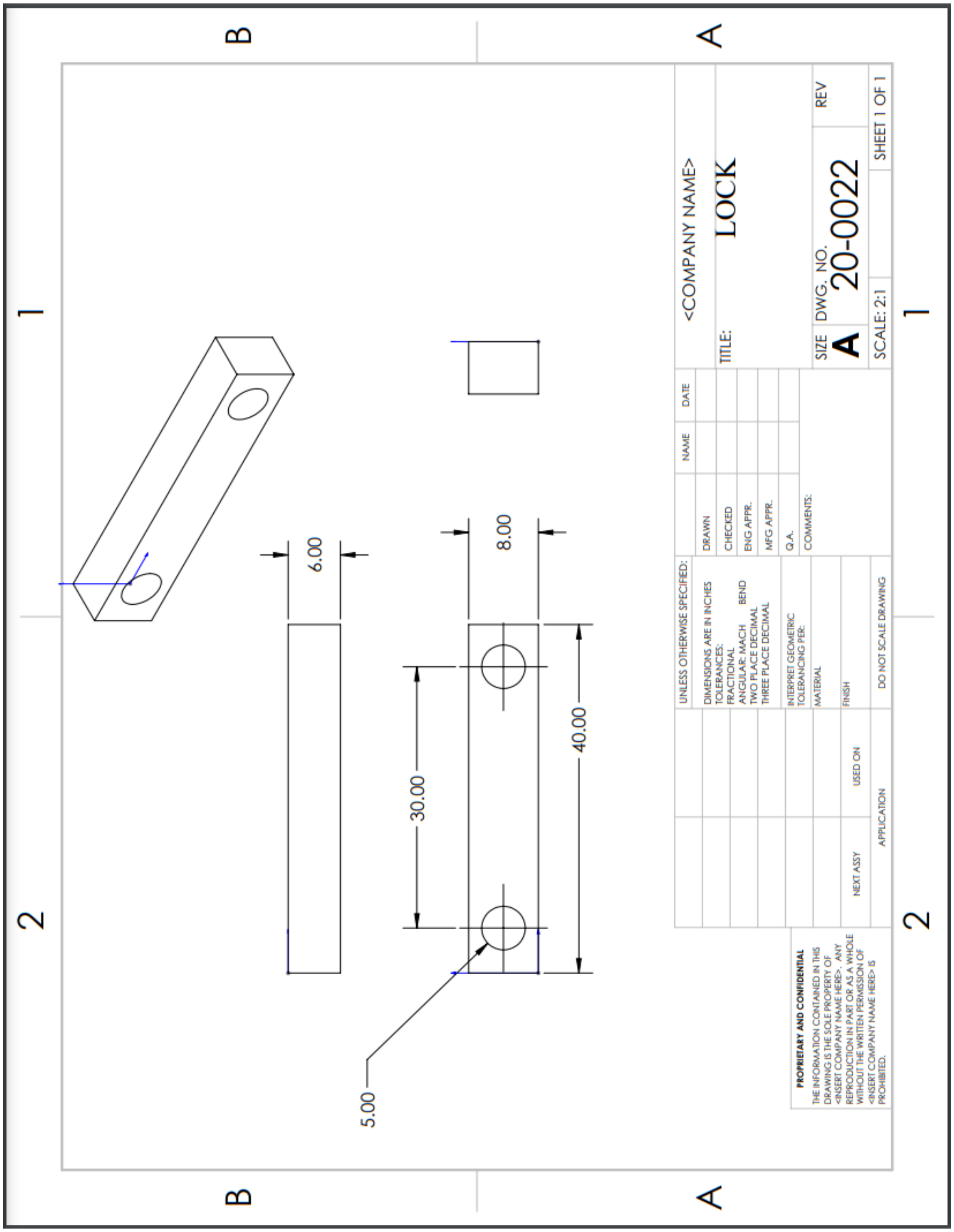
Appendix B-7: Crank Pin



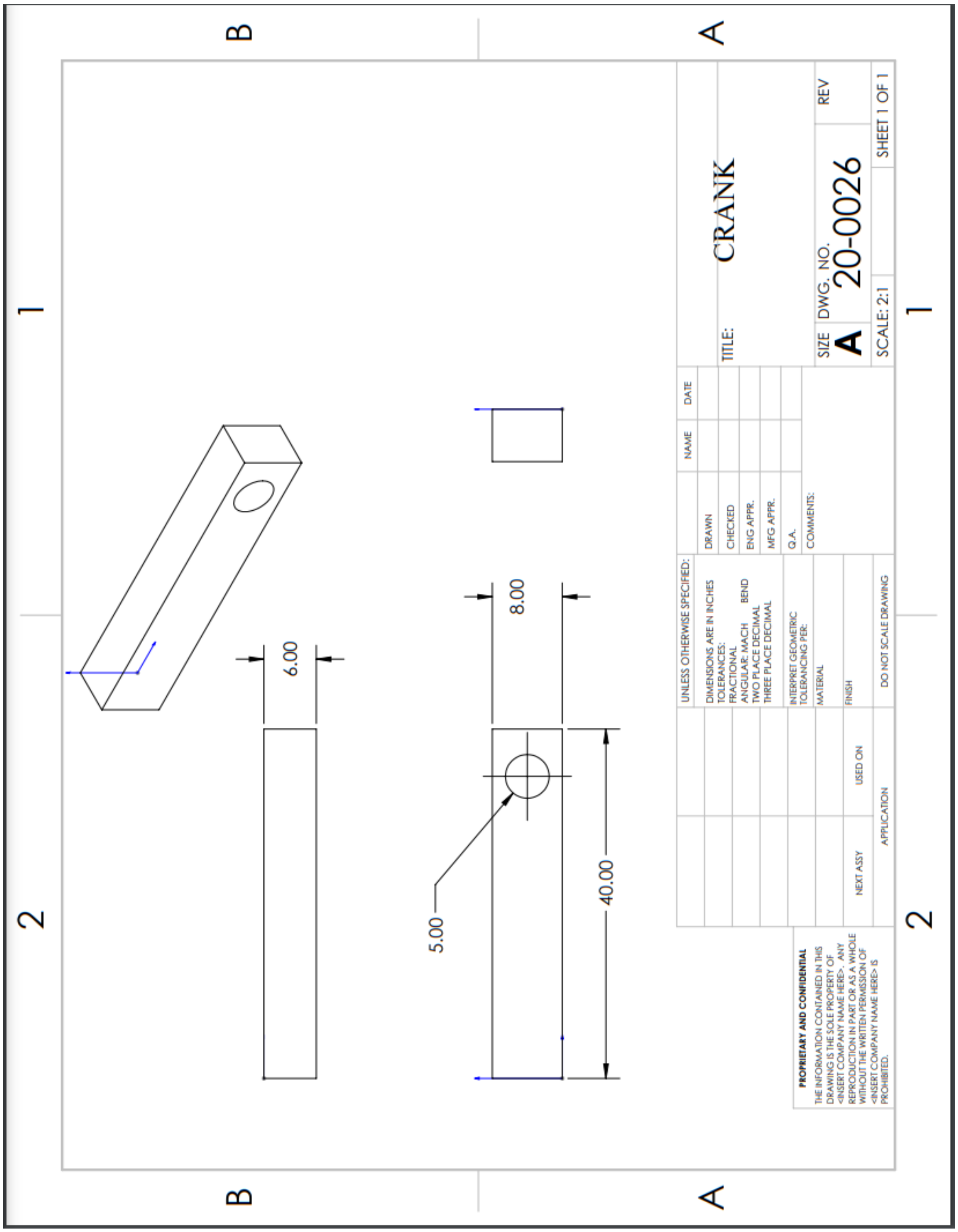
Appendix B-8: Crank Lock EXCLUDED



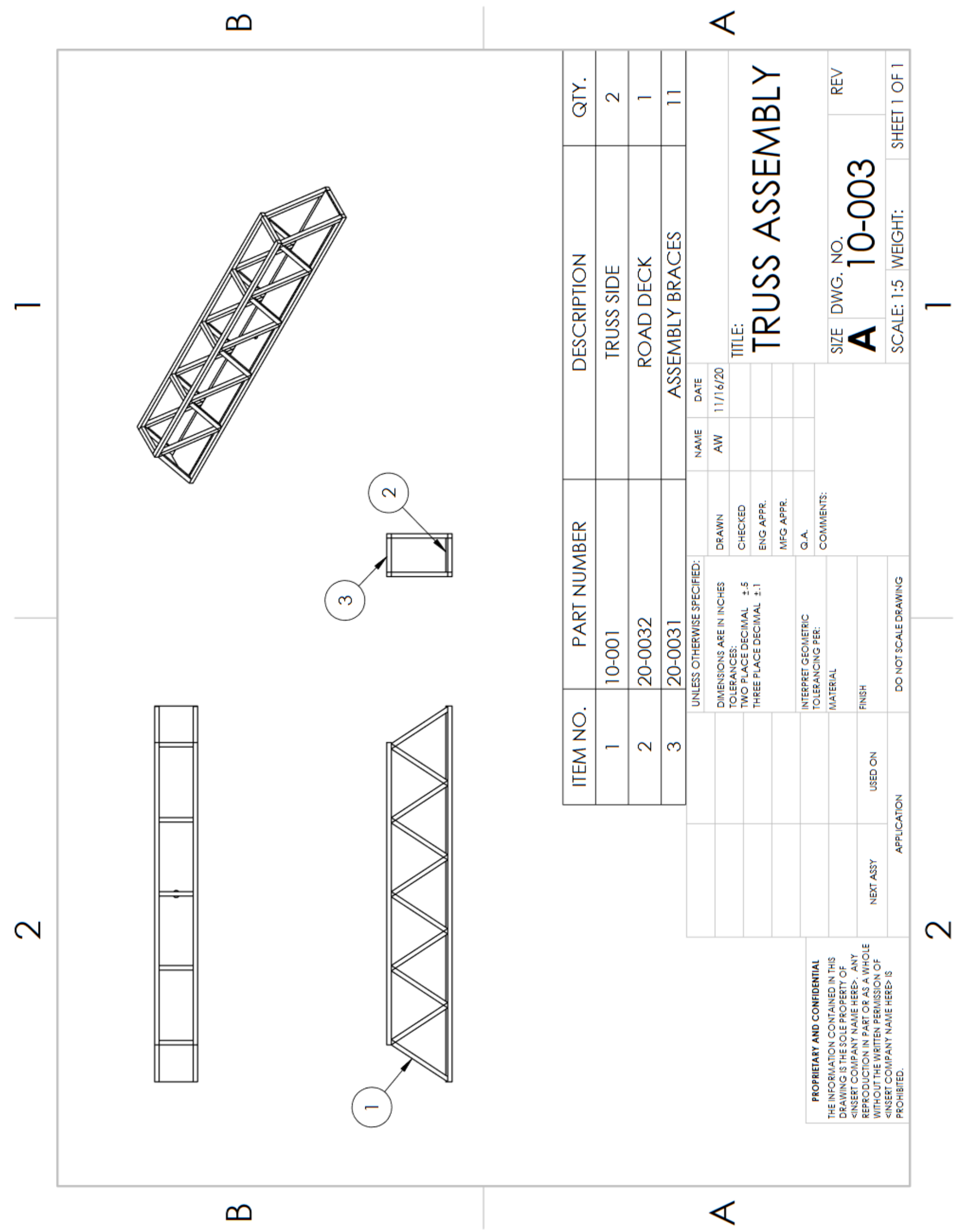
Appendix B-8a: Crank ADDITION



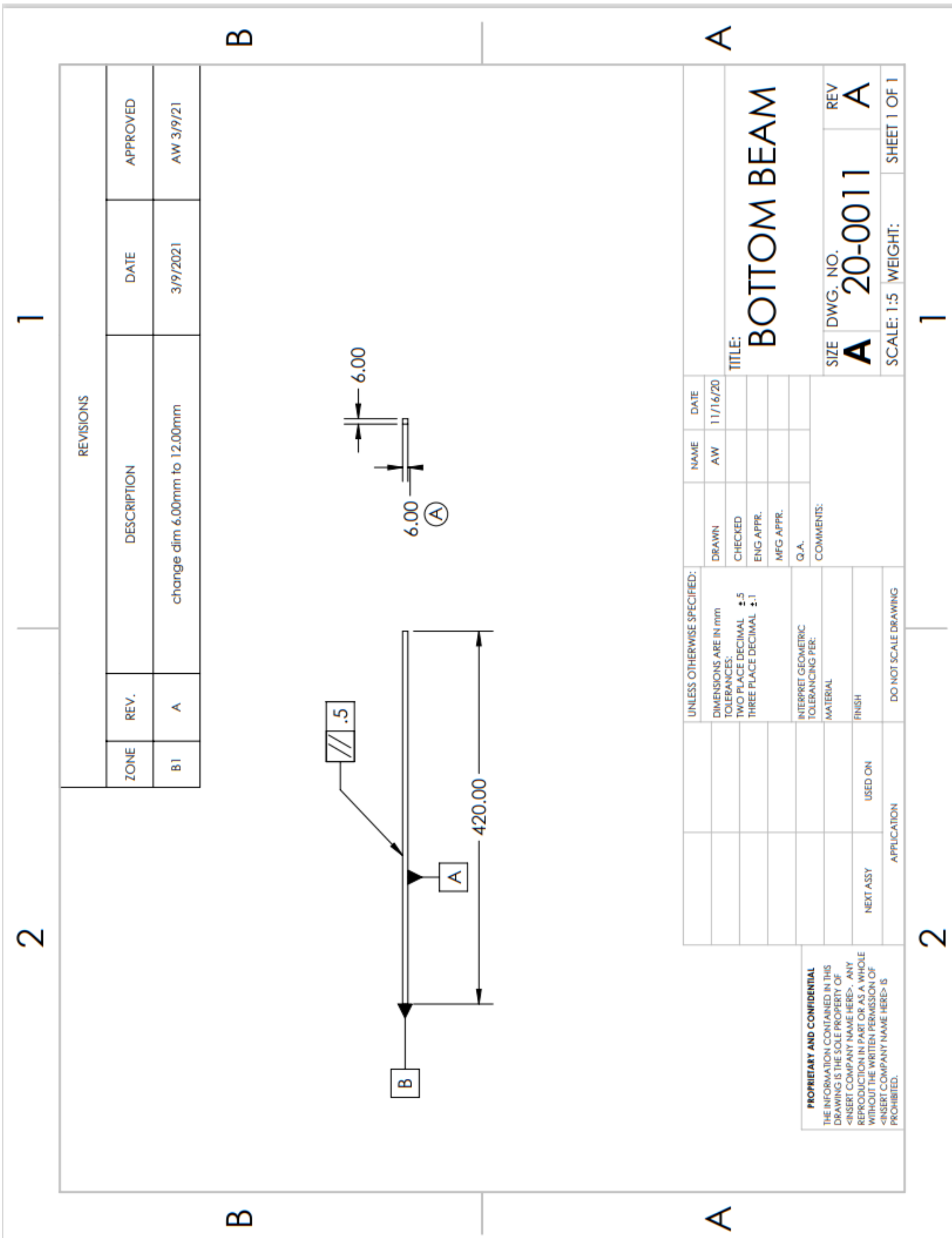
Appendix B-8b: Lock ADDITION



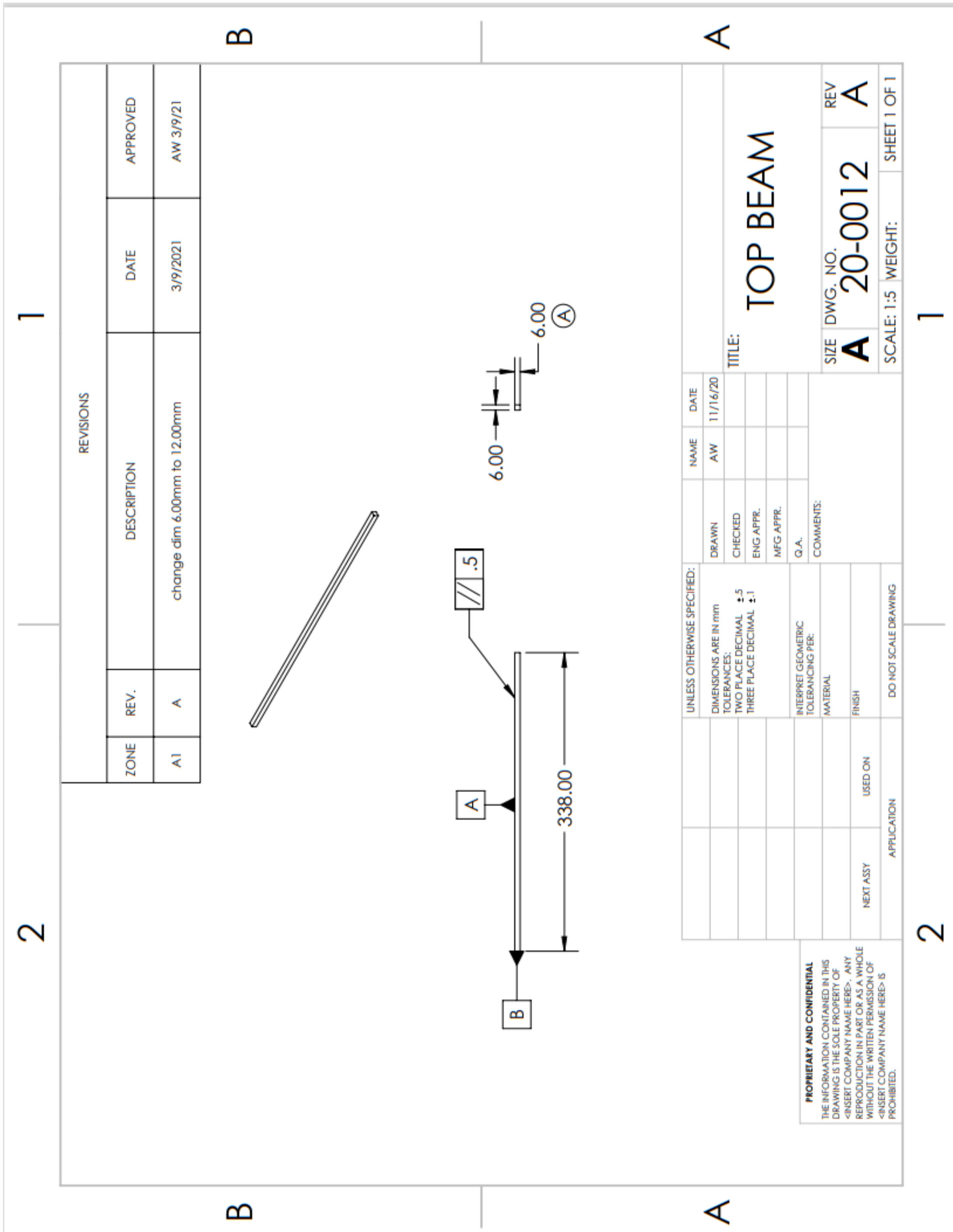
Appendix B-9: Truss Assembly



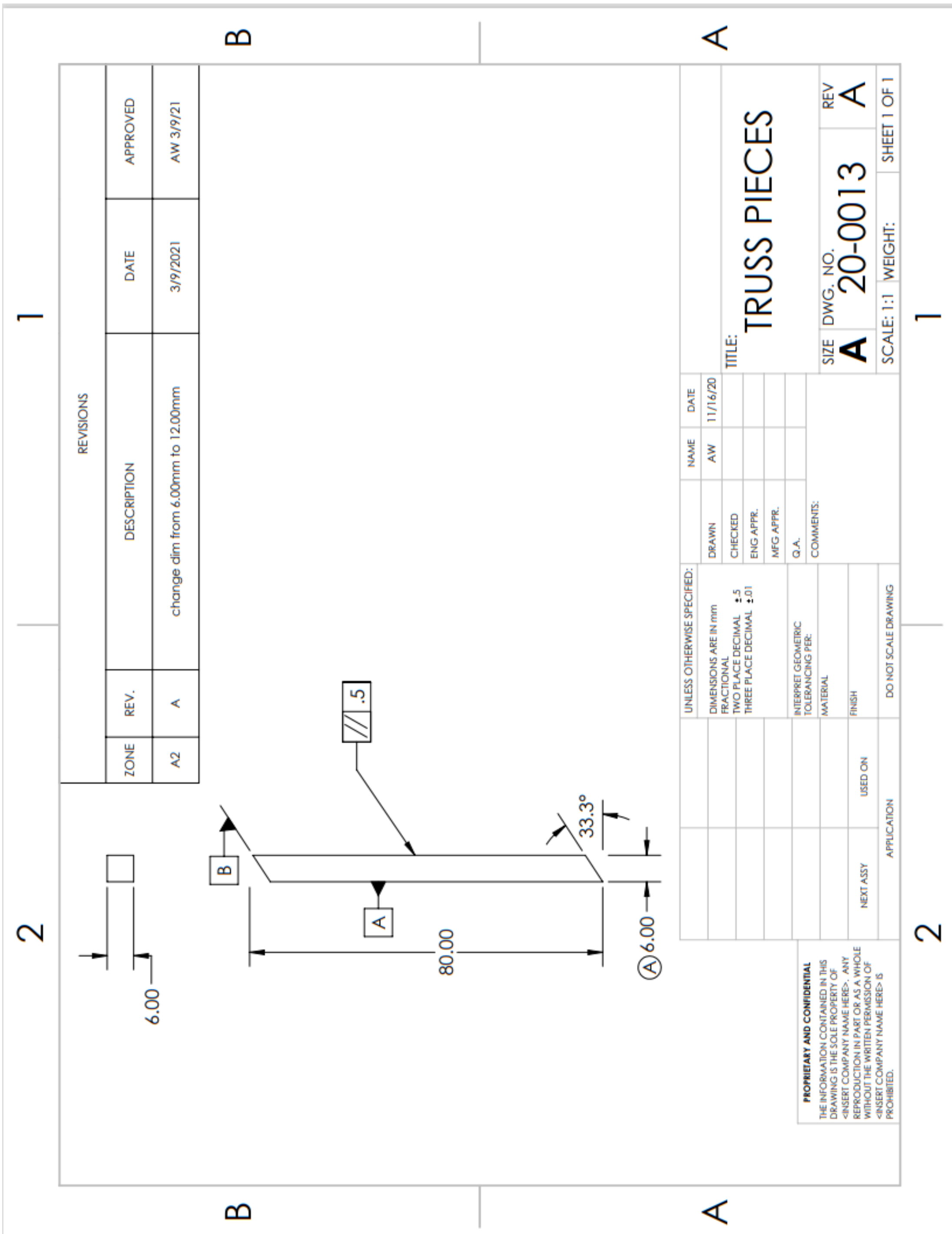
Appendix B-10: Truss top beam



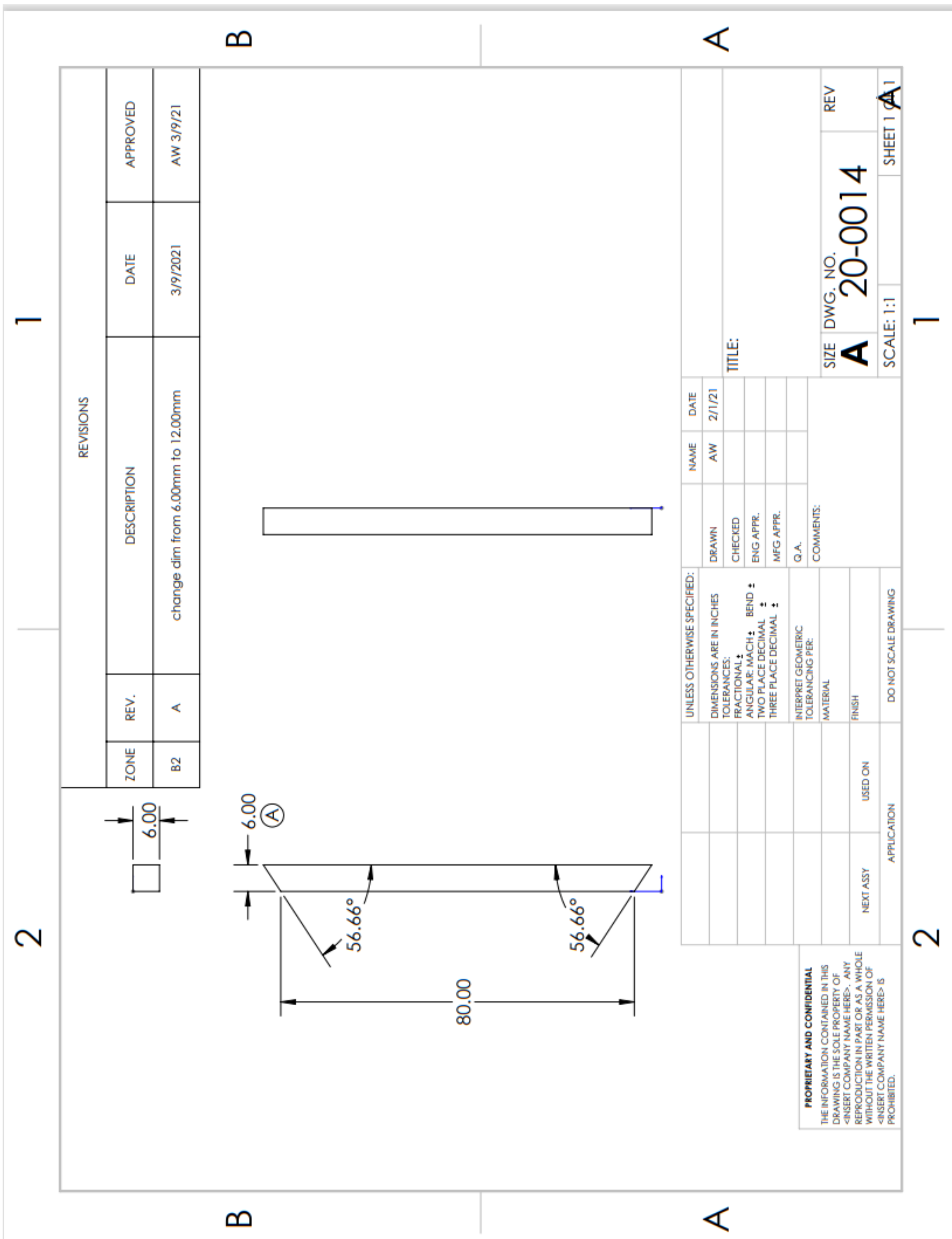
Appendix B-11: Bottom Beam



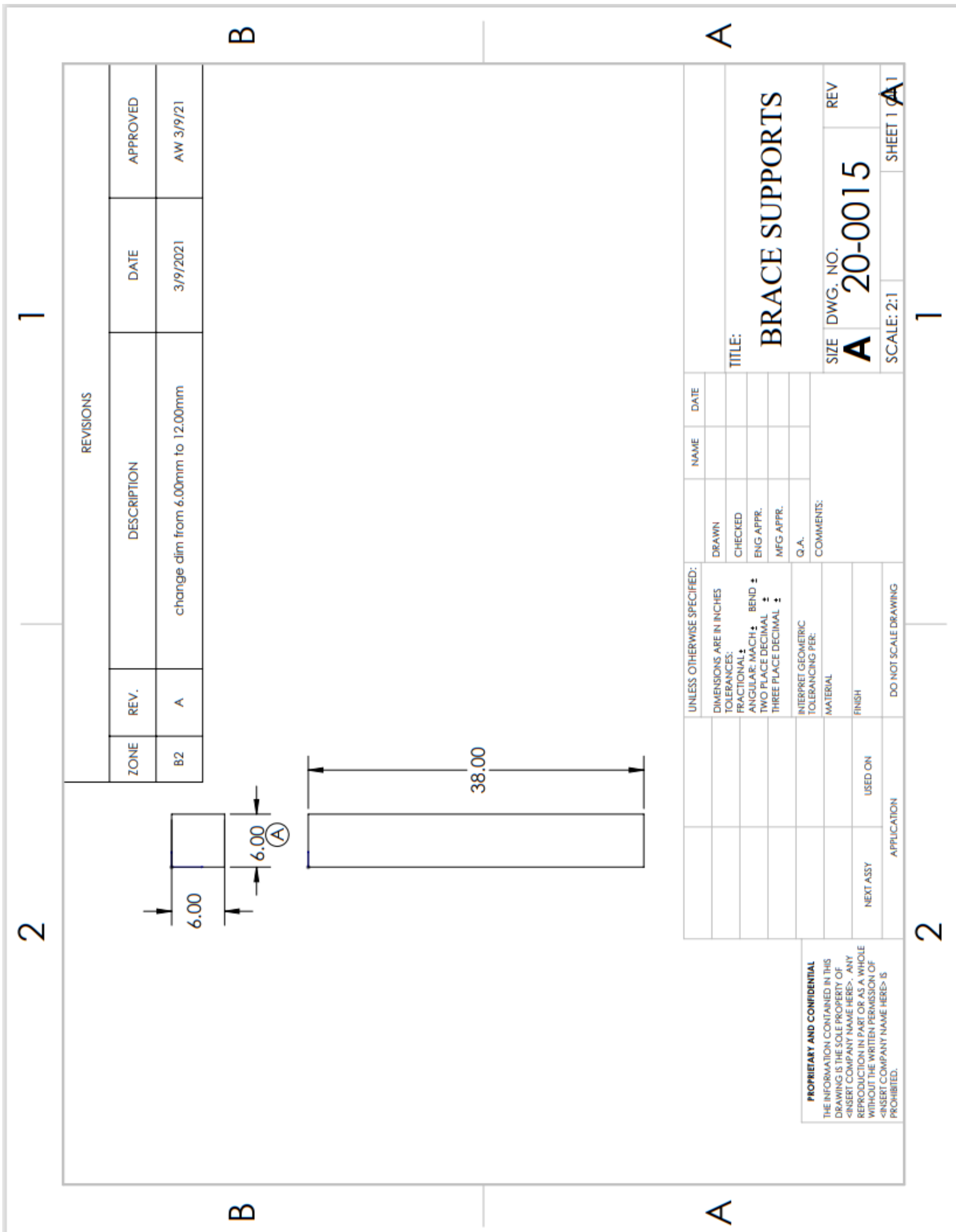
Appendix B-12: Truss Pieces



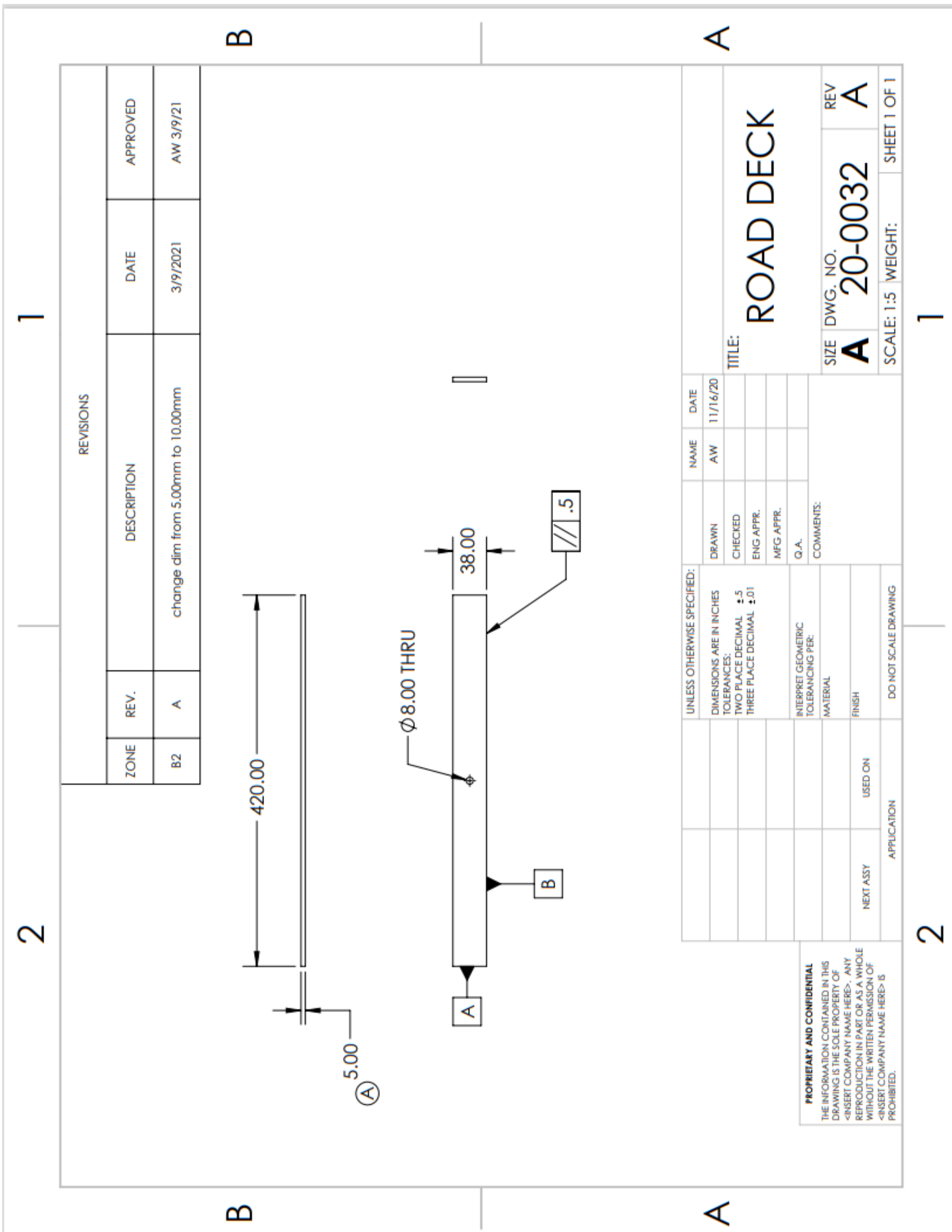
Appendix B-13: Assembly Braces



Appendix B-14: End Supports



Appendix B-15: Road Deck



Appendix C - Parts List

Part #	Qty	Description	Source	Cost
20-0012	2	5mmx5mmx350mm top beam	Amazon	8c
20-0013	24	5mmx5mmx80mm truss pieces	amazon	2c
20-0011	2	5mmx5mmx420mm Bottom beam	Amazon	9c
20-0032	1	38mmx420mmx2mm road deck	Amazon	65c
20-0031	9	38mmx5mmx5mm side supports	Amazon	2c
55-001	1	Wood glue	Amazon	$10
20-0043	4	10mmx10mmx100mm long side	Amazon	16c
20-0042	2	10mmx10mmx200mm legs	Amazon	12c
20-0044	2	10mmx10mmx40mm brace support	Amazon	4c
20-0041	4	20mmx20mmx10mm brace feet	Amazon	2c
50-001	4	6mm pulley	amazon	$3
20-0021	1	4mm Crank shaft	Amazon	$4
20-0022	1	Crank Lock gear	Amazon	$1
20-0023	1	Lock	Amazon	$3
50-003	1	Crank wheel	amazon	$4
55-002	1	.5m Pulley rope	warehouse	$0

APPENDIX D – Budget

Part #	Qty	Cost per part	Total
20-0012	2	8c	$.16
20-0013	24	2c	$.48
20-0011	2	9c	$.18
20-0032	1	65c	$.65
20-0031	9	2c	$.18
55-001	1	$10	$10
20-0043	4	16c	$.96
20-0042	2	4c	$.08
20-0044	2	2c	$.08
20-0041	4	$3	$12
50-001	4	$4	$4
20-0021	1	$1	$1
20-0022	1	$3	$3
20-0023	1	$4	$4
50-003	1	$0	$0
55-002	1	$.5	$.5

Total:
Cost of items + labor costs + miscellaneous costs= total budget

$37.27 + $0 + $12.73 = $50

APPENDIX E – Schedule

PROJECT TITLE: Balsa Bridge														
Principal Investigator.: Anndie Watterson														
		Duration												
TASK: ID	Description	Est. (hrs)	Actua (hrs)	%Com	Septembe	October	November	Dec	January	February	March	April	May	June
1	Proposal*													
1a	Outline	1	0.5											
1b	Intro	2	2											
1c	Methods	1	2											
1d	Analysis	12	20											
1e	Discussion		2											
1f	Parts and Budget	1	1											
1g	Drawings	10	12											
1h	Schedule	1	1											
1i	Summary & Appx		2											
	subtotal:	28	42.5											
2	Analyses													
2a	Truss 1	2	2											
2b	Pulley system	2	2											
2c	Brace	2	2											
2d	Truss 2	2	2											
2e	Combined truss and brace	2	2											
	subtotal:	10	10											
3	Documentation													
3a	Truss dwg	2	2											
3b	Brace dwg	1	1											
3c	Brace component dwg	1	1											
3d	Brace assembly	1	1											
3e	Truss 2 dwg	2	2											
3f	Entire assembly	1	2											
	subtotal:	8	9											
4	Proposal Mods													
4a	Bridge schedule	1	1											
4b	Bridge part inv.	1	1											
4c	Crit Des Review*	1	1											
	subtotal:	3	3											
7	Part Construction													
7a	Order wood and glue	1	2											
7b	Cut truss pieces to size	6	6											
7c	Assemle trusses	2	2											
7d	Cut brace pieces	1.5	2											
7e	Make pins	1	2											
	subtotal:	11.5	14											
9	Device Construct													
9a	Assemble truss	2	2											
9b	Assemble brace	1.5	2											
9c	Assemble truss and brace	1	1											
9d	Take dev pictures	1	1											
9e	Update website	1	1											
	subtotal:	6.5	7											
10	Device Evaluation													
10a	List Parameters		1											
10b	Design Test&Scope		1											
10c	Obtain resources		1											
10d	Make test sheets		1											
10e	Plan analyses		1											
10f	Instrument Robot		1											
10g	Test Plan*		1											
10h	Perform Evaluation		1											
10i	Take Testing Pics		1											
10h	Update Website		1											
	subtotal:	0	10											
11	489 Deliverables													
11a	Get Report Guide		1											
11b	Make Rep Outline		1											
11c	Write Report		1											
11d	Make Slide Outline		1											
11e	Create Presentation		1											
11f	Make CD Deliv. List		1											
11e	Write 495 CD parts		1											
11f	Update Website		1											
11g	Project CD*		1											
	subtotal:	0	9											
	Total Est. Hours=	67	2820				=Total Actual Hrs							
Labor!	100	6700												
Note:	Deliverables*													
	Draft Proposal													
	Analyses Mod													
	Document Mods													
	Final Proposal													
	Part Construction													
	Device Construct													
	Device Evaluation													
	495 Deliverables													

APPENDIX F – Expertise and Resources

Without the expertise and assistance offered by all current or recent past professors in the Central Washington University mechanical engineering technology program, the design and construction of this project could not have been completed. The use of software programs provided by CWU were also essential to the process.
The construction could not have been completed without the assistance of the family of the engineer, who provided resources used in the process.

APPENDIX G – Testing Report

Weight of bridge:
    Less than 83 grams? (Y/N):

Length of bridge:
    At least 400 mm? (Y/N):

Object capable of passing through bridge on road deck? (Y/N):

Road deck within 12mm of abutment? (Y/N):

Road deck curvature:
    Less than 25mm? (Y/N):

Bridge raised at least 120 mm and locked for 10 seconds? (Y/N):

Bridge holds 18.9-20 kg of weight? (Y/N):

Success criteria: if "yes" is answered to all questions above: Success

APPENDIX G-1
Testing report 1: road deck functionality

The test procedure for the car crossover functionality test:

14. Collect equipment
    a. 25mm x 32mm block of wood to represent the "car"
    b. Tablet with a functioning camera
    c. The bridge, not including the brace
    d. A ruler that will be used to push the car
    e. A printed test report sheet and a pen
15. Take all the equipment to the designated testing table in the mud room of the Lund residence.
16. Set up the tablet using the free-standing case on the South West corner of the table with the camera app open
17. Place the bridge on the table 24 inches directly in front of the camera from the tablet, parallel to the tablet
18. Set the block on the right end of the bridge, "right" being determined by standing behind the tablet and looking at the bridge. The layout should look similar to what is pictured below (North is up)

19. While holding the ruler, start recording on the tablet.
20. Use the ruler to push the block across the entire bridge at a rate close to one in which the entire crossing takes roughly 5 seconds. Do not push the block off the bridge.
21. Turn the bridge 90 degrees counter-clockwise and move it within 12 inches of the camera so that the short end of the bridge is clearly visible on to the camera, similar to below (North is up)

22. Use the ruler to measure the height of the road deck in millimeters from the table to the top of the deck, standing to the side of the video to ensure the measurement taken is visible on the video.
23. Stop recording
24. Record the bridge deck height on the test report sheet. Use the camera of the tablet to take a picture of the sheet
25. Edit the video so that walking to and from the bridge is cut out and ensure that the bridge is well visible and centered in the video.
26. Compress the video and send it from the tablet along with the picture of the test report sheet via email to wattersona@cwu.edu. Use the "send from photos" feature and select the Microsoft Outlook app. Include in the email any issues that occurred during the test, or any changes or variations from the test procedure.

APPENDIX H – Resume

Anndie Watterson

wattersona@cwu.edu 801-380-9299

Summary

I have always been described as a very passionate and dedicated person, both in and out of the work place. I enjoy learning new skills and working at a fast and productive pace, while still producing quality work. I get along well with others and work great on my own. I interact professionally and confidently with costumers, superiors, and peers. I strive to do the best job I can every day, and fulfill my duties to the best of my abilities.

Work Experience

Laborer at Western Ridge Concrete, Cedar Valley Utah. May 2014-November 2015
Western Ridge Concrete specializes in footings for residential buildings. My duties at the company were to help lay out houses, set up forms, pour concrete, and remove forms when done.
Reference: Tandie Watterson (co-owner) 801-319-5156

Veterinary Technician at South Valley Equine, South Jordan Utah. May 2016-September 2019
I worked at South Valley as an equine veterinary technician. I was expected to assist an assigned vet, handle horses, clean up facilities if needed between appointments, go on farm calls, prep for injections and procedures, and assist with surgeries. On days that I work as the hospital technician, I was in charge of treating anywhere from around 10-45 horses, and keeping a close eye on any critical/emergency cases, and horses on fluids.
Reference: Amanda Nielson (senior technician) 801-243-3087

Hospital/Boarding Caretaker, Valley Veterinary, Ellensburg Wa. February 2017-April 2018
At Valley Vet, my primary position was boarding caretaker, where I was responsible for looking after all boarding animals. This included letting dogs out, feeding and medicating all animals, keeping a clean work space and ensuring that kennels were clean, and assisting in the arrival or departure of animals. I was also responsible for cleaning the boarding facility at the end of the day. I also occasionally worked as a veterinary technician assistant in the animal hospital.
Reference: Melissa Wolford (boarding manager and senior tech) 509-607-9771

GIS Technician at Central Washington University Facilities Mgt. December 2019-June 2020.
My primary duty was to update the University's AutoCAD drawings for campus buildings to include data used for space-assigning and area usage statistics. I was also tasked with redrawing several buildings in AutoCAD, doing locates on campus, tracking progress on ongoing projects, and inserting new structures into the master campus map.
Reference: Cheyanne Manning (student employee manager) 509-899-9454

Education

I graduated from Westlake High school in May 2016 with a GPA of 3.64. I am currently attending Central Washington University as a Mechanical Engineering Technology student, with plans to graduate in the spring of 2021. I am a certified SolidWorks user, and I am currently pursuing the Lean Manufacturing Bronze certification.