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Grant County Public Utilities District - Rotor Pole Lifting Device

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GCPUD Rotor Pole Lifting Device

Baylie Johnson

TABLE OF CONTENTS

INTRODUCTION

MOTIVATION

In August 2016, Grant County PUD plans to begin upgrades to the turbines and generators of all 10 hydroelectric units. The generator rotor poles will need to be detached from the generators rotor and placed into a shipping container. The poles will then be shipped to a location where they will be refurbished and later sent back. This lifting device will then need to place the pole back onto the rotor.

A device that can do these things quickly does not currently exist for Priest Rapids. This project will include the design and analysis, manufacture and testing of a rotor pole lifting device.

FUNCTION STATEMENT

This device is to perform the following:

- To lift and orient the generator rotor poles during upgrades and maintenance.

REQUIREMENTS

The device is required to withstand the following conditions:

- The device must lift 3500 pounds straight up with a safety factor of 5.
- The device must last 10+ years and lift an approximate total of 1,680 poles.
- The device has a production quantity of 2.
- The weight of the lifting device and rotor pole must not exceed crane limits (10,000 lbs).
- The device must cost less than $10,000.
- The device must be able to fit between installed rotor poles.
- The device must interface with the available crane.

ENGINEERING MERIT

The function of this device is to lift a weight. All materials and connections must be able to support all loads applied to them. These loads will be applied is different ways based on the orientation of the device. Each part of the device will be looked at in its maximum stress scenario, and the parts will be made in a way that keeps this stress under the maximum stress of the material.

SCOPE OF EFFORT

The entire lifting device will be designed by the turbine/generator engineering team at Grant County PUD. Then, the device will be manufactured and assembled at the expense of Grant County PUD. Lastly, the device will be tested by engineers and maintenance workers at Priest Rapids Dam.

SUCCESS CRITERIA

The success of this device is based on the ability for the device to be used as intended. Multiple load tests will be performed to test the success of the device.

DESIGN AND ANALYSIS

APPROACH & BENCHMARK

This design is based on a similar design made by Alstom and used for installing generator rotor poles at Wanapum Dam. There is a drawing for a device used by English Electric when Priest Rapids Dam was first constructed. Through discussion with a diverse group of people, a design similar to the one used at Wanapum was chosen because of the ease of use and the ability to build this design in a way that would allow it to be used when the rotor is installed in the unit as well as when it is outside the unit. The image to the right shows the device being used at Wanapum.

A decision matrix (shown below) was also used to decide on the better design.

	Importance Factor	**EE Design**	**Importance**	**WAN Design**	**Importance**
Safety	3	1	3	2	6
Ease of Use	2	1	2	2	4
Ease of Manufacturing	1	2	2	1	1
Likelihood of Pole Damage	2	1	2	2	4
Likelihood of lost pieces	2	1	2	2	4
Ability to use for maintenance	1	1	1	2	2
		Total:	12	Total:	21

PERFORMANCE PREDICTIONS

No part of the device will exceed a strain of 400 µs for A36 parts. This strain was determined based on a maximum stress of 12,000 psi and a modulus of elasticity of 29,000 ksi.

DESIGN PARAMETERS

For A36 Structural Steel parts:

Minimum Ultimate Strength of Structural Steel	$S_{ultimate}$ = 60000 lb_f/in^2
Safety Factor Required	n = 5
Maximum Allowable Tensile Stress	$\sigma_{max} = \frac{S_{ultimate}}{n}$ = 12000 lb_f/in^2
Maximum Allowable Shear Stress	$\tau_{max} = \frac{0.577S_{ultimate}}{n}$ = 6924 lb_f/in^2

For Weld Joints:

Minimum Ultimate Strength of Weld Metal	S_{weld} = 70000 lb_f/in^2
Safety Factor Required	n = 5
Maximum Allowable Tensile Stress	$\sigma_{max\ weld} = \frac{S_{weld}}{n}$ = 14000 lb_f/in^2
Maximum Allowable Shear Stress	$\tau_{max\ weld} = \frac{0.577S_{weld}}{n}$ = 8078 lb_f/in^2

SCOPE OF TESTING AND EVALUATION

Testing of this device included two load tests; one test loaded the device when it was in a vertical position and the other when the device in a horizontal position.

OTHER DEVICE DECISIONS

Most of the design decisions that were not made based on calculations were based on items similar to those found on Wanapum's device. For instance, the size of the hole used in the crane lug is the same size as that used in Wanapum's device to ensure that the proper equipment was available.

TECHNICAL RISK ANALYSIS

The risks involved in this project are somewhat minimal. The most risk is within the manufacturing portion of this device. Getting a shop to build the device in the necessary time frame and getting them to actually deliver on time is the riskiest element of this build.

FAILURE MODE ANALYSES

The failure modes of each part and all connections were analyzed in Appendix A. Different parts have different critical load scenarios and therefore they were each analyzed based on this scenario.

SAFETY FACTORS

The rule of thumb at Grant County PUD is that any overhead lifting device requires a safety factor of 5. Although not all of the parts of this device are intended to be used overhead, a common safety factor of 5 was used throughout the analysis.

OPERATION LIMITS

This device is intended to be used with a crane rated at, at least 10,000 pounds. Using this device for a rotor pole on a smaller crane could result in failure.

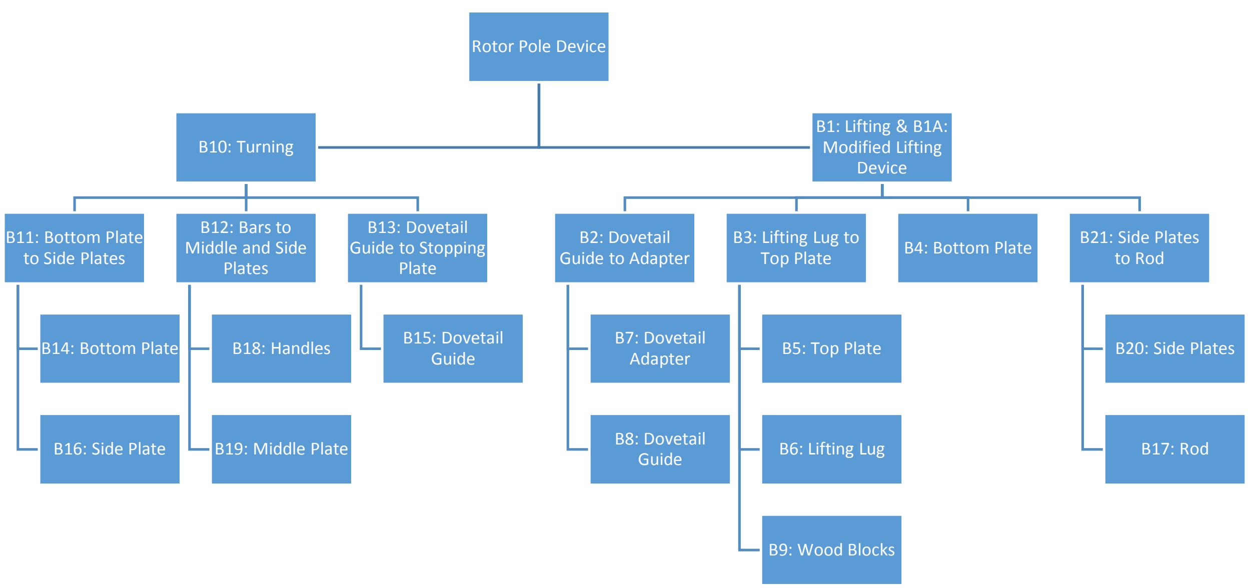
METHODS AND CONSTRUCTION

DESCRIPTION

This project was conceived, analyzed and designed at both Central Washington University and Grant County Public Utilities District. Grant County PUD has outsourced the construction of the device to Busby International, Co.

DRAWING TREE, DRAWING ID'S

The drawing tree below shows the drawing numbers and names for each drawing and how they relate to each other. The turning device is comprised of three subassemblies, each include their own parts. The lifting device is comprised of three subassemblies, each with parts, and one part that is not included in any subassemblies.



PARTS LIST AND LABELS

Lifting Device:

B1: Lifting Device Bill of Materials
B1A: Modified Lifting Device Assembly
B2: Dovetail Guide to Adapter
B3: Lifting Lug to Top Plate
B4: Bottom Plate
B5: Top Plate
B6: Lifting Lug
B7: Dovetail Adapter
B8: Dovetail Guide
B9: Wood Blocks
B17: Threaded Rod
B20: Lifting Device Side Plates
B21: Side Plate to Rod Welds

Turning Device:

B10: Turning Device Bill of Materials
B11: Bottom Plate to Side Plates
B12: Bars to Middle and Side Plates
B13: Dovetail Guide and Stopping Plate
B14: Bottom Plate
B15: Dovetail Guide
B16: Side Plate
B18: Handles
B19: Middle Plate

MANUFACTURING ISSUES

The manufacturing of this device occurred at Busby International, Co in Moses Lake, WA following the guidelines laid out in the technical specification found in Appendix E. Extensive equipment and expertise is available at this facility.

Manufacturing issues were mainly trouble with constructing the device as the engineer (who is fairly inexperienced) had designed it. This included the weld size between the side plates and the bottom plate of the turning device. Creating a 5/8 inch weld on a ¼ inch plate is not common practice. It was decided that this weld could be down sized to ¼ inch because the 5/8 inch weld was based on a safety factor of 5, which is not necessary for the turning device because it will never be lifted overhead. Most other issues were simply that the drawings needed either more information or clarification.

After the device was delivered to Priest Rapids Dam it was load tested and then an attempt to use the device was made. Although the load test went very well, during the attempt to use the device it was found that the bottom plate was too large to pull the pole straight up without hitting the poles on either side of the pole being removed. This issue required a complete redesign because simply making the bottom plate smaller would create a loss of material to hold the rods. The redesign changed the rods to plates that bolt to the outside ends of the bottom plate.

OPERATION

Horizontal to Vertical –

The first thing to do is secure the device around the rotor pole. This will take two people to accomplish. The two should hold the device around the pole and tighten the nuts to 75 ft*lb. Then the turning device should be slid onto the pole. The crane can then begin to lift the pole. The turning device will allow it to come to a vertical position without damaging the pole. Once the pole is vertical, someone needs to hold onto the turning device while the crane lifts the rotor pole up. The turning device should always remain on the ground.

Putting the pole on the rotor (inside or outside unit) –

The pole should be lifted above the generator rotor. With someone guiding the pole, the crane can slowly lower the pole into place. Once the pole is about half way down the rotor, the dovetail adapter piece can be removed by unscrewing the bolts and sliding the piece upward. The pole can then be lowered the rest of the way into the rotor. If the rotor is outside the unit, the nuts can be loosened and the device can be moved horizontally away from the pole. If the rotor is inside the unit, the bottom plate must be detached completely and then the crane can lift the rest of the device up and out of the unit.

Taking the pole off the rotor (outside unit) –

The device, without the dovetail guide attached, can be lifted by the crane to a place where the device can be slid horizontally onto the rotor pole. Once the device is in position, the nuts should be tighten to 75 ft*lb. The crane can then begin to pull the pole up. Once the pole is halfway out of the rotor, the dovetail guide should be secured to the device. The pole can then be pulled off of the rotor.

Taking the pole off the rotor (inside unit) –

The device, without the dovetail guide or the bottom plate attached, can be lifted above the generator. The side plates should be lined up so that they are lowered in between the poles. Once the top plate is resting on the pole, the bottom plate can be secured to the device. The crane can then begin to pull the pole up. Once the pole is halfway out of the rotor, the dovetail guide should be secured to the device to prevent the pole from sliding out one side of the device. The pole can then be pulled off of the rotor.

Vertical to Horizontal –

As the rotor pole approaches the floor, someone should be guiding the pole into the turning device. Once the pole is resting on the turning device, the pole can be lowered to a horizontal position.

DISCUSSION OF PARTS MANUFACTURING

Busby International, Co has the freedom to construct the device in the order and manner that they see fit, as long as the device is delivered on time. The dovetails will be outsourced to a secondary supplier because Busby does not have the resources to complete this part themselves.

TESTING METHOD

INTRODUCTION

The main goal of this device is to be able to lift 3500 pounds with a safety factor of 5. This requirement will be measured through two load tests. One test will be performed in a vertical lifting manor in order to test the integrity of the top plate and side plates. The second test will be performed in a horizontal lifting manor in order to test the integrity of the dovetails.

METHOD/APPROACH

For vertical testing, the device will be mounted to the floor and attached to the crane with a dynamometer between the device and the crane to properly load the device to specified loads. At each load, the strain will be recorded from each strain gage. Three strain gages were used for this test. Two were located on one of the rods. One was oriented axially to measure elongation and the other radially to measure any change in diameter. The third strain gage was located on the top of the top plate to measure and bending in the plate.

For horizontal testing, both top plate/dovetail subassemblies were placed on either side of a rotor pole. They were then attached to a crane and lifted. There was one strain gage placed on the dovetail adapter plate to record any bending in the plate.

When the rotor pole is being tilted to or from a horizontal position the load is being carried in the dovetail. It was decided that this test be performed to ensure safety. Based on a distance from the strain gage to the midpoint of dovetail contact, the strain read by the strain gage should have been 195 µs.

TEST PROCEDURE

Vertical and horizontal testing follow the same basic procedure, however the configuration of the device is different in each scenario. The basic procedure is to set up the device in the desired configuration, set up the strain gages and then use the crane to apply four different loads and measure the load and strain.

DELIVERABLES

The full test reports, including the configuration of the device in each case, can be found in Appendix I.

BUDGET

Busby International, Inc. manufactured two rotor pole lifting and turning devices for an after tax cost of $17,809.97. This amount was paid to them after the delivery of the devices to the Hydro Warehouse located at Wanapum Dam on Friday, February 12, 2016.

After attempting to use the original device, it was found that modifications needed to be made in order to use the device. A change order to the purchase order was approved on Monday, February 29, 2016. This change order was quoted at $1,705.00.

The total cost of two lifting and turning devices, after tax, came to $19,649.67. This does not include the labor required for testing the devices.

PROPOSED SCHEDULE

The Gantt chart that was created for this project acted as a guideline for the class. It shows that a proposal was due on Wednesday, December 9, 2015, that the device was to be built by Wednesday March 9, 2016 and that the testing be completed by Wednesday June 1, 2016.

This Gantt chart shows that it should take a total of 210 hours to complete this project. The actual amount of time spent on the project was 271 hours.

PROJECT MANAGEMENT

HUMAN RESOURCES:

Engineering resources include Brad Strickler, Molly Hill, Steve Gwynn and Pat Oldham.

Manufacturing resources include Steve Stanley, Arkady Pashovsky and other employees of Busby International, Inc.

Testing resources include GCPUD employees Tom Marty, Beau Campbell and Mike Garrett.

PHYSICAL RESOURCES:

Grant County PUD supplied all physical resources for testing, except for strain reading equipment, which was provided by GCPUD. PUD equipment includes the crane, shackles and spare rotor poles. Manufacturing resources were all supplied by Busby International, Inc.

SOFT RESOURCES:

Resources such as SolidWorks and Microsoft Office applications were provided by both Grant County PUD and Central Washington University.

FINANCIAL RESOURCES:

All financials of this project are taken care of by GCPUD.

DISCUSSION

DESIGN EVOLUTION / PERFORMANCE CREEP

When this project was first presented, a drawing of the device used by English Electric during the original construction of the dam was available. At first, this was the only information given and a SolidWorks model had begun to attempt FEA analysis.

After some discussion and further research, it became apparent that Wanapum Dam had a device that was being used during the construction of their generators. Further information gathering on this device was done. The next step was to discuss the preferred design with other people who had knowledge of the use of each device. The ultimate conclusion of the discussion was that a device similar to that at Wanapum but with some modifications was the best decision.

Once the drawings were approved, they were sent out for bid and Busby International, Inc. was awarded the bid. Once they began work, they had several suggestions to make manufacturing easier that did not hinder the integrity of the device. Most of these suggestions were taken.

The device was delivered to Grant County PUD and vertically load tested before use. The first attempt at use proved that the bottom plate was too large to pull straight up through the installed poles on either side of the one being removed. This meant that the device did not work and redesign was required.

The redesign required some parts to be modified and others to be made. These changes were done by Busby International, Inc. and sent back to Grant PUD.

The device was then vertically and horizontally load tested and these tests showed that the device was ready for use.

PROJECT RISK ANALYSIS

This project required quite a bit of coordination. The coordination between CWU and GCPUD was quite difficult at times. Things that were acceptable for the District were not acceptable for CWU and vice versa. Luckily, most aspects of the project were started early and this allowed for there to be time to coordinate between locations.

SUCCESSFUL

This project can be considered a success in the idea that a great amount of real life knowledge has been gained. Reports such as these will be required in the future and the experience of writing one will prove to be very useful. Also, experience working with an outside manufacturer is great.

The design can now be considered successful because it is ready to be used during the rehabilitation of Priest Rapids Dam generators.

CONCLUSION

This proposal has shown that this device is ready to be used. The analysis was done paying careful attention to the loads and stress that would be created in each component and their connections. This device has the following capabilities:

- It lifts 3500 lbs with a safety factor of 5.
- It cost less than $10,000 per device.
- It lifts and orients the rotor poles without damaging the poles.
- It is able to operate during construction and also during maintenance.

This device was designed specifically for Priest Rapids Dam and will be a great addition to their custom lifting devices. The device will work for the many years ahead that will be spent rehabilitating the generators and hopefully even longer than that.

ACKNOWLEDGEMENTS

Grant County Public Utilities District sponsored this project for use at their facilities.

The Turbine/Generator engineering group at Grant County PUD, including engineers Molly Hill, Brad Strickler, Steve Gwynn and Pat Oldham, along with Dr. Johnson and Professor Pringle at Central Washington University mentored the design engineer to create a successful device.

The first vertical test was assisted by Grant County PUD hydro mechanic foreman Tom Marty and hydro mechanic Beau Campbell.

The second vertical test was assisted by Grant County PUD hydro mechanic Beau Campbell.

The horizontal test was assisted by Grant County PUD hydro mechanics Beau Campbell and Mike Garrett.

Busby International, Inc. constructed and later modified the device in Moses Lake, WA.

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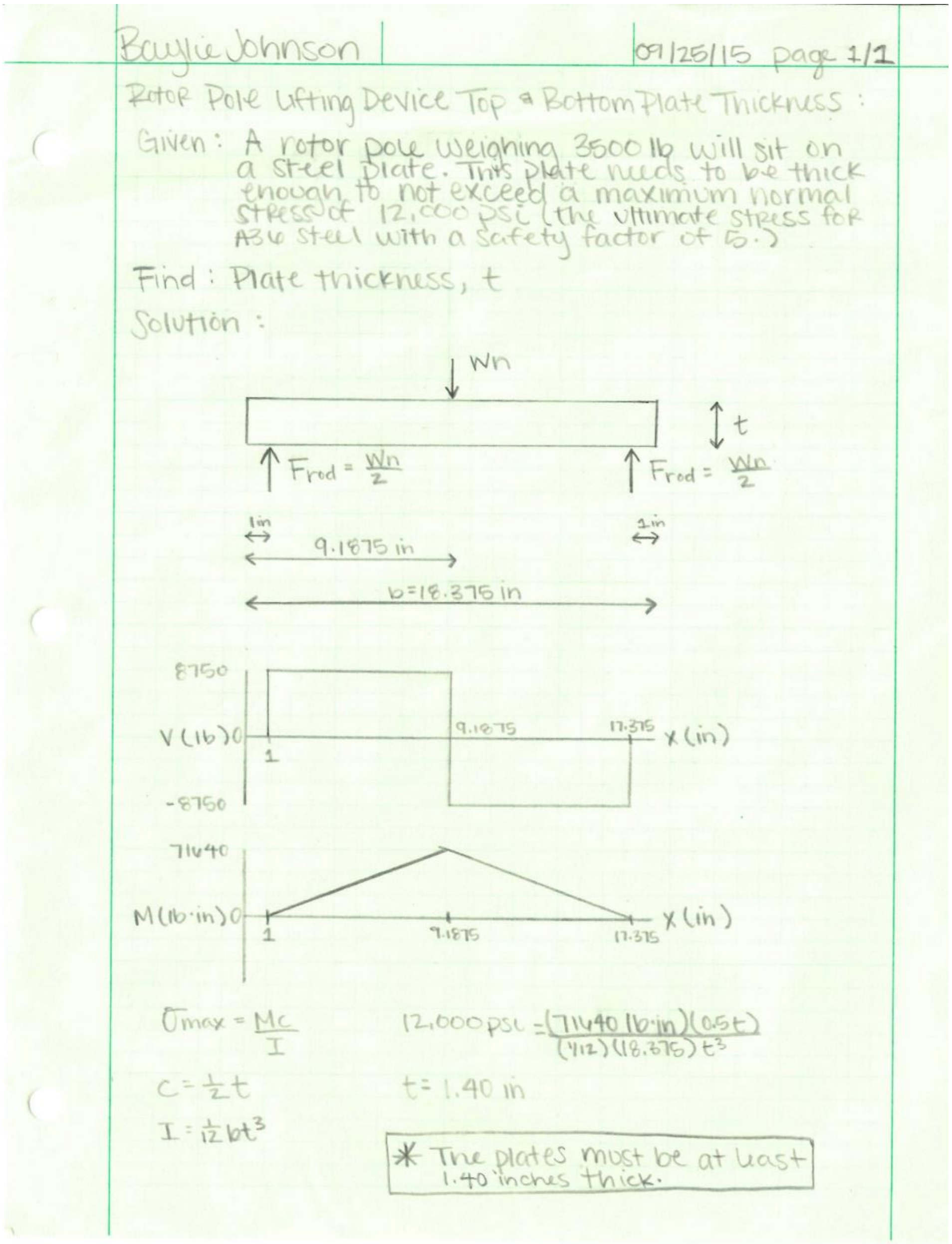
APPENDIX A – ANALYSES


Baylie Johnson 09/25/15 page 1/1

Rotor Pole Lifting Device Top & Bottom Plate Thickness:

Given: A rotor pole weighing 3500 lb will sit on a steel plate. This plate needs to be thick enough to not exceed a maximum normal stress of 12,000 psi (the ultimate stress for A36 steel with a safety factor of 5.)

Find: Plate thickness, t

Solution:

$\sigma_{max} = \frac{Mc}{I}$

$c = \frac{1}{2}t$

$I = \frac{1}{12}bt^3$

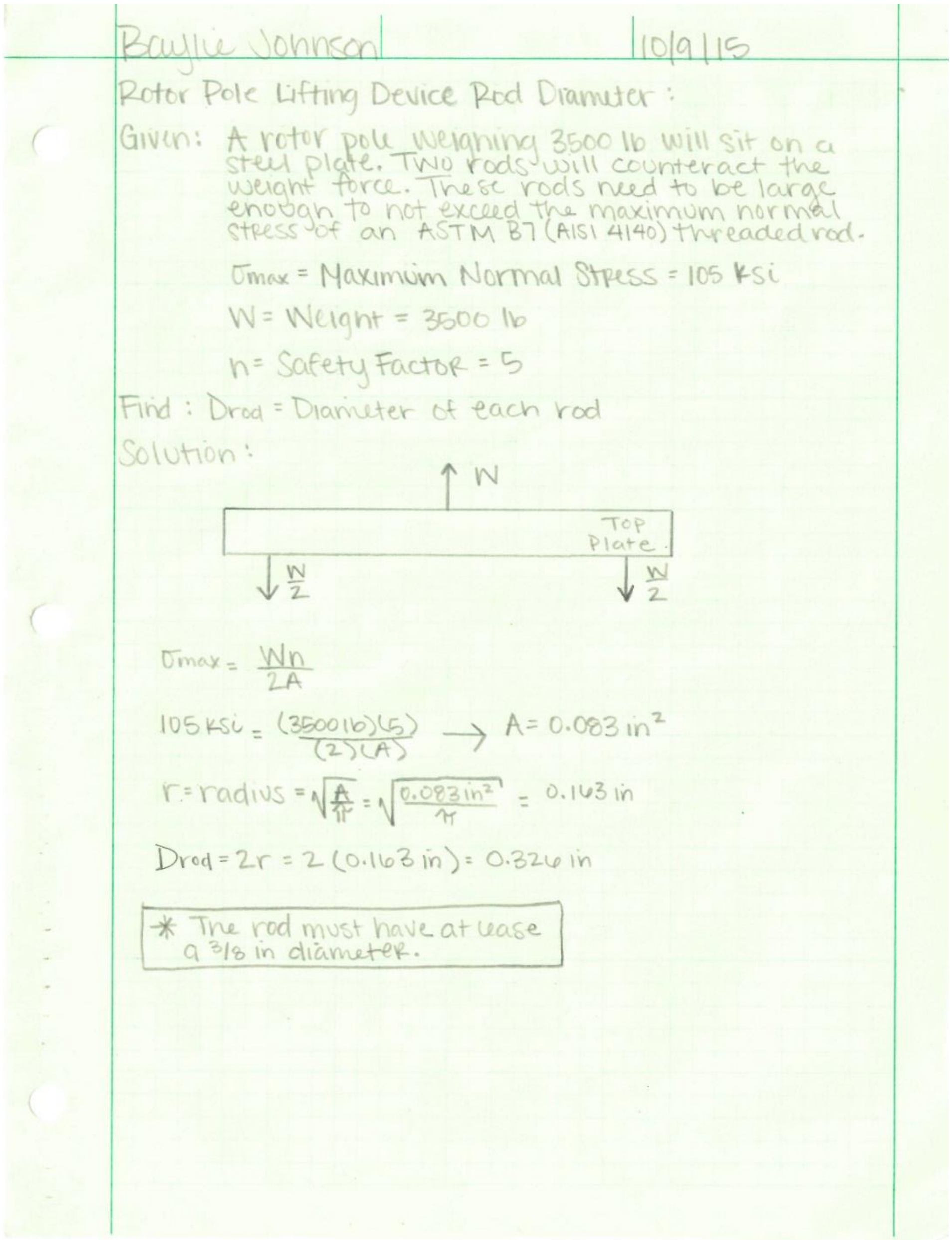
$12{,}000\ psi = \frac{(71640\ lb \cdot in)(0.5t)}{(1/12)(18.375)t^3}$

$t = 1.40\ in$

* The plates must be at least 1.40 inches thick.

FIGURE A 1: DETERMINING THE REQUIRED THICKNESS OF THE TOP AND BOTTOM PLATES OF THE LIFTING DEVICE.

The thickness of the top and bottom plates was determined based on the bending stress developed by the weight of the rotor pole. A maximum moment of 71,640 pound inches was found using a shear and moment diagram. It was found that a 1.5 inch thick plate would result in a normal stress of 10,397 psi; which is below the maximum normal stress of ASTM A36 steel (12,000 psi which includes a safety factor of 5).



Baylie Johnson 10/9/15

Rotor Pole Lifting Device Rod Diameter:

Given: A rotor pole weighing 3500 lb will sit on a steel plate. Two rods will counteract the weight force. These rods need to be large enough to not exceed the maximum normal stress of an ASTM B7 (AISI 4140) threaded rod.

σ_{max} = Maximum Normal Stress = 105 ksi

W = Weight = 3500 lb

n = Safety Factor = 5

Find: D_{rod} = Diameter of each rod

Solution:

$$\sigma_{max} = \frac{Wn}{2A}$$

$$105\ \text{ksi} = \frac{(3500\ \text{lb})(5)}{(2)(A)} \rightarrow A = 0.083\ \text{in}^2$$

$$r = \text{radius} = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{0.083\ \text{in}^2}{\pi}} = 0.163\ \text{in}$$

$$D_{rod} = 2r = 2(0.163\ \text{in}) = 0.326\ \text{in}$$

* The rod must have at lease a 3/8 in diameter.

Figure A 2: Determining the diameter of the rods.

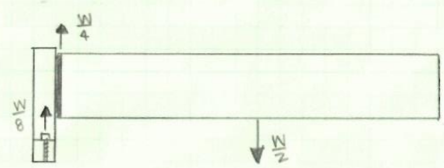
The size of the rods was determined based on the maximum normal stress of ASTM B7 threaded rod; which has a maximum normal stress of 105 ksi. With a weight of 3500 pounds and a safety factor of 5, the diameter of the rod necessary to support the weight of the rotor pole came to 0.326 inches. This was rounded to 3/8 inch. Later it was decided that the rod would not be fully threaded and would be made from AISI 4140, whose ultimate stress is 165,000 psi, which only adds safety factor.

Baylie Johnson 10/16/15

Rotor Pole Lifting Device Removable Dovetail Bolt Size

Given: When the rotor pole is in a near horizontal position (just before it touches the floor), half of the weight is supported by a Removable dovetail piece. The dovetail piece will be welded to a plate & this plate will bolt to the top plate. These welds & bolts must not exceed their maximum stresses.

σ_{BMAX} = Bolt maximum normal stress = 33 ksi (Grade 1)
W = Weight = 3500 lb
n = Safety Factor = 5
A = Bolt Area
r = Radius of Bolt



Find: D = Diameter of Bolt

Solution:

$$\sigma_{BMAX} = \frac{Wn}{8A} = \frac{(3500\,lb)(5)}{8(A)} = 33\ ksi \rightarrow A = 0.066\ in^2$$

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{0.066\ in^2}{\pi}} = 0.145\ in$$

$$D = 2r = 2(0.145\ in) = 0.290\ in$$

* The bolt must be at least a Grade 1 & have a 3/8" Diameter.

FIGURE A 3: DETERMINING THE BOLT SIZE ON THE REMOVABLE DOVETAIL.

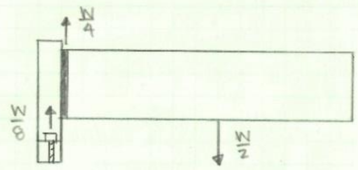
(For A3 and A4) The dovetail guide has to be made from two pieces, an adapter and a guide. The adapter will be welded to the guide and then the adapter will bolt to the top plate. The size of the bolts was determined to be 3/8 inch based on a maximum normal stress of 33,000 psi for a grade 1 bolt. The size of the welds was determined to be at least ¼ inch based on a maximum normal weld stress of 14,000 psi. A weld size of 3/8" was chosen.

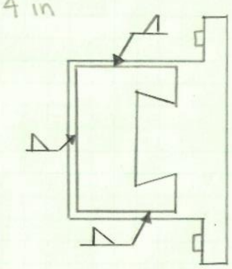
Baylie Johnson | 10/16/15

Rotor Pole Lifting Device Dovetail Weld Size :

Given : when the rotor pole is in a near horizontal position (just before it touches the floor) half of the weight of the rotor pole is supported by a removeable dovetail piece. The dovetail piece will be welded to a plate & this plate will bolt to the top plate. The stress in these welds must not exceed their maximum stress.

σ_{max} = Maximum Normal Stress = 14,000 psi
W = Weight = 3500 lb
n = Safety Factor = 5
A = Area of the weld
h = Weld size
b = Length of base weld = 7.5 in
d = Length of side welds = 4 in





Find : h = Weld Size

Solution :

$$A = 0.707 \cdot h(2b + d)$$

$$\sigma = \frac{W \cdot n}{A}$$

h = Weld Size (in)	1/16	1/8	3/16	1/4	5/16
Area (in^2)	0.68	1.37	2.05	2.74	3.42
Stress (psi)	25551	12775	8517	6388	5110

* A 1/8" or better fillet weld is required.

FIGURE A 4: DETERMINING THE WELD SIZE ON THE REMOVABLE DOVETAIL.

Baylie Johnson | 10/16/15 page 1/2

Rotor Pole Lifting Device Lifting Lug Weld Size:

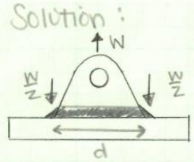
Given: A lifting lug will be welded to the top plate in order to attach the crane. Two analysis's will be performed.

a) Direct Normal Stress (when vertical)

b) Bending Stress (when horizontal)

a) Find: Weld size & Length of weld

Solution:



σ = Normal Stress $\sigma_{max} = 14000$ psi
W = Weight = 3500 lb
n = Safety Factor = 5
A = Area of Weld
h = Weld size
d = Length of weld

$\sigma_{max} = \frac{Wn}{A} = \frac{(3500\,lb)(5)}{A} = 14000\,psi \rightarrow A = 1.25\,in^2$

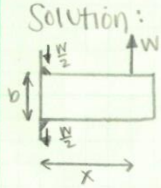
$A = 1.414hd$

Fillet Weld Size (in)	1/16	1/8	3/16	1/4
d (in)	14.14	7.07	4.71	3.54

*** A Length of 5 inches & weld size of >3/16 is required.**

b) Find: x = distance from welds to load

Solution:



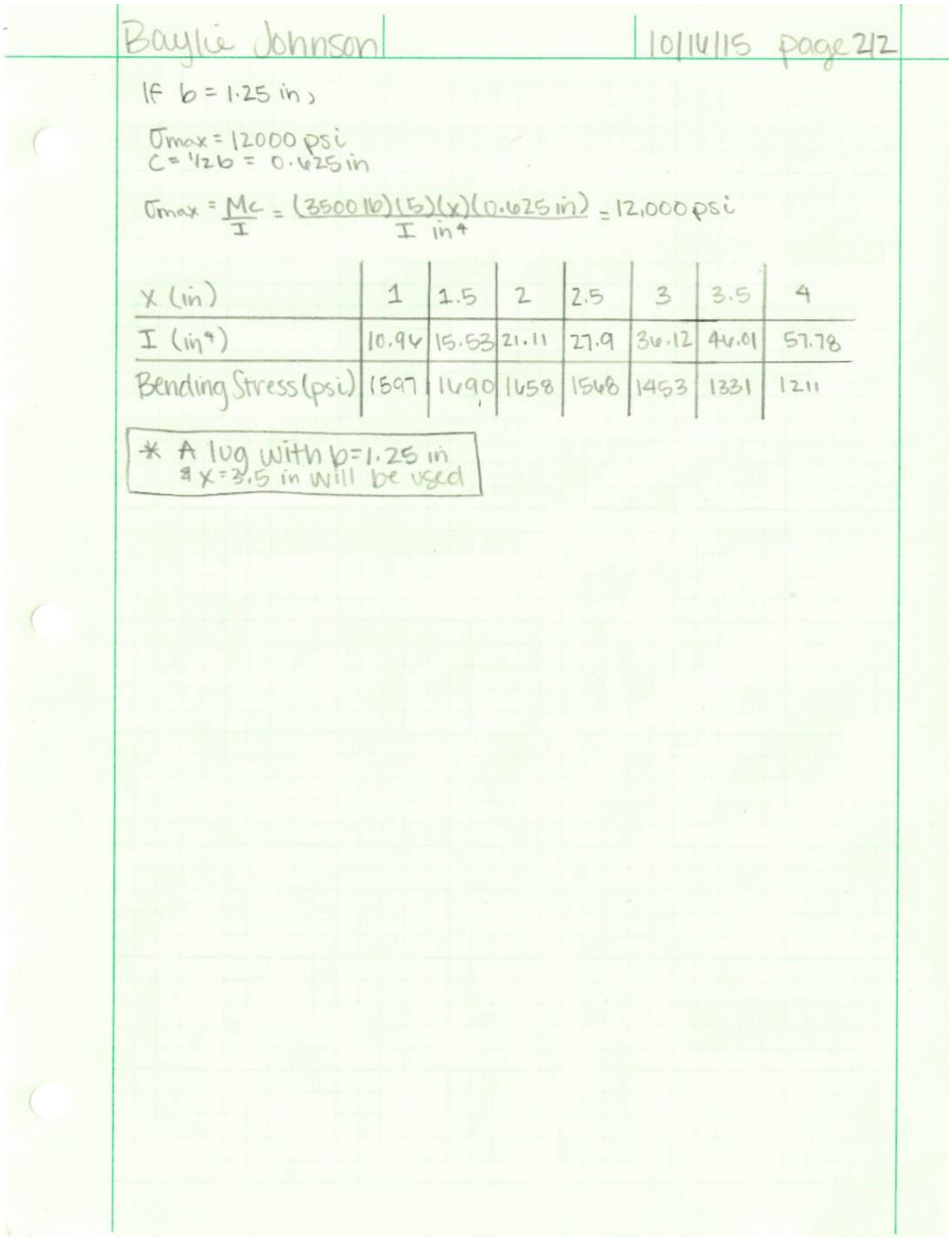
I = Moment of Inertia = $\frac{1}{2}bd^2$
b = Lug thickness = 1.25 in (assumed)
d = Weld Length = 5 in
σ_{max} = Max. Normal = 14000 psi
W = Weight = 3500 lb
n = Safety Factor = 5
M = Moment = Wx
c = Distance to outer point = 2.5 in

$\sigma_{max} = \frac{Mc}{I}$

$14000\,psi = \frac{(3500\,lb)(5)(x)(2.5\,in)}{(2)(1/2)(b)(5\,in)^2}$

$\frac{x}{b} = 8$

This analysis resulted in a tradeoff between the length of the weld and the area of the weld. It was decided that a 5 inch long, 3/8 inch weld would withstand appropriate stresses.



Baylie Johnson 10/14/15 page 2/2

If $b = 1.25$ in,

$\sigma_{max} = 12000$ psi
$c = \frac{1}{2}b = 0.625$ in

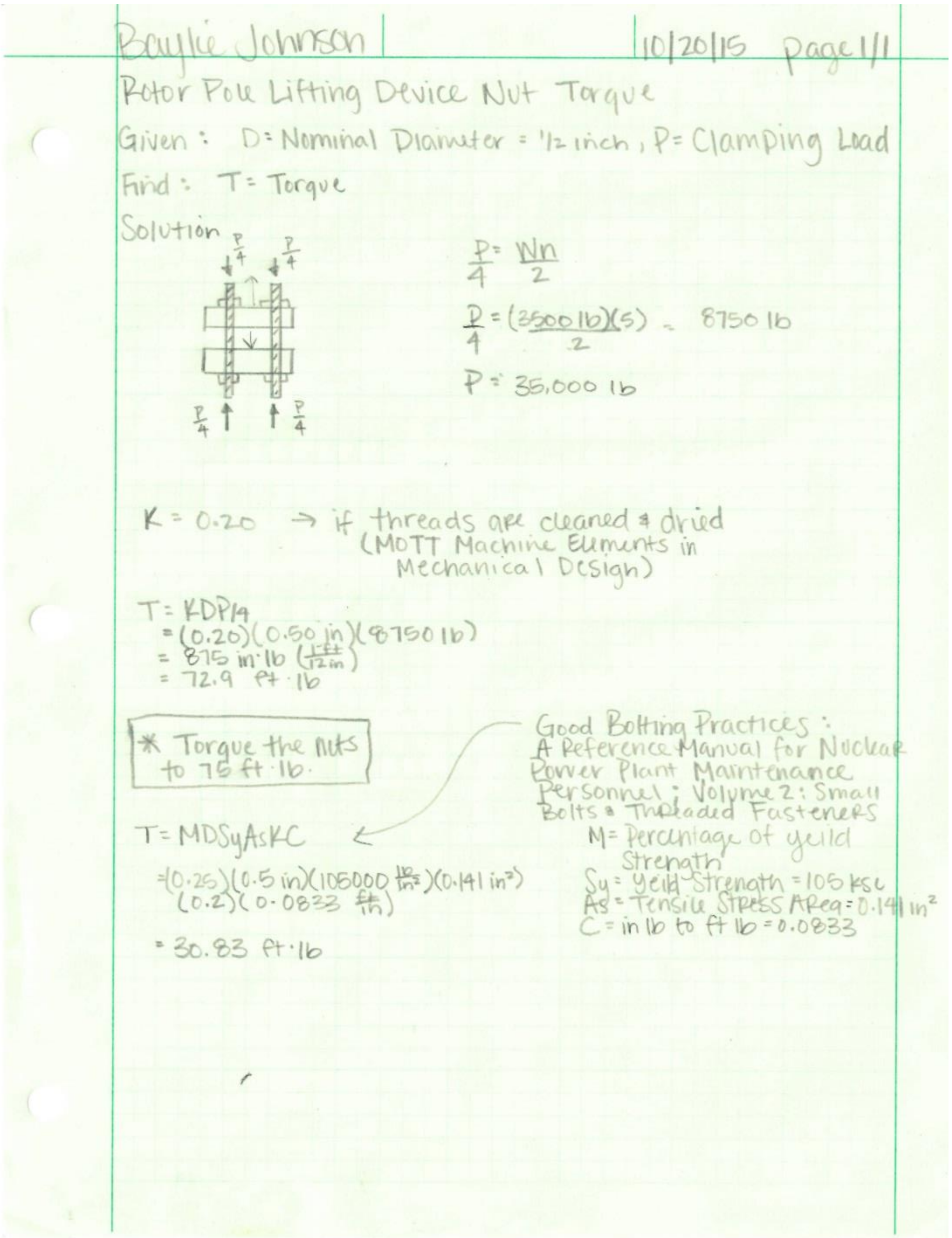
$$\sigma_{max} = \frac{Mc}{I} = \frac{(3500\ lb)(5)(x)(0.625\ in)}{I\ in^4} = 12{,}000\ psi$$

x (in)	1	1.5	2	2.5	3	3.5	4
I (in^4)	10.94	15.53	21.11	27.9	36.12	46.01	57.78
Bending Stress (psi)	1597	1690	1658	1568	1453	1331	1211

* A lug with b=1.25 in & x=3.5 in will be used

FIGURE A 5: DETERMINING THE LIFTING LUG TO TOP PLATE WELD SIZE.

Bending stress will be present in the lifting lug welds as well. The bending stress equation gave information about the ratio between the thickness of the lug and the distance from the weld to the lifting point (assumed to be the center of the hole). A thickness of 1.25 inches was chosen. The bending stress created in the lug itself could then be calculated and it was found that a distance of 3.5 inches from the base of the lug to the center of the hole would withstand the stresses inflicted.



Baylie Johnson | 10/20/15 Page 1/1

Rotor Pole Lifting Device Nut Torque

Given: D = Nominal Diameter = 1/2 inch, P = Clamping Load

Find: T = Torque

Solution

$\frac{P}{4} = \frac{Wn}{2}$

$\frac{P}{4} = \frac{(3500\ lb)(5)}{2} = 8750\ lb$

$P = 35{,}000\ lb$

K = 0.20 → if threads are cleaned & dried (MOTT Machine Elements in Mechanical Design)

$T = KDP/4$

$= (0.20)(0.50\ in)(8750\ lb)$

$= 875\ in \cdot lb \left(\frac{1\ ft}{12\ in}\right)$

$= 72.9\ ft \cdot lb$

* Torque the nuts to 75 ft·lb.

Good Bolting Practices: A Reference Manual for Nuclear Power Plant Maintenance Personnel; Volume 2: Small Bolts & Threaded Fasteners

$T = MDS_yA_sKC$

$= (0.25)(0.5\ in)(105000\ \frac{lb}{in^2})(0.141\ in^2)(0.2)(0.0833\ \frac{ft}{in})$

$= 30.83\ ft \cdot lb$

M = Percentage of yeild Strength

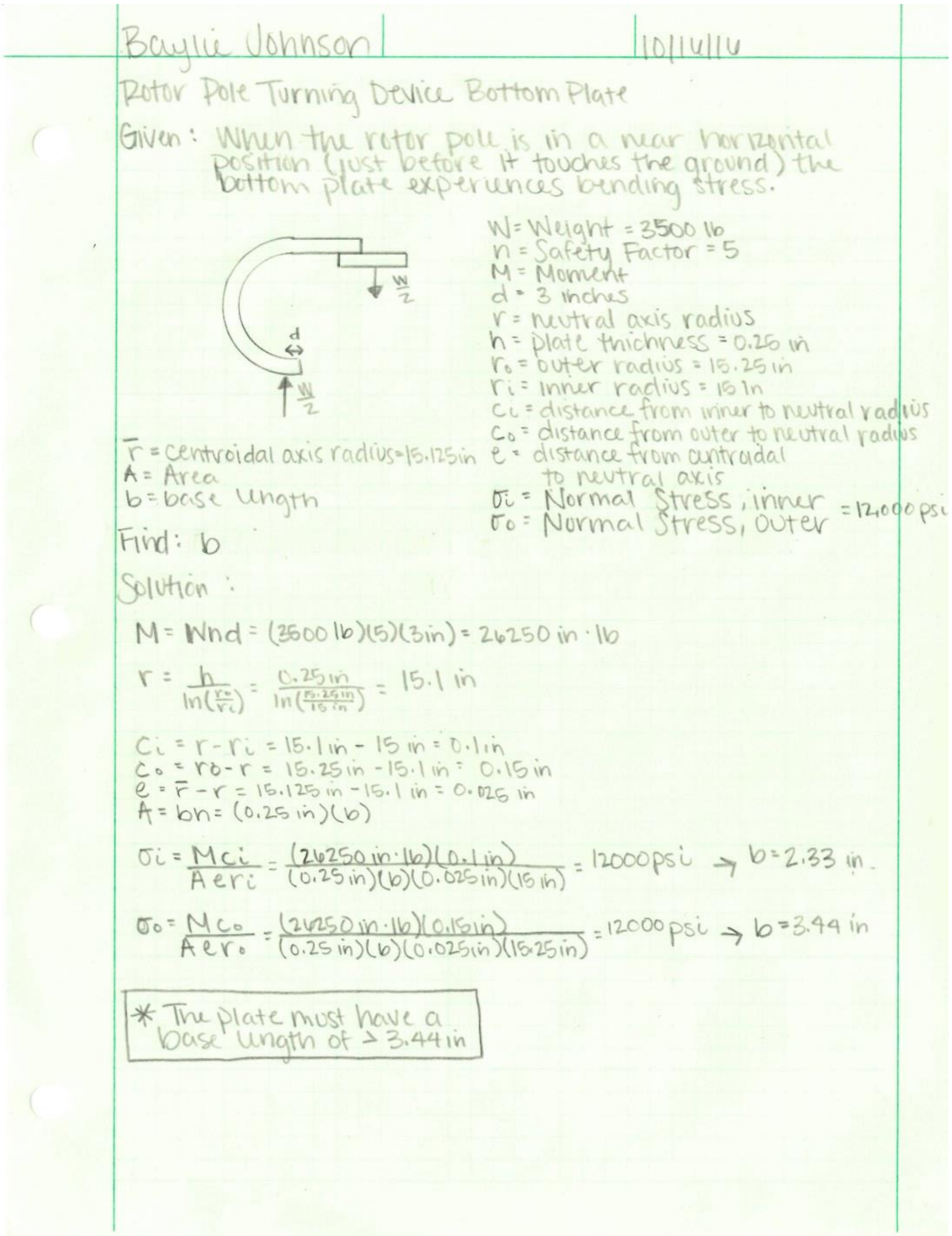
S_y = Yeild Strength = 105 ksi

A_s = Tensile Stress Area = 0.141 in²

C = in lb to ft lb = 0.0833

FIGURE A 6: DETERMINING THE TORQUE REQUIRE ON THE NUTS.

The amount of torque that is needed on the nuts was analyzed using two different torque equations. The maximum torque of 75 ft*lbs was chosen for the specification.



Baylie Johnson 10/14/14

Rotor Pole Turning Device Bottom Plate

Given: When the rotor pole is in a near horizontal position (just before it touches the ground) the bottom plate experiences bending stress.

W = Weight = 3500 lb
n = Safety Factor = 5
M = Moment
d = 3 inches
r = neutral axis radius
h = plate thickness = 0.25 in
r_o = outer radius = 15.25 in
r_i = inner radius = 15 in
c_i = distance from inner to neutral radius
c_o = distance from outer to neutral radius
$\bar{r}$ = centroidal axis radius = 15.125 in
A = Area
b = base length
e = distance from centroidal to neutral axis
σ_i = Normal Stress, inner
σ_o = Normal Stress, outer
= 12,000 psi

Find: b

Solution:

$$M = Wnd = (3500\,lb)(5)(3\,in) = 26250\,in \cdot lb$$

$$r = \frac{h}{\ln\left(\frac{r_o}{r_i}\right)} = \frac{0.25\,in}{\ln\left(\frac{15.25\,in}{15\,in}\right)} = 15.1\,in$$

$$c_i = r - r_i = 15.1\,in - 15\,in = 0.1\,in$$

$$c_o = r_o - r = 15.25\,in - 15.1\,in = 0.15\,in$$

$$e = \bar{r} - r = 15.125\,in - 15.1\,in = 0.025\,in$$

$$A = bh = (0.25\,in)(b)$$

$$\sigma_i = \frac{Mc_i}{Aer_i} = \frac{(26250\,in \cdot lb)(0.1\,in)}{(0.25\,in)(b)(0.025\,in)(15\,in)} = 12000\,psi \rightarrow b = 2.33\,in.$$

$$\sigma_o = \frac{Mc_o}{Aer_o} = \frac{(26250\,in \cdot lb)(0.15\,in)}{(0.25\,in)(b)(0.025\,in)(15.25\,in)} = 12000\,psi \rightarrow b = 3.44\,in$$

* The plate must have a base length of ≥ 3.44 in

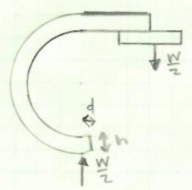
FIGURE A 7: ANALYZING STRESSES IN THE TURNING DEVICE BOTTOM PLATE.

(For A7 and A8) The bending stress that is created in the bottom and side plates was determined using curved beam principles. It was found that a bottom plate with a minimum of 3.44 inches would suffice. Due to the assembly of the part, a distance of 11 inches was chosen. The side plates were analyzed in a similar fashion and a thickness of ½ inch was found to be the minimum. Ultimately, a thickness of ¾ inch was chosen.

Baylie Johnson | 10/16/15

Rotor Pole Turning Device Side Plates

Given: When the rotor pole is in a near horizontal position (just before it touches the ground) the side plate experience bending stress.



W = Weight = 3500 lb
n = Safety Factor = 5
M = Moment
d = 3 inches
r = neutral axis radius
h = 5 in
r_o = outer radius = 15 in
r_i = inner radius = 10 in
c_i = distance from inner to neutral radius
c_o = distance from outer to neutral radius
b = plate thickness
A = Area
e = distance from centroidal to neutral axis
$\bar{r}$ = centroidal axis radius = 12.5 in
σ_i = Normal Stress, inner
σ_o = Normal Stress, outer
→ 12000 psi

Find: b = plate thickness

Solution:

$$M = Wnd = (3500\text{ lb})(5)(3\text{ in}) = 26250\text{ in}\cdot\text{lb}$$

$$r = \frac{h}{\ln\left(\frac{r_o}{r_i}\right)} = \frac{5\text{ in}}{\ln\left(\frac{15\text{ in}}{10\text{ in}}\right)} = 12.3\text{ in}$$

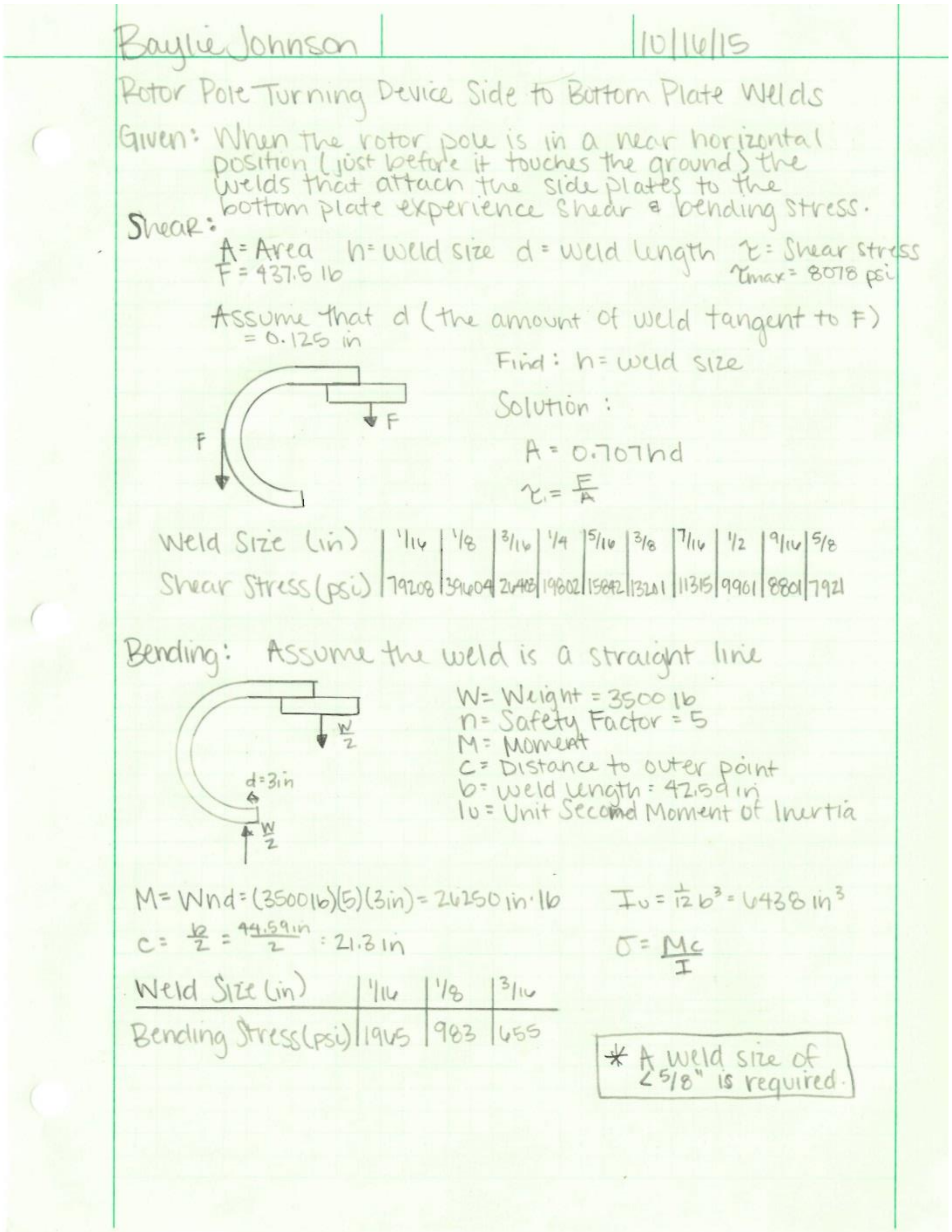
$$c_i = r - r_i = 12.3\text{ in} - 10\text{ in} = 2.3\text{ in}$$
$$c_o = r_o - r = 15\text{ in} - 12.3\text{ in} = 2.7\text{ in}$$
$$A = bh = (5\text{ in})(b)$$
$$e = \bar{r} - r = 12.5\text{ in} - 12.3\text{ in} = 0.2\text{ in}$$

$$\sigma_i = \frac{Mc_i}{Aer_i} = \frac{(26250\text{ in}\cdot\text{lb})(2.3\text{ in})}{(5\text{ in})(b)(0.2\text{ in})(10\text{ in})} = 12000\text{ psi} \rightarrow b = 0.50\text{ in}$$

$$\sigma_o = \frac{Mc_o}{Aer_o} = \frac{(26250\text{ in}\cdot\text{lb})(2.7\text{ in})}{(5\text{ in})(b)(0.2\text{ in})(15\text{ in})} = 12000\text{ psi} \rightarrow b = 0.39\text{ in}$$

* These plate must have a thickness > 0.50 in.

FIGURE A 8: ANALYZING STRESSES IN THE SIZE PLATES.



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Rotor Pole Turning Device Side to Bottom Plate Welds

Given: When the rotor pole is in a near horizontal position (just before it touches the ground) the welds that attach the side plates to the bottom plate experience shear & bending stress.

Shear:

A = Area h = weld size d = weld length τ = Shear stress
F = 437.5 lb τ_{max} = 8078 psi

Assume that d (the amount of weld tangent to F) = 0.125 in

Find: h = weld size

Solution:

$A = 0.707hd$

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

Weld Size (in)	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8
Shear Stress (psi)	79208	39604	26403	19802	15842	13201	11315	9901	8801	7921

Bending: Assume the weld is a straight line

W = Weight = 3500 lb
n = Safety Factor = 5
M = Moment
c = Distance to outer point
b = weld length = 42.59 in
Iu = Unit Second Moment of Inertia

d = 3 in

$M = Wnd = (3500 lb)(5)(3 in) = 26250 in \cdot lb$ $I_u = \frac{1}{12}b^3 = 6438 in^3$

$c = \frac{b}{2} = \frac{44.59 in}{2} = 21.3 in$ $\sigma = \frac{Mc}{I}$

Weld Size (in)	1/16	1/8	3/16
Bending Stress (psi)	1965	983	655

* A weld size of ≥ 5/8" is required.

FIGURE A 9: DETERMINING THE SIDE TO BOTTOM PLATE WELD SIZE.

The bottom and side plates would need to be welded together. After analyzing the shear and bending stress created, it was found that a weld size of at least 5/8 inch was required and this size will be used.

Baylie Johnson 10/16/15

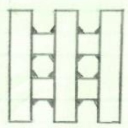
Rotor Pole Turning Device Bar Welds

Given: The bars that connect the side plates to the middle plate will experience shear stress in the welds.

A = Weld Area h = weld size r = radius = 0.6875 in

τ = Shear Stress W = Weight = 3500 lb

↳ τ_{max} = 8078 psi n = Safety Factor = 5



Find: Weld Size

Solution:

$A = 1.414hr$

$\tau = \frac{Wn}{A}$

Weld Size (in)	1/8	1/4	3/8	1/2
Shear Stress (psi)	22921	11460	7640	5730

* A weld size ≥ 3/8" is required

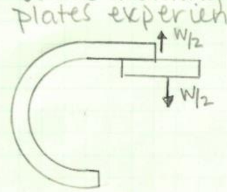
FIGURE A 10: DETERMINING THE BARS TO MIDDLE AND SIDE PLATE WELD SIZE.

The bars that connect the side plates to the middle plate were analyzed under shear stress. It was found that a weld size of at least 3/8 inch was required and this size will be used.

Baylie Johnson | 10/16/15

Rotor Pole Turning Device Dovetail Guide Welds

Given: When the rotor pole is in a near horizontal position (just before it touches the floor) the welds holding the Dovetail guide to the side plates experiences normal stress.



A = Area
h = Weld size
d = Weld length = 7.81 in
σ = Normal Stress
↳ σ_{max} = 14000 psi
W = Weight = 3500 lb
n = Safety Factor = 5

$$A = 1.414hd$$

$$\sigma = \frac{Wn}{2A}$$

$$\sigma = \frac{Wn}{2(1.414hd)} = 14000 \text{ psi} = \frac{(3500 \text{ lb})(5)}{2(1.414)(h)(7.81 \text{ in})}$$

$$h = 0.057 \text{ in}$$

* These welds must be > 0.057 in.

FIGURE A 11: DETERMINING THE DOVETAIL GUIDE TO SIDE PLATES WELD SIZE.

The dovetail guide needs to be welded to the side plates. By analyzing the direct normal stress that is inflicted on these welds when the pole is in an unsupported horizontal position, a minimum weld size of 0.057 inches was determined. An actual weld size of 1/8 inch will be used.

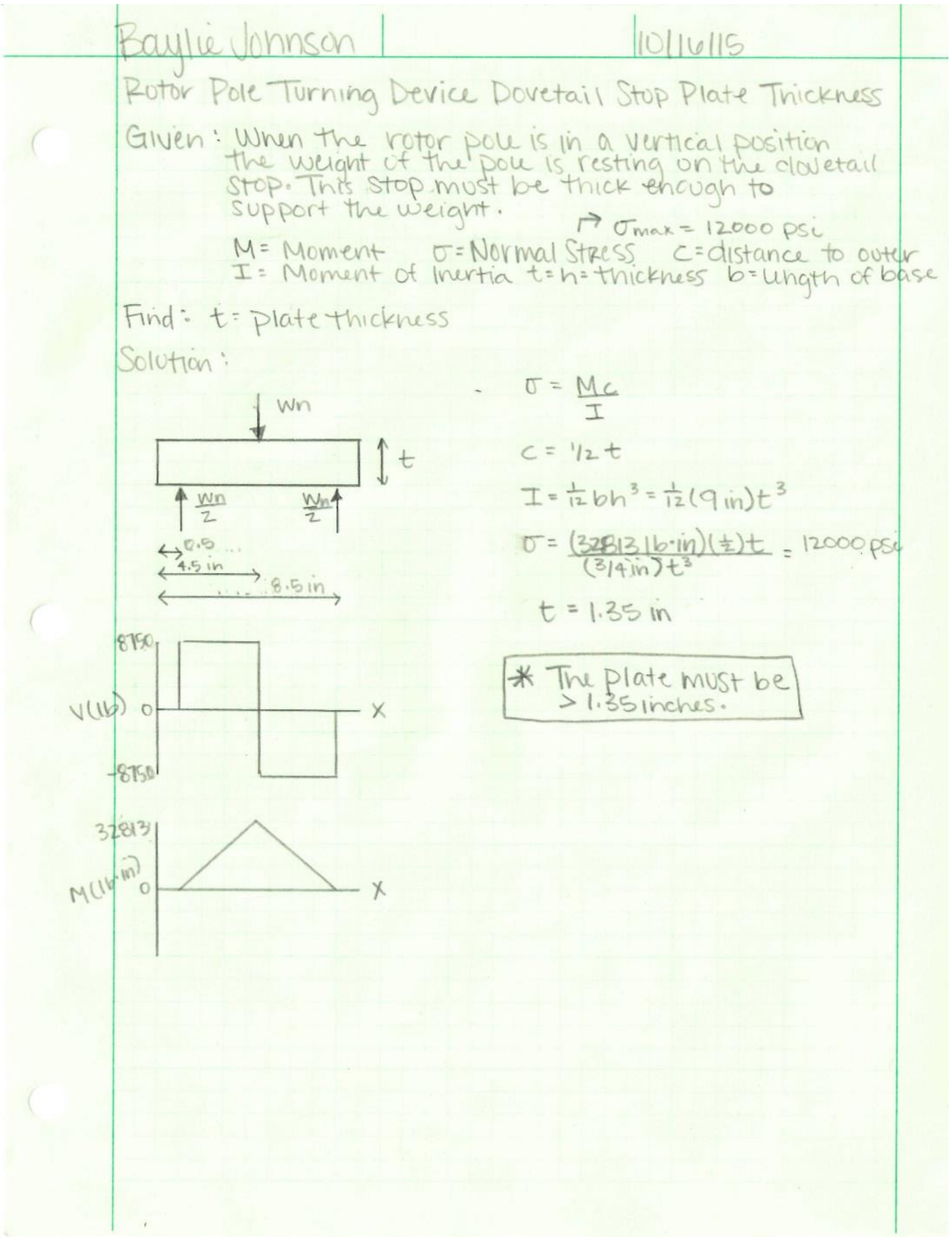


FIGURE A 12: DETERMINING THE REQUIRED THICKNESS OF THE DOVETAIL STOP PLATE.

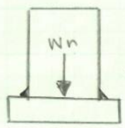
The dovetail stopping plate experiences a significant amount of bending stress when the pole is in a vertical position. By using a shear and moment diagram to determine the maximum moment, a plate thickness of at least 1.35 inches was determined. A thickness of 1.5 inches will be used.

Baylie Johnson | 10/16/15

Rotor Pole Turning Device Dovetail Stop Welds

Given: When the rotor pole is in a vertical position the weight of the pole is resting on the dovetail stop. The welds that hold the stop to the plate will experience shear stress.

τ_{max} = Maximum Shear Stress = 8078 psi
W = Weight = 3500 lb
n = Safety Factor = 5
A = Area
h = Weld Size
b = Weld Length = 4 in



Find: h = Weld Size

Solution

$$\tau_{max} = \frac{Wn}{A}$$

$$A = 1.414hb$$

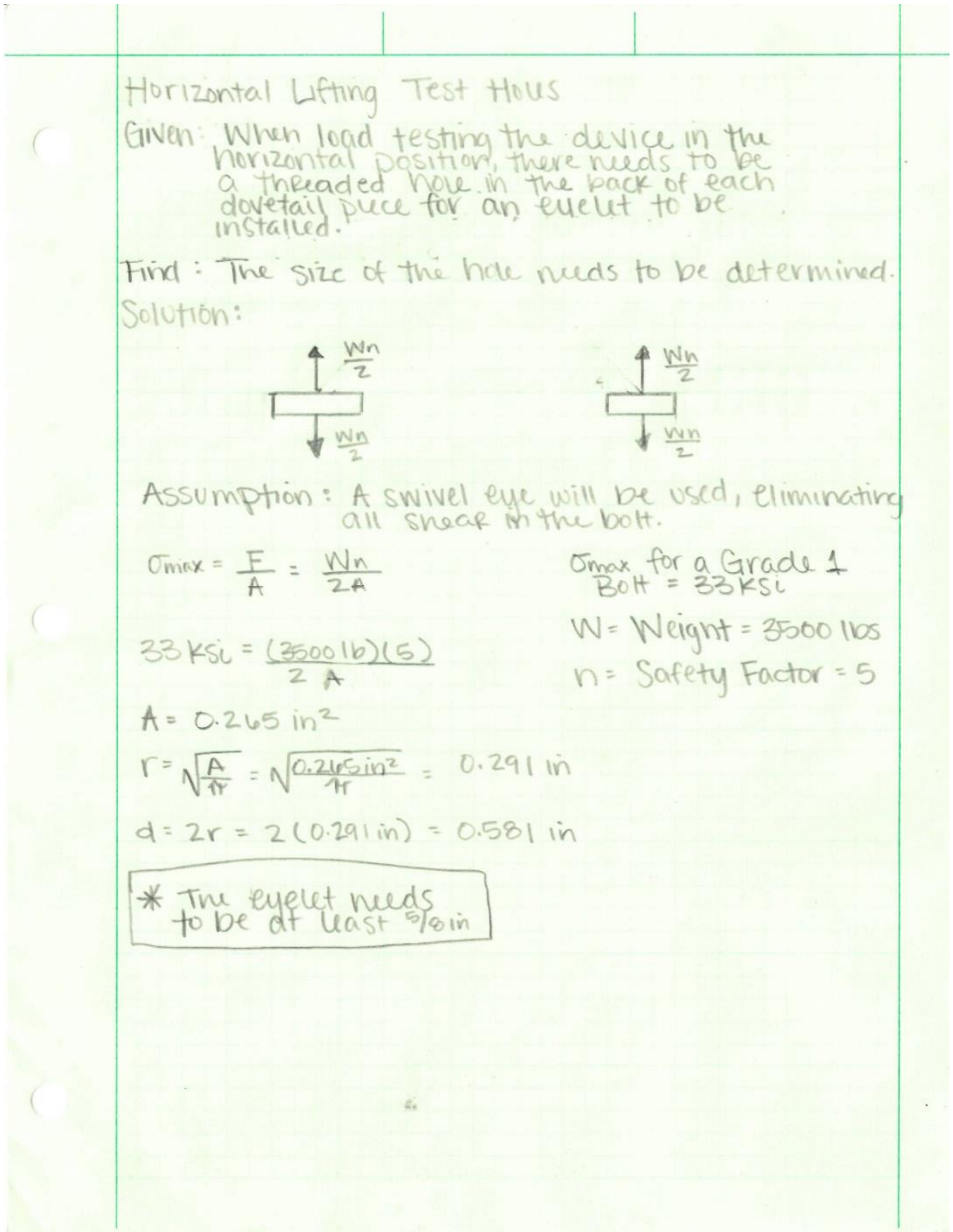
$$8078\ psi = \frac{(3500lb)(5)}{1.414(h)(4in)}$$

$$h = 0.383\ in$$

* These welds must be > 0.383 inches.

FIGURE A 13: DETERMINING THE DOVETAIL GUIDE TO DOVETAIL STOP PLATE WELD SIZE.

The dovetail stopping plate gets welded to the dovetail guide. These welds will experience shear stress when the pole is in a vertical position. A weld size of at least 0.383 inches was determined to be adequate. The weld size chosen was ½ inch.



Horizontal Lifting Test Hous

Given: When load testing the device in the horizontal position, there needs to be a threaded hole in the back of each dovetail piece for an eyelet to be installed.

Find: The size of the hole needs to be determined.

Solution:

Assumption: A swivel eye will be used, eliminating all shear in the bolt.

$\sigma_{max} = \frac{F}{A} = \frac{Wn}{2A}$

σ_{max} for a Grade 1 Bolt = 33 ksi

W = Weight = 3500 lbs

n = Safety Factor = 5

$33\ ksi = \frac{(3500\ lb)(5)}{2A}$

$A = 0.265\ in^2$

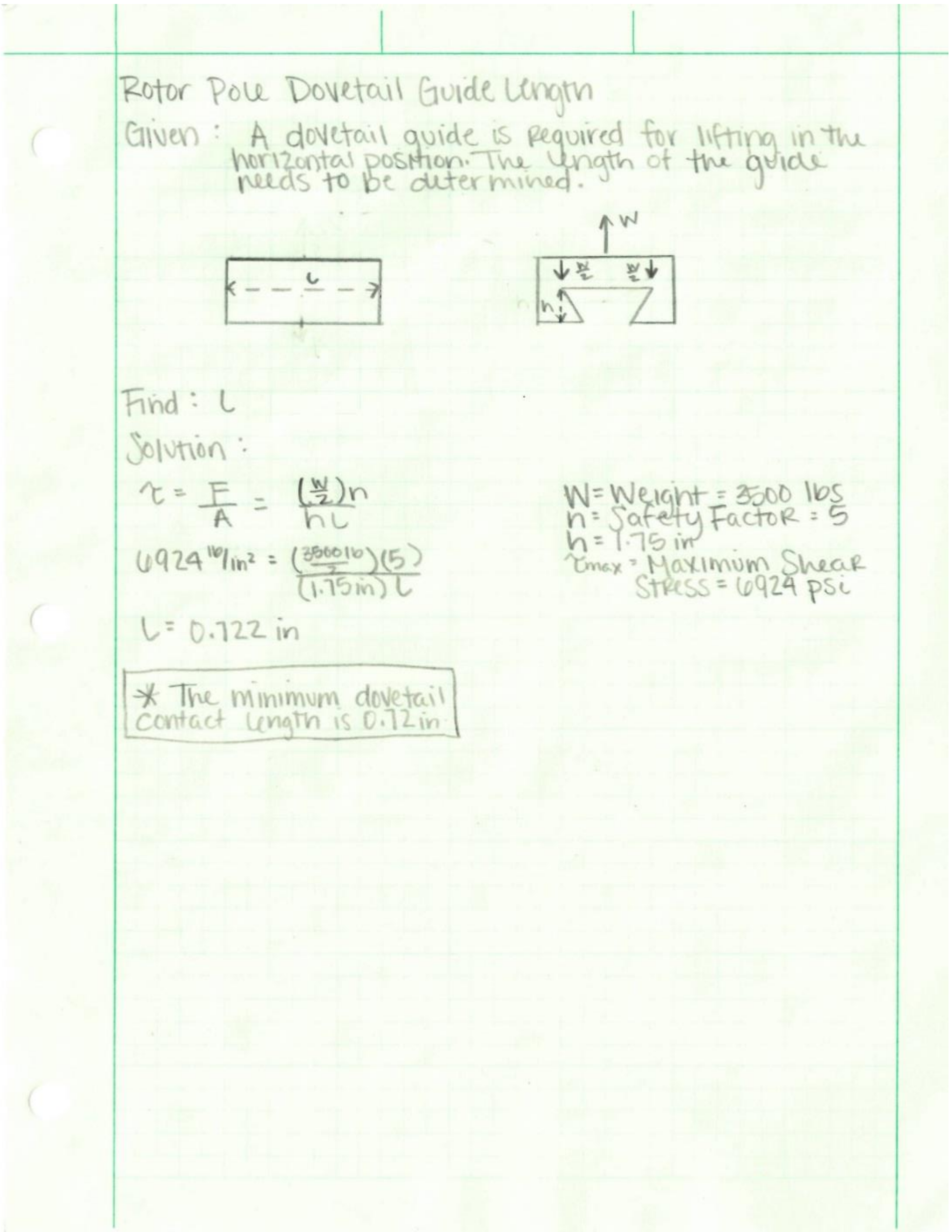
$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{0.265\ in^2}{\pi}} = 0.291\ in$

$d = 2r = 2(0.291\ in) = 0.581\ in$

* The eyelet needs to be at least 5/8 in

FIGURE A 14: HORIZONTAL LIFTING EYELET ANALYSIS

When the device is tested in the horizontal configuration, eyelets will be threaded into the back of the dovetail on the lifting device. The size of these eyelets was determined using the direct tension equation, knowing that grade 1 bolts have a maximum stress of 33 ksi, the diameter of eyelets needed was determined to be 5/8 inch, which was used.



Rotor Pole Dovetail Guide Length

Given: A dovetail guide is required for lifting in the horizontal position. The length of the guide needs to be determined.

Find: L

Solution:

$$\tau = \frac{F}{A} = \frac{\left(\frac{W}{2}\right)n}{hL}$$

$$6924\ lb/in^2 = \frac{\left(\frac{3500\ lb}{2}\right)(5)}{(1.75\ in)L}$$

$$L = 0.722\ in$$

W = Weight = 3500 lbs
n = Safety Factor = 5
h = 1.75 in
τ_{max} = Maximum Shear Stress = 6924 psi

* The minimum dovetail contact length is 0.72 in

FIGURE A 15: DOVETAIL LENGTH ANALYSIS

The length of the dovetail required to avoid shearing was determined using the direct shear stress equation. Knowing the maximum shear stress for ASTM A36 steel with a safety factor of 5 is 6924 psi, the minimum dovetail length was determined to be 0.72 inches. A contact length of 6" was chosen.

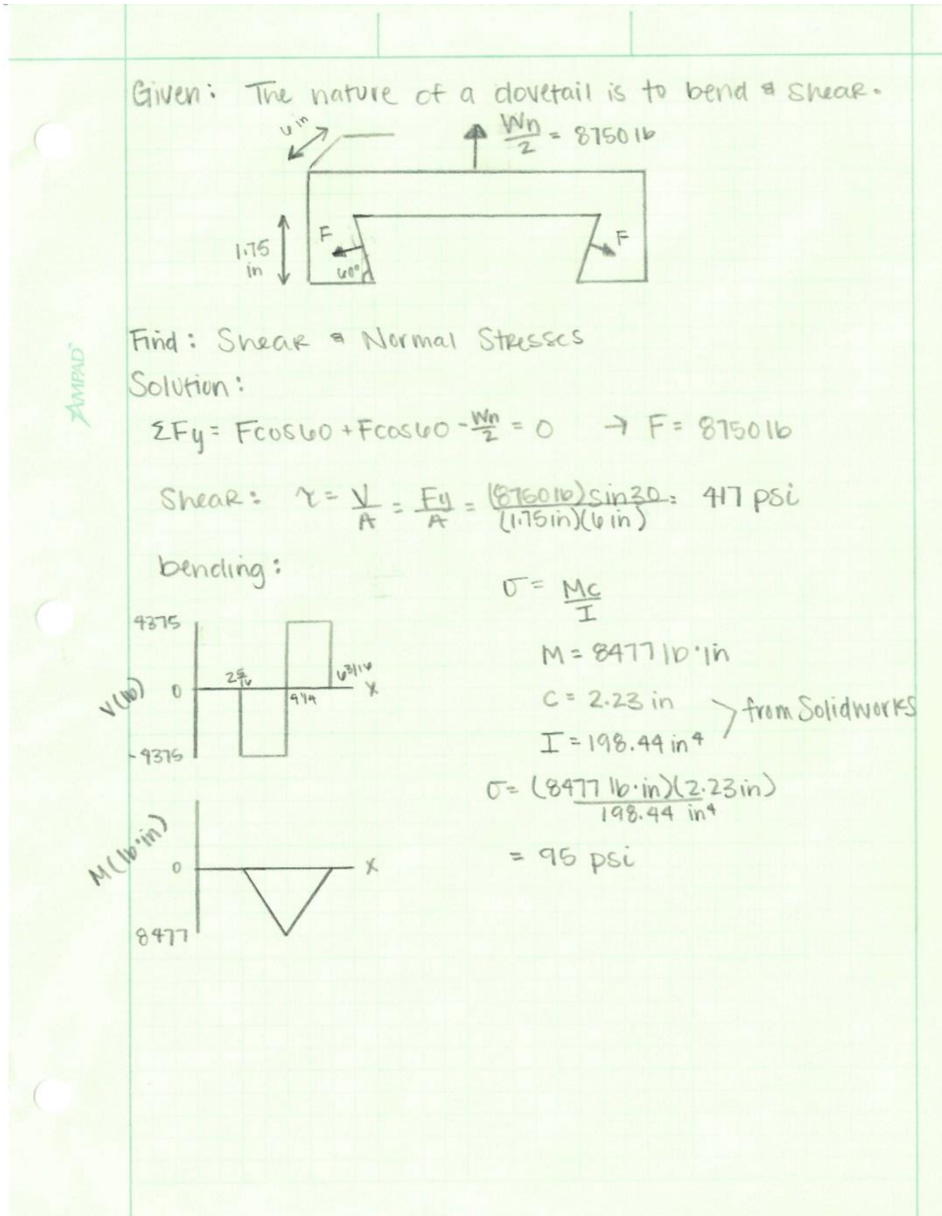
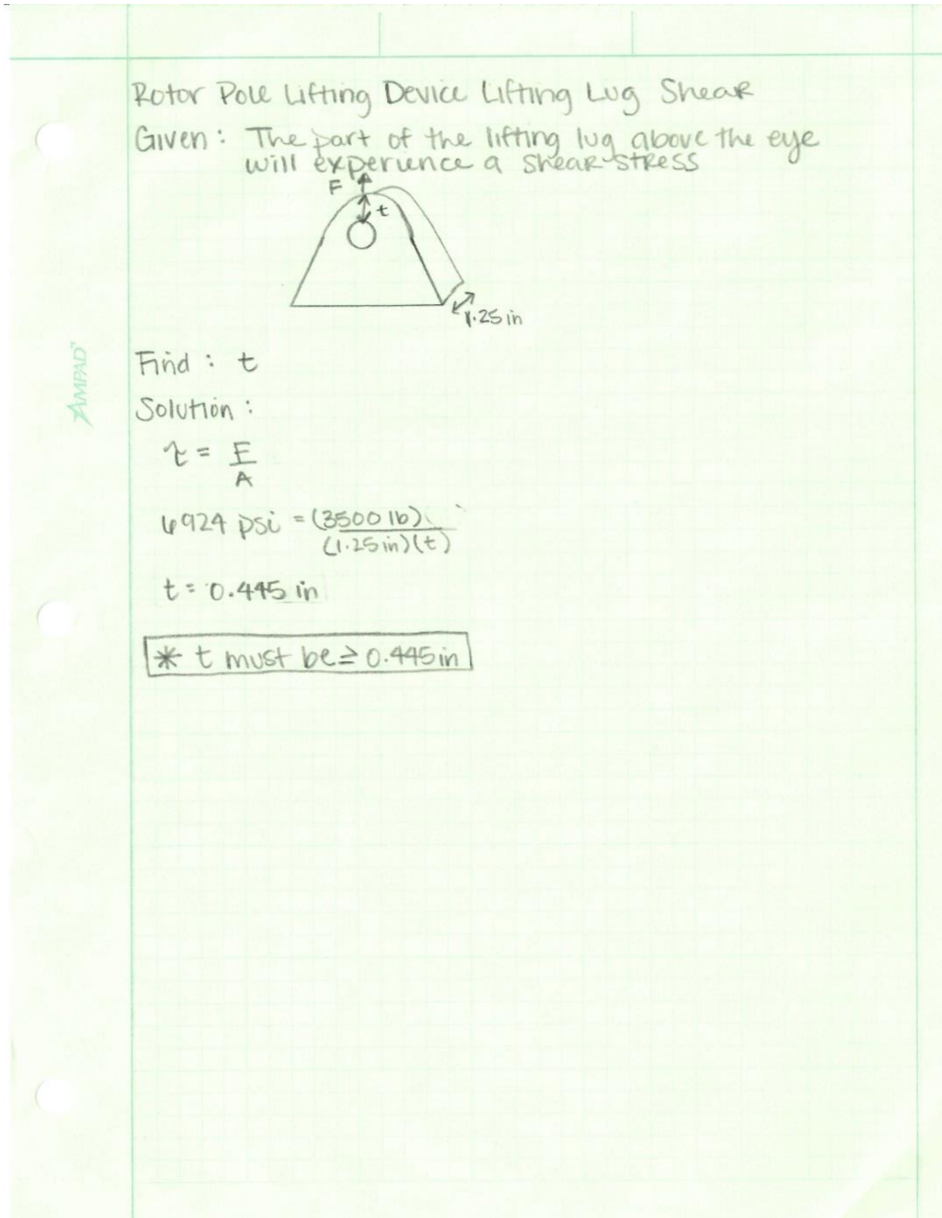


FIGURE A 16: DOVETAIL GEOMETRY ANALYSIS

The forces on the dovetail create direct shear stress and bending stress. Based a weight on 3500 pounds with a safety factor of 5, the shear stress was determined to be 417 psi. This is well under the maximum stress of the material. Bending stress was found to be only 95 psi, which is also well below the maximum. This dovetail geometry is suitable.


Rotor Pole Lifting Device Lifting Lug Shear

Given: The part of the lifting lug above the eye will experience a shear stress

Find: t

Solution:

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

$6924 \text{ psi} = \frac{(3500 \text{ lb})}{(1.25 \text{ in})(t)}$

$t = 0.445 \text{ in}$

$*\ t$ must be $\geq 0.445 \text{ in}$

FIGURE A 17: LIFTING LUG SHEAR ANALYSIS

The lifting lug will experience shear stress. Based on a weight of 3500 pounds, the length between the hole and the top of the lug needed to be greater than 0.445 inches. The part already had a length of 0.6875 inches.

Rotor Pole Lifting Device Rod Elongation Prediction

Given: Due to loading, the rods will have some elongation:

Find: Predict Elongation

Solution:

$$\text{Elongation} = \frac{L_{final} - L_o}{L_o} \cdot 100\%$$

$$L_{final} = L_o(1+\varepsilon)$$

$$\varepsilon = \frac{\sigma}{E}$$

$$\sigma = \frac{F}{A} = \frac{(7000\ lb)}{\pi/4\,(0.625in)^2} = 22816\ psi$$

$$E = 29{,}000{,}000\ psi$$

$$\varepsilon = \frac{22816\ psi}{29{,}000{,}000\ psi} = \boxed{0.00079\ in/in}$$

$$L_o = 6\ feet = 72\ in$$

$$\text{Elongation} = \frac{[72\ in\,(1+0.00079\ in/in)] - 72\ in}{72\ in} \cdot 100\%$$

$$= 0.079\ in$$

GRANT COUNTY PUBLIC UTILITY DISTRICT NO. 2

Facility		Computed By	
Proj. I.D.	W.O.	Date	20
Title Rod Strain / Top Plate Strain		Checked By	
		Date	20
		Page	of

@ 3500 lb (each rod holds 1750 lb)

$$\sigma = \frac{F}{A} = \frac{1750\ lb}{\pi/4\,(3/8\ in)^2} = 15845\ psi$$

$$\varepsilon = \frac{\sigma}{E} = \frac{15845\ psi}{29\times10^6\ psi} = 0.000546 = \boxed{546\ \mu S}$$

@ 7000 lb (each rod holds 3500 lb)

$$\sigma = \frac{F}{A} = \frac{3500\ lb}{\pi/4\,(3/8\ in)^2} = 31690\ psi$$

$$\varepsilon = \frac{\sigma}{E} = \frac{31690\ psi}{29\times10^6\ psi} = 0.001093 = \boxed{1093\ \mu S}$$

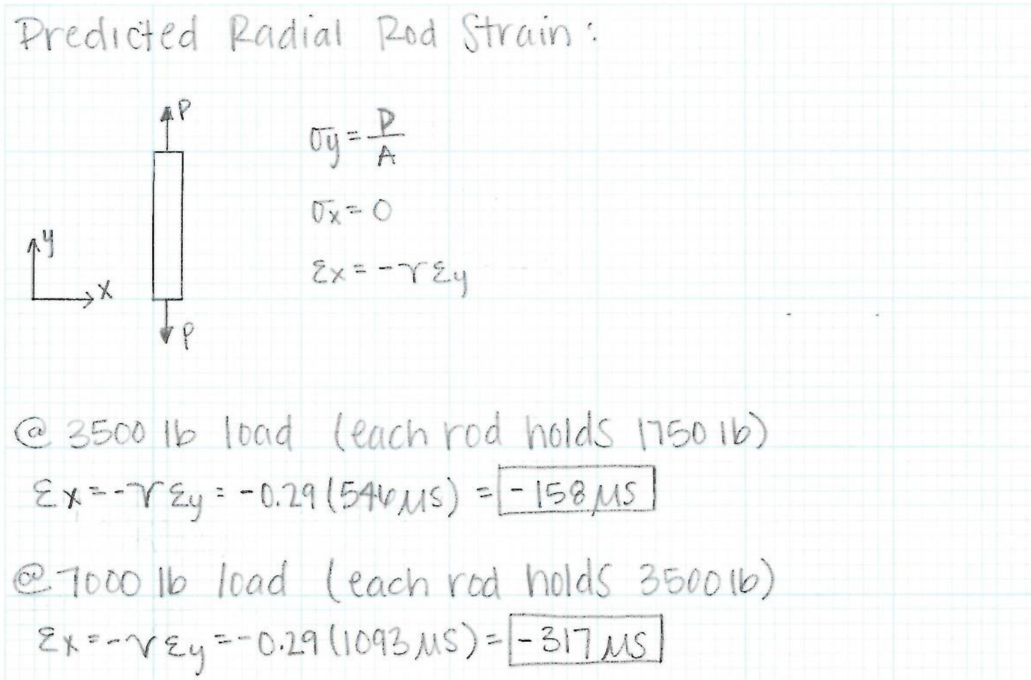
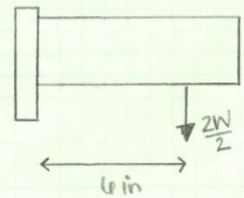


FIGURE A 18: ROD STRAIN PREDICTION

The rods are loaded in direct normal stress. This stress value was determined and the strain can be found based on that number. A predicted axial stain of 546 µs was found. And a radial strain of -158 µs was calculated.

Rotor Pole Lifting Device Removable Dovetail Prediction

Given: The strain in the adapter will be measured using a strain gauge.



Find: Predict Strain

Solution:

$$\sigma = \frac{Mc}{I}$$

$$M = (3500\ \text{lb})(6\ \text{in}) = 21000\ \text{lb}\cdot\text{in}$$

$$c = \tfrac{1}{2}(1.5\ \text{in}) = 0.75\ \text{in}$$

$$I = 1/12\,(8.5\ \text{in})(1.5\ \text{in})^3 = 2.391\ \text{in}^4$$

$$\sigma = \frac{(21000\ \text{lb}\cdot\text{in})(0.75\ \text{in})}{2.391\ \text{in}^4} = 6587\ \text{psi}$$

$$\varepsilon = \frac{\sigma}{E} = \frac{6587\ \text{psi}}{29000\ \text{ksi}} = \boxed{0.00023\ \text{in/in}}$$

GRANT COUNTY PUBLIC UTILITY DISTRICT NO. 2

Facility ______ Proj. I.D. ______ W.O. ______

Title Dovetail Strain

Computed By ______ Date ______ 20____

Checked By ______ Date ______ 20____

Page ______ of ______

@ 3500 lb (each dovetail holds 1750 lb)

$$\sigma = \frac{Mc}{I} = \frac{(10500\ \text{lb}\cdot\text{in})(0.75\ \text{in})}{2.391\ \text{in}^4} = 3294\ \text{psi}$$

$$\varepsilon = \frac{\sigma}{E} = \frac{3294\ \text{psi}}{29\times10^6\ \text{psi}} = 0.000114 = \boxed{114\ \mu s}$$

@ 7000 lb (each dovetail holds 3500 lb)

$$\sigma = \frac{Mc}{I} = \frac{(21000\ \text{lb}\cdot\text{in})(0.75\ \text{in})}{2.391\ \text{in}^4} = 6587\ \text{psi}$$

$$\varepsilon = \frac{\sigma}{E} = \frac{6587\ \text{psi}}{29\times10^6\ \text{psi}} = 0.000227 = \boxed{227\ \mu s}$$

FIGURE A 19: ADAPTER STRAIN PREDICTION

The dovetail adapter is loaded in bending at the transition. This stress was determined, followed by the strain. A predicted strain of 114 µs was found.

GRANT COUNTY PUBLIC UTILITY DISTRICT NO. 2

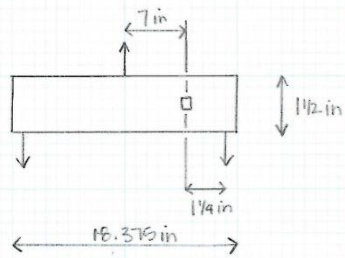
Facility ______ Computed By ______ Date ______ 20___

Proj. I.D. ______ W.O. ______ Checked By ______ Date ______ 20___

Title ______ Page ____ of ____

Top Plate Strain:

* Note: Strain gage is located 7 inches from center and 1 1/4 inches from rod hole.



@ 3500 lb

$M = 1.25\text{ in}\,(3500/2\text{ lb}) = 2187.5\text{ lb}\cdot\text{in}$

$c = 1.5\text{ in}/2 = 0.75\text{ in}$

$I = 1/12\,(18.375\text{ in})(1.5\text{ in})^3 = 5.168\text{ in}^4$

$\sigma = \frac{Mc}{I} = \frac{(2187.5\text{ lb}\cdot\text{in})(0.75\text{ in})}{5.168\text{ in}^4} = 317.5\text{ psi}$

$\varepsilon = \frac{\sigma}{E} = \frac{317.5\text{ psi}}{29\times10^6\text{ psi}}(10^6) = \boxed{11\ \mu S}$

@ 7000 lb

$M = 1.25\text{ in}\,(7000/2\text{ lb}) = 4375\text{ lb}\cdot\text{in}$

$\sigma = \frac{Mc}{I} = \frac{(4375\text{ lb}\cdot\text{in})(0.75\text{ in})}{5.168\text{ in}^4} = 635\text{ psi}$

$\varepsilon = \frac{\sigma}{E}\cdot10^6 = \frac{635\text{ psi}}{29\times10^6\text{ psi}}(10^6) = \boxed{22\ \mu S}$

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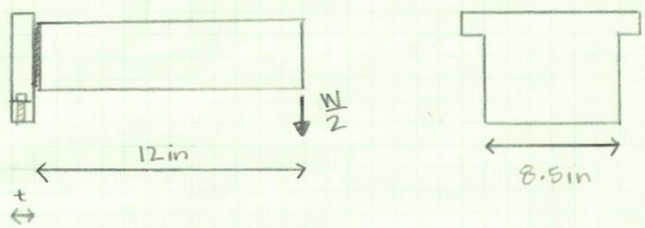
FIGURE A 20: TOP PLATE STRAIN PREDICTION

The top plate will be loaded in bending. A stress of 10,400 psi was determined, followed by a strain of 0.00036 in/in.

Rotor Pole Lifting Device Removable Dovetail

Given: When the device is in the horizontal position, half of the weight is supported by the piece shown. The adapter plate will experience bending & torsion.



Find: Plate thickness

Solution: (bending)

$$\sigma = \frac{Mc}{I}$$

$$M = \frac{W}{2}(12in) = \frac{(3500lb)(12in)}{2} = 21000\ lb\cdot in$$

$$c = \frac{1}{2}t$$

$$I = \frac{1}{12}(8.5in)t^3$$

$$12000\ psi = \frac{(21000\ lb\cdot in)(\frac{1}{2}t)}{\frac{1}{12}(8.5in)t^3}$$

$$t = 1.11\ in$$

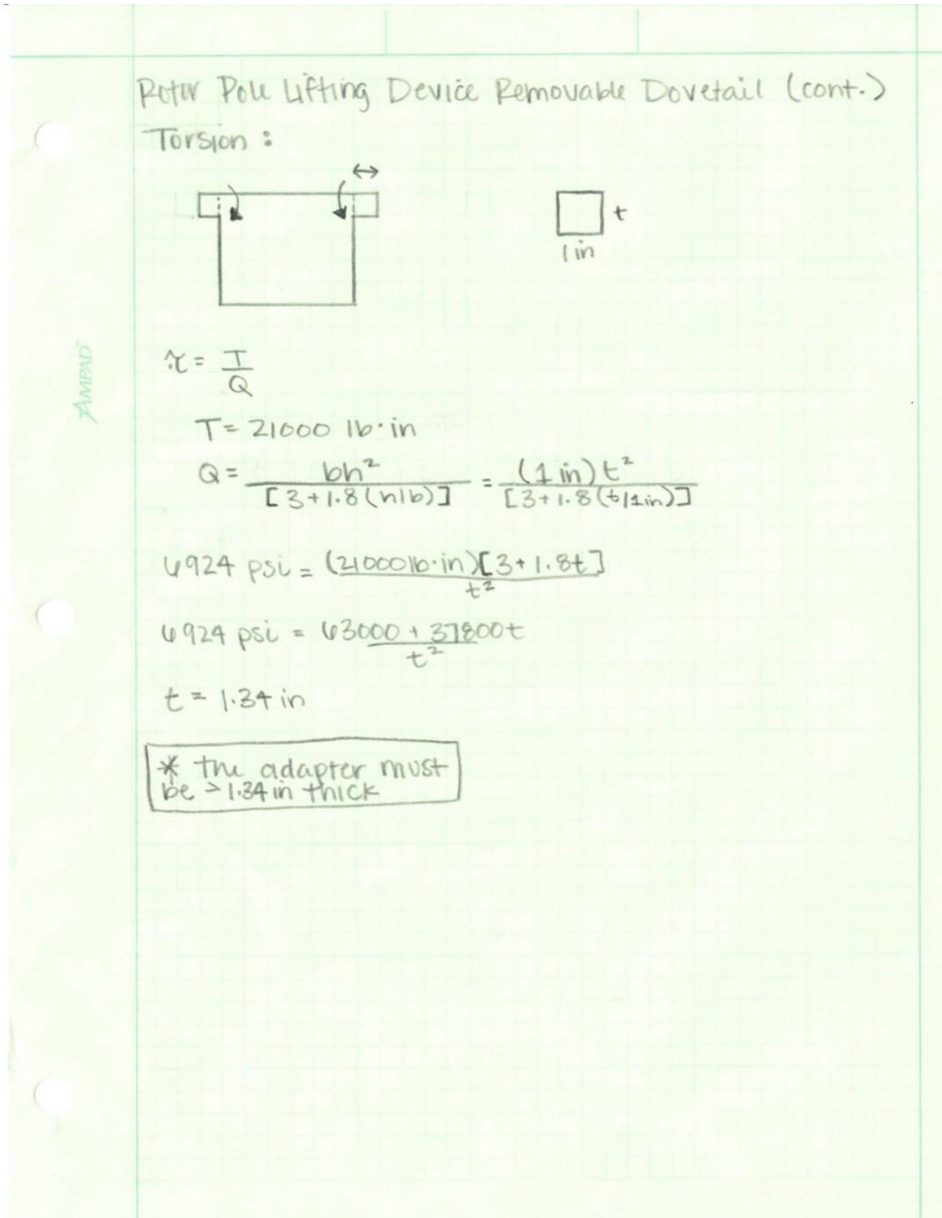


FIGURE A 21: ADAPTER THICKNESS ANALYSIS

The adapter plate is loaded in bending and torsion. The thickness of the plate that is required to overcome each loading was determined to be at least 1.34 inches. A thickness of 1.5 inches was chosen.

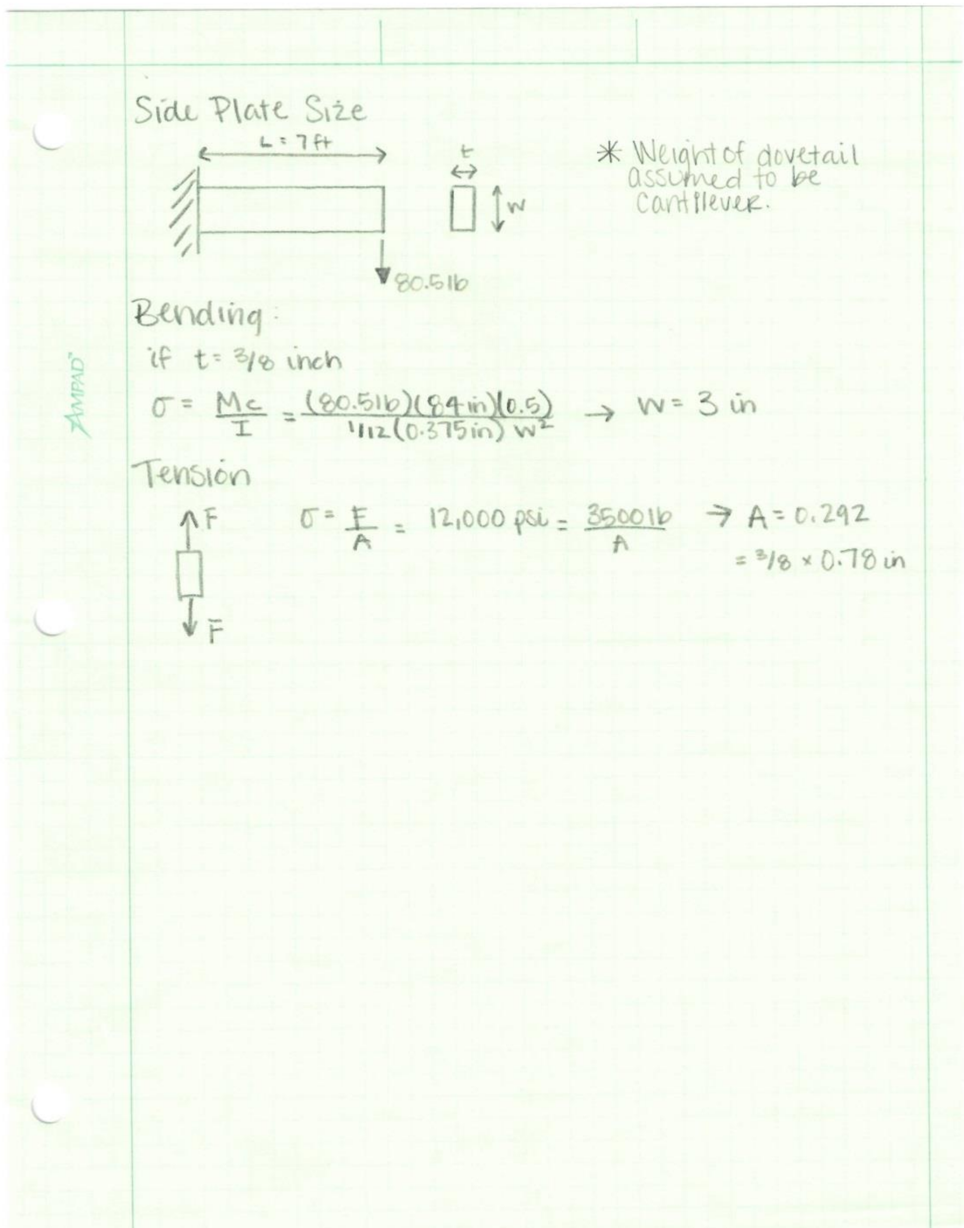


FIGURE A 22: LIFTING DEVICE SIDE PLATE SIZE

The size of the top plate was determined by analyzing the bending that would occur when the dovetail was attached and when the device was in tension. It was found that if the thickness of the plate was 3/8 inch, then the width of the plate only needs to be 3 inches.

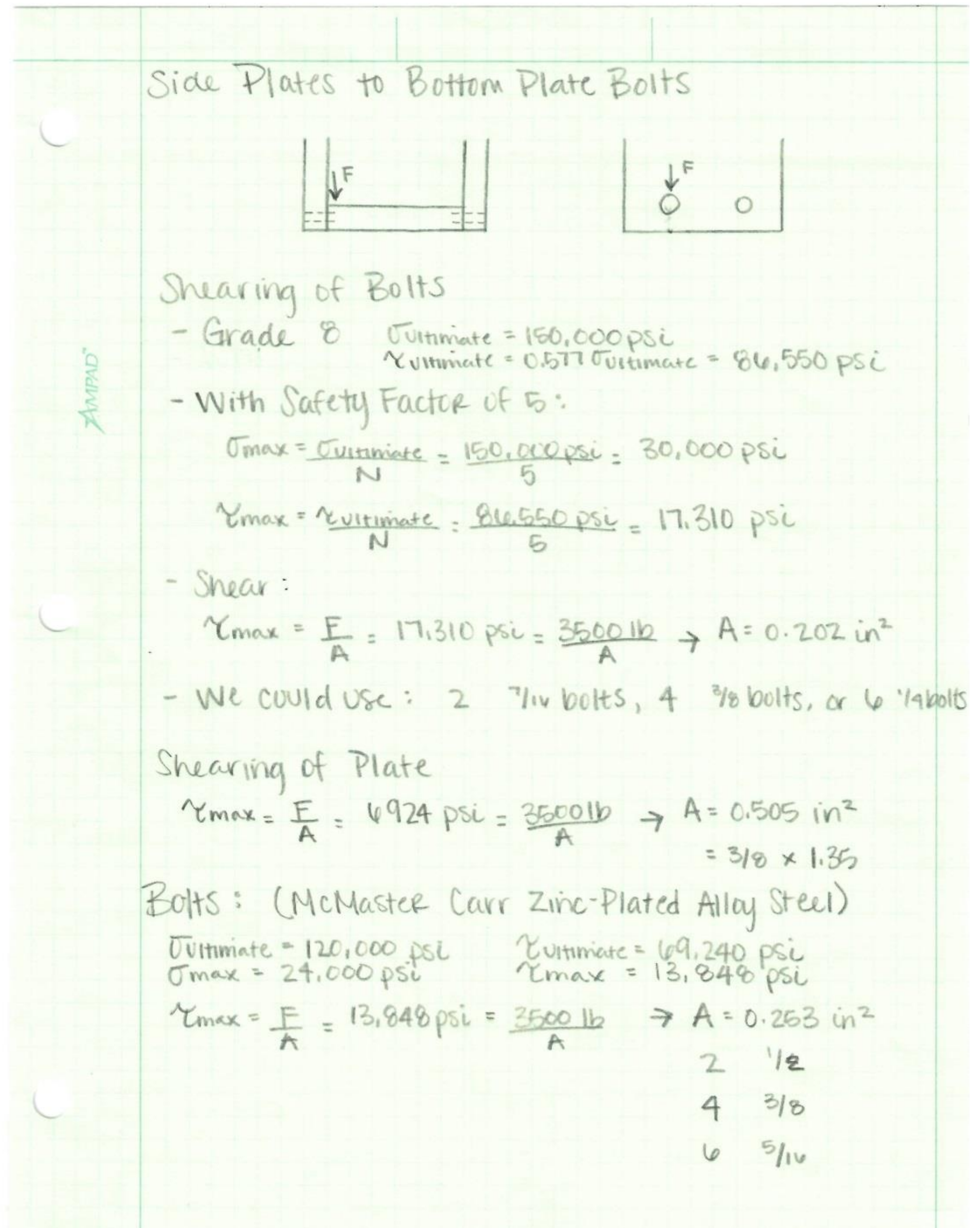
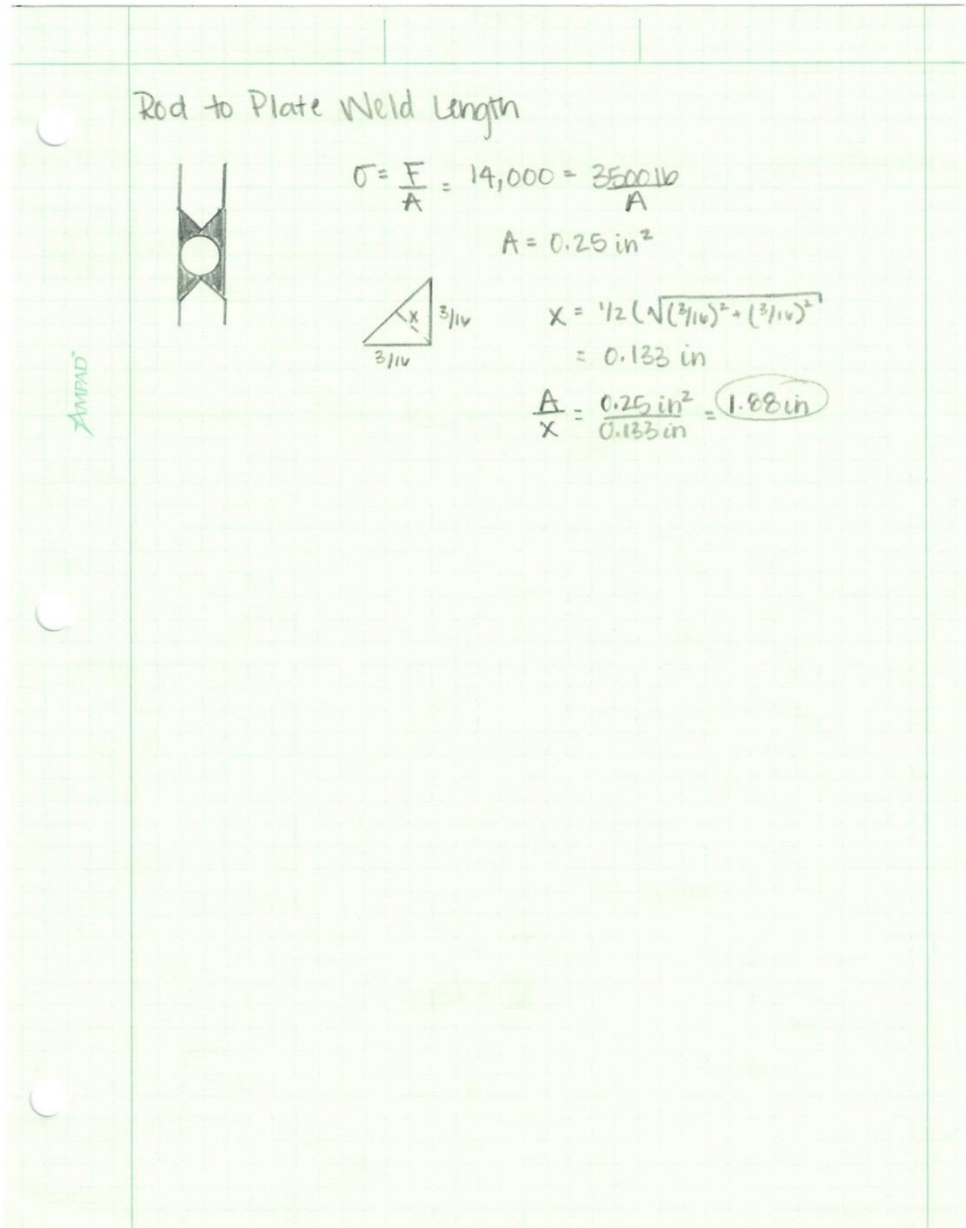


FIGURE A 23: LIFTING DEVICE SIDE PLATE TO BOTTOM PLATE BOLTS

First, to determine the size and number of bolts required, the shear area needed to keep failure from happening was determined and then this was broken out to find what size bolts would be needed if two, four or six bolts were used. Then the amount of plate that needed to be present underneath the bolts to prevent shearing was determined.


Rod to Plate Weld Length

$\sigma = \frac{F}{A} = 14{,}000 = \frac{3500\,lb}{A}$

$A = 0.25\ in^2$

$x = \frac{1}{2}\left(\sqrt{(3/16)^2 + (3/16)^2}\right)$

$= 0.133\ in$

$\frac{A}{x} = \frac{0.25\ in^2}{0.133\ in} = 1.88\ in$

FIGURE A 24: RODS TO SIDE PLATE WELD LENGTH

Using a bevel weld, the throat size of the weld was determined to be 0.133 in. The total area of weld needed to prevent failure was determined and the total length of weld needed was determined to be 1.88 inches.

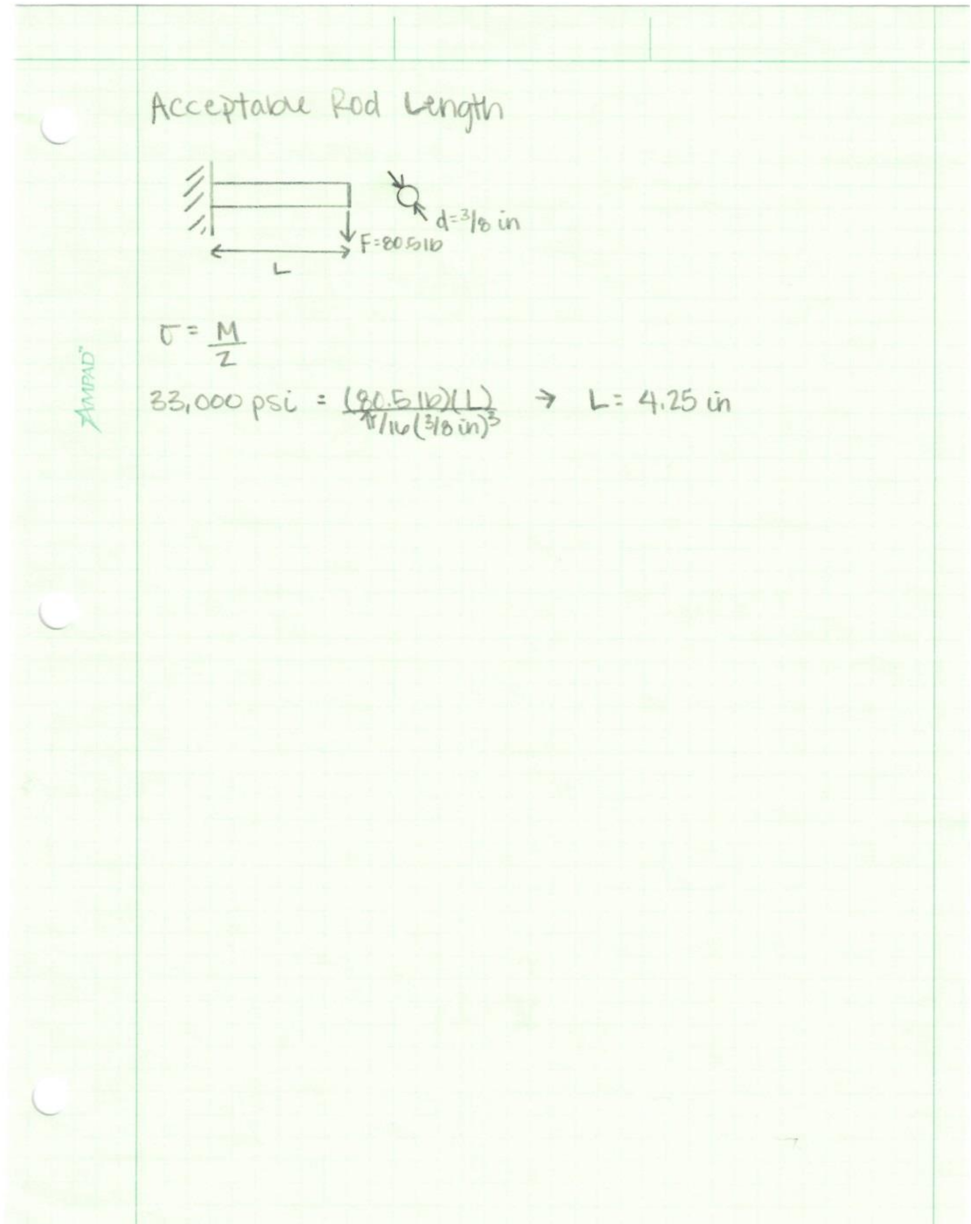
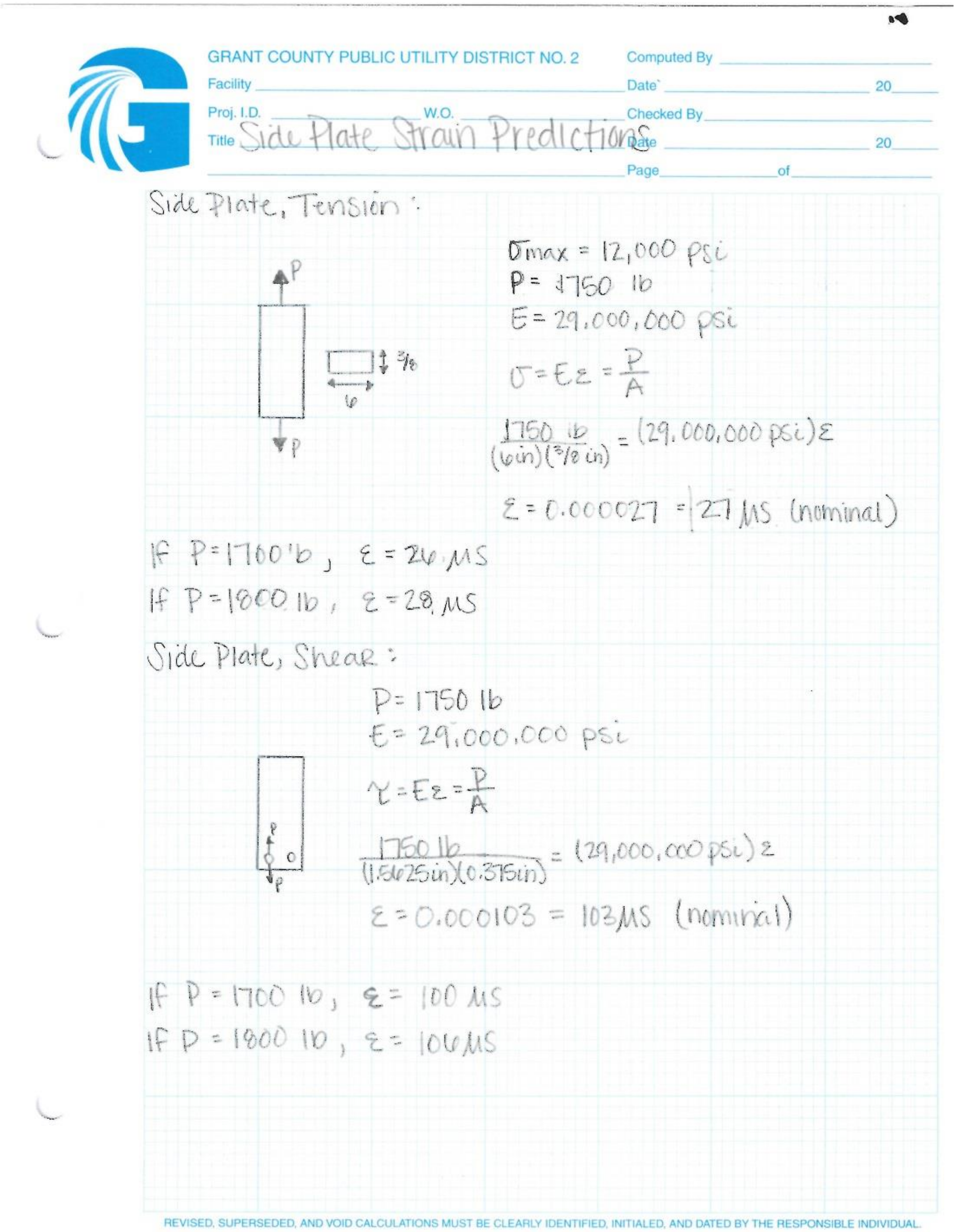


FIGURE A 25: ACCEPTABLE ROD LENGTH

The amount of rod that could be present when the dovetail was attached was determined to be 4.25 inches.



GRANT COUNTY PUBLIC UTILITY DISTRICT NO. 2

Facility ______ Computed By ______ Date ______ 20__

Proj. I.D. ______ W.O. ______ Checked By ______

Title Side Plate Strain Predictions Date ______ 20__

Page ______ of ______

Side Plate, Tension:

$\sigma_{max} = 12{,}000$ psi

$P = 1750$ lb

$E = 29{,}000{,}000$ psi

$\sigma = E\varepsilon = \frac{P}{A}$

$\frac{1750 \text{ lb}}{(6 \text{ in})(3/8 \text{ in})} = (29{,}000{,}000 \text{ psi})\varepsilon$

$\varepsilon = 0.000027 = 27$ μS (nominal)

If $P = 1700$ lb, $\varepsilon = 26$ μS

If $P = 1800$ lb, $\varepsilon = 28$ μS

Side Plate, Shear:

$P = 1750$ lb

$E = 29{,}000{,}000$ psi

$\tau = E\varepsilon = \frac{P}{A}$

$\frac{1750 \text{ lb}}{(1.5625 \text{ in})(0.375 \text{ in})} = (29{,}000{,}000 \text{ psi})\varepsilon$

$\varepsilon = 0.000103 = 103$ μS (nominal)

If $P = 1700$ lb, $\varepsilon = 100$ μS

If $P = 1800$ lb, $\varepsilon = 106$ μS

REVISED, SUPERSEDED, AND VOID CALCULATIONS MUST BE CLEARLY IDENTIFIED, INITIALED, AND DATED BY THE RESPONSIBLE INDIVIDUAL.

FIGURE A 26: LIFTING DEVICE SIDE PLATE STRAIN PREDICTION

APPENDIX B – DRAWINGS

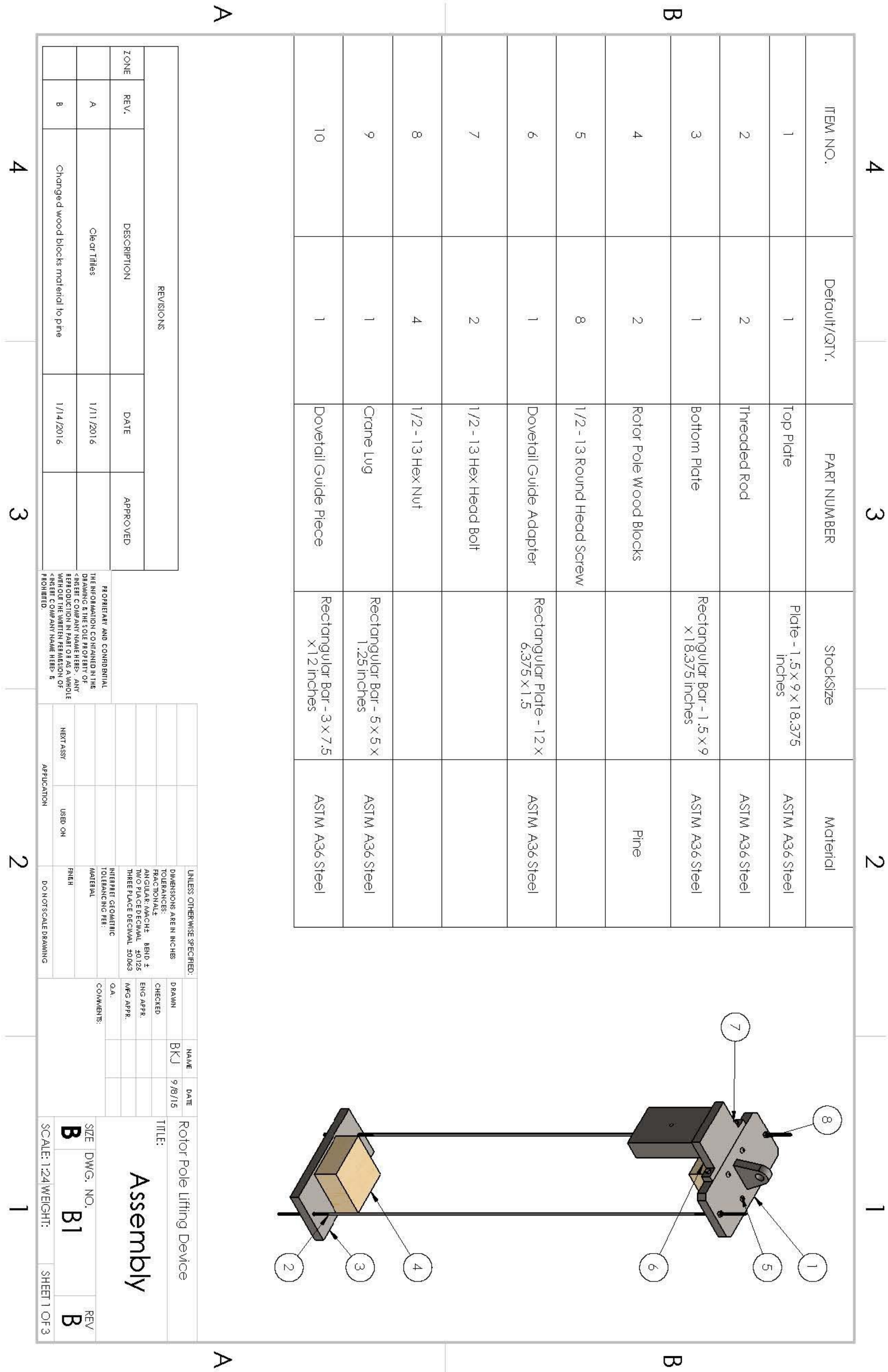


FIGURE B 1: DRAWING OF LIFTING DEVICE ASSEMBLY DESIGN 1

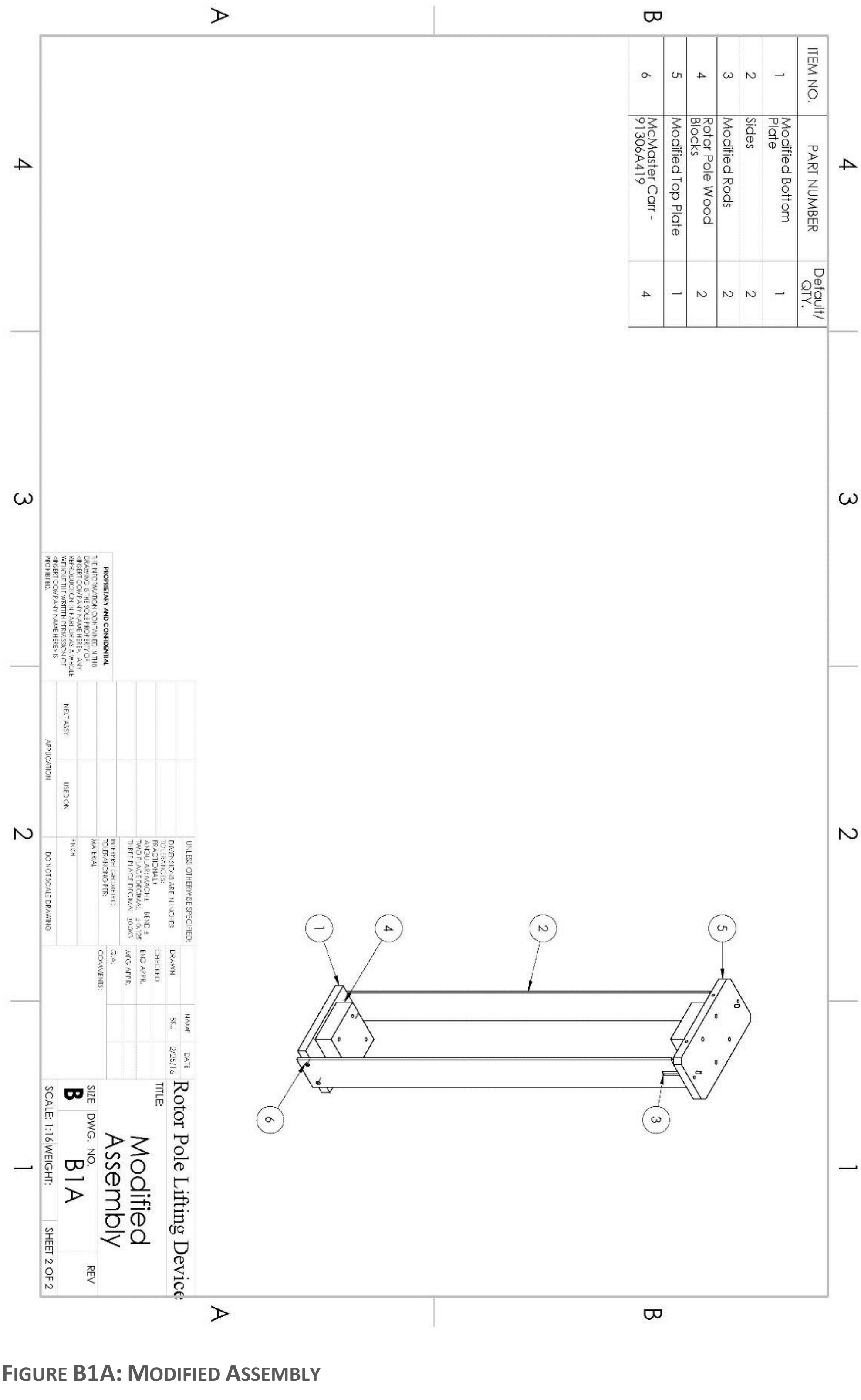


FIGURE B1A: MODIFIED ASSEMBLY

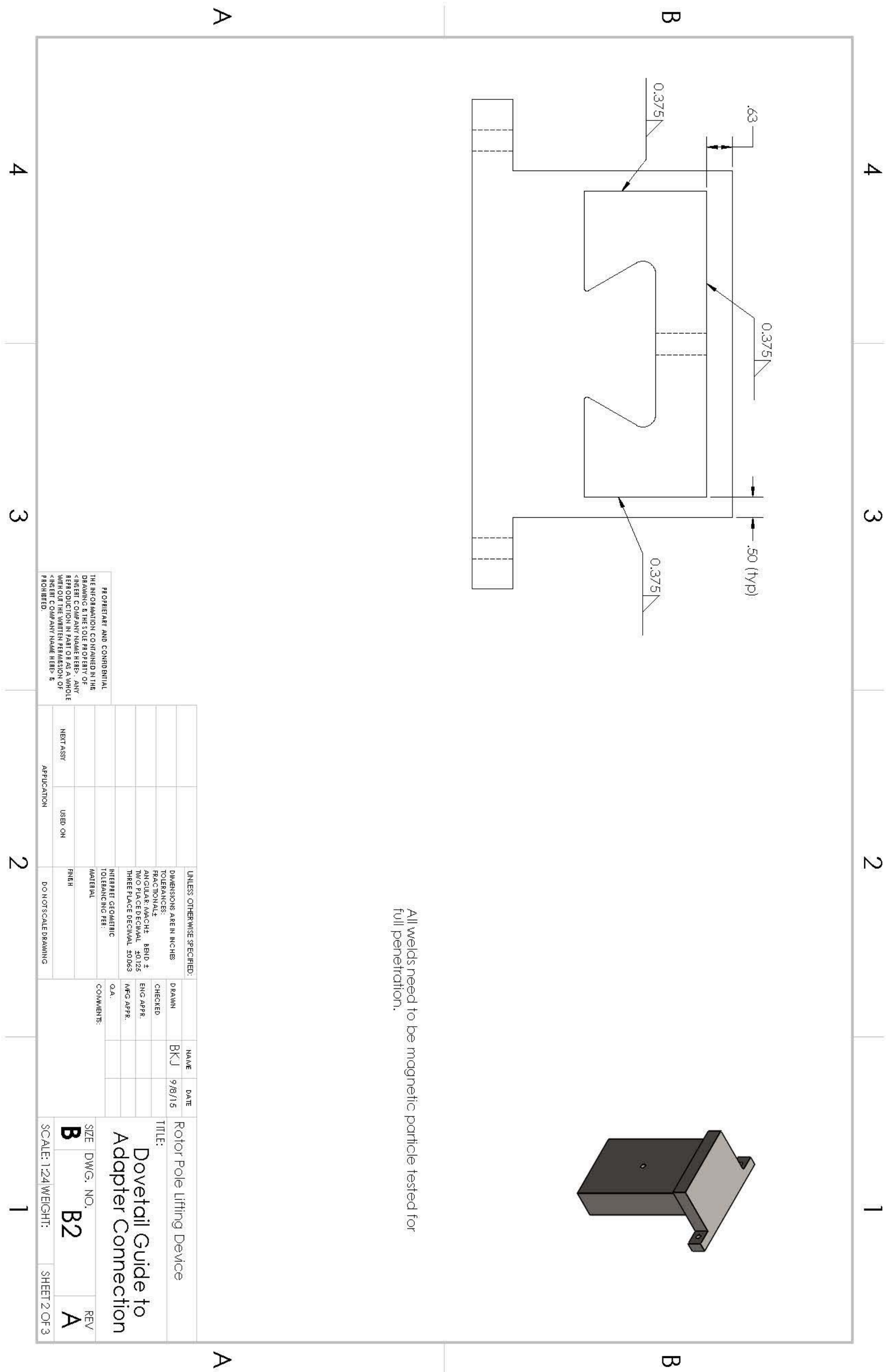


FIGURE B 2: DRAWING OF DOVETAIL GUIDE TO ADAPTER CONNECTION.

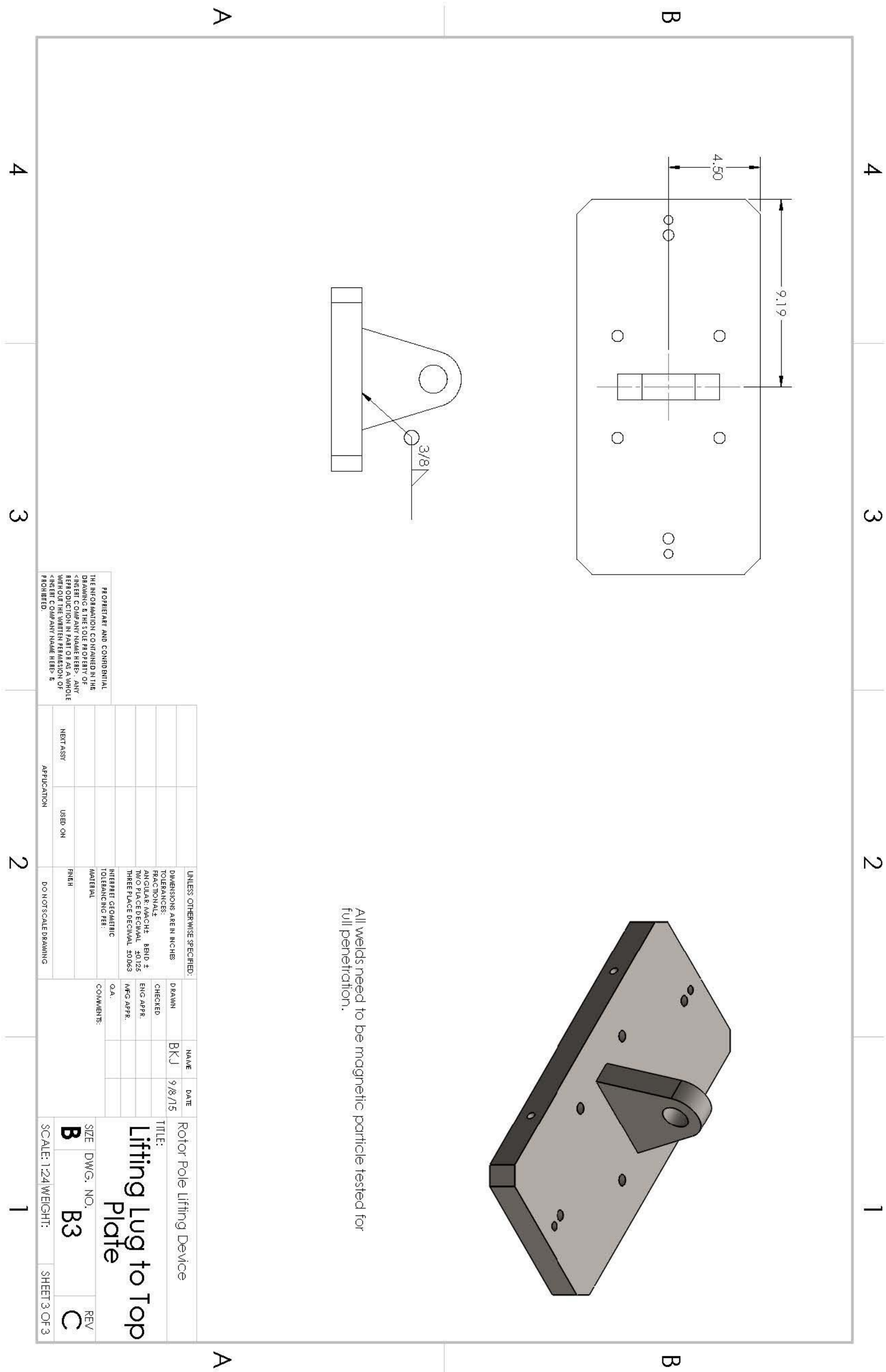


FIGURE B 3: DRAWING OF LIFTING LUG TO TOP PLATE

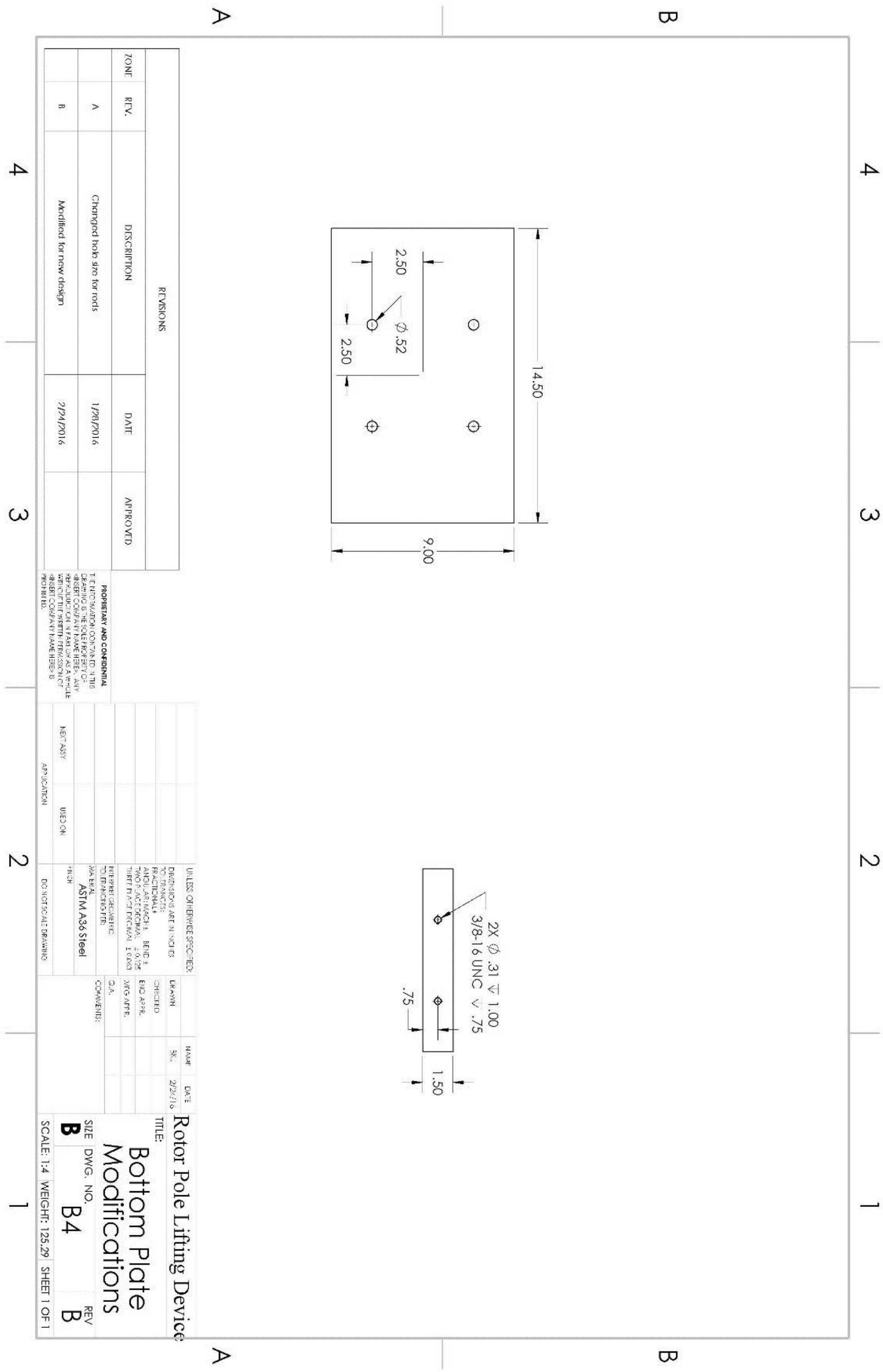


FIGURE B 4: DRAWING OF LIFTING DEVICE BOTTOM PLATE

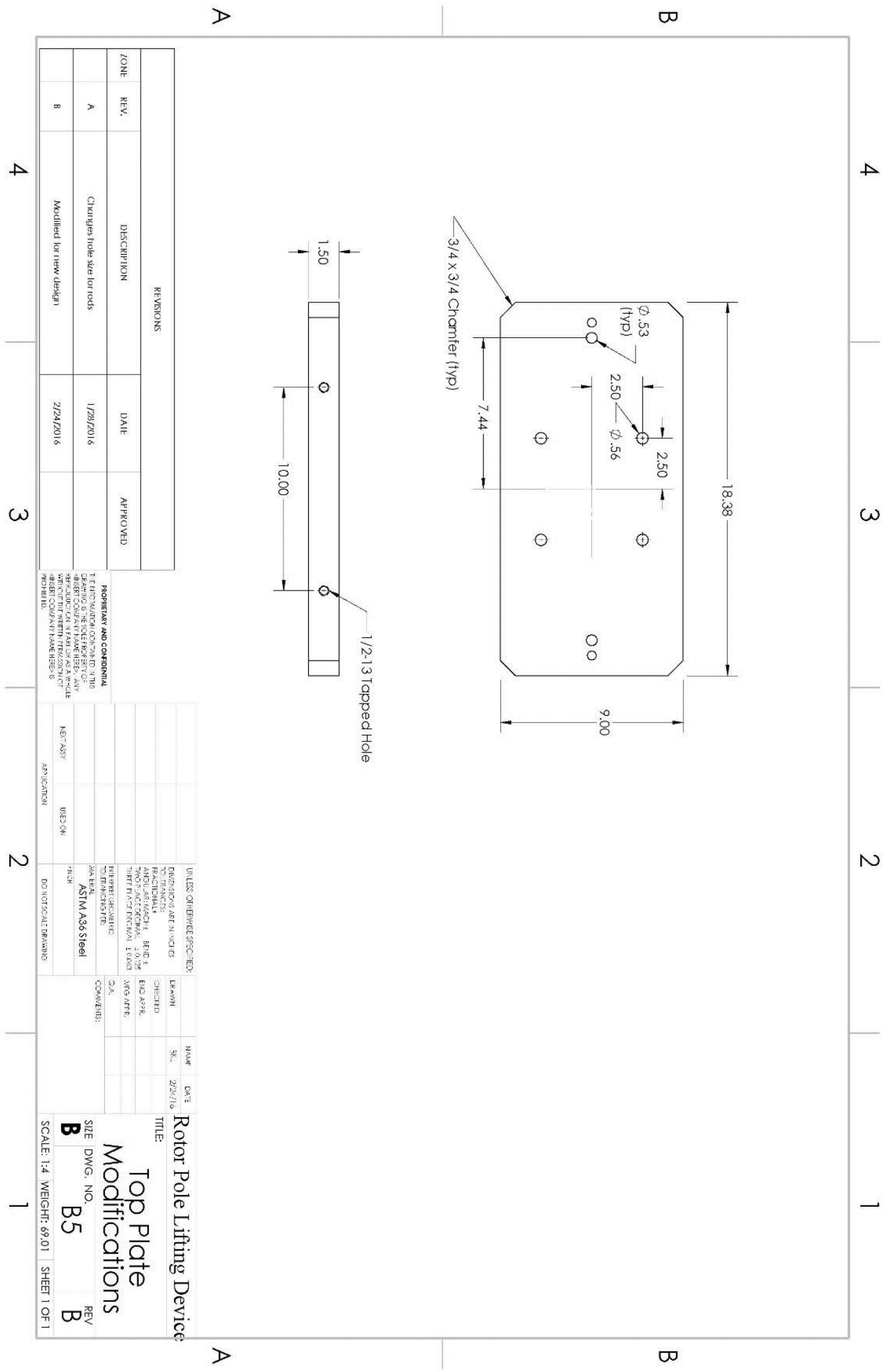


FIGURE B 5: DRAWING OF TOP PLATE

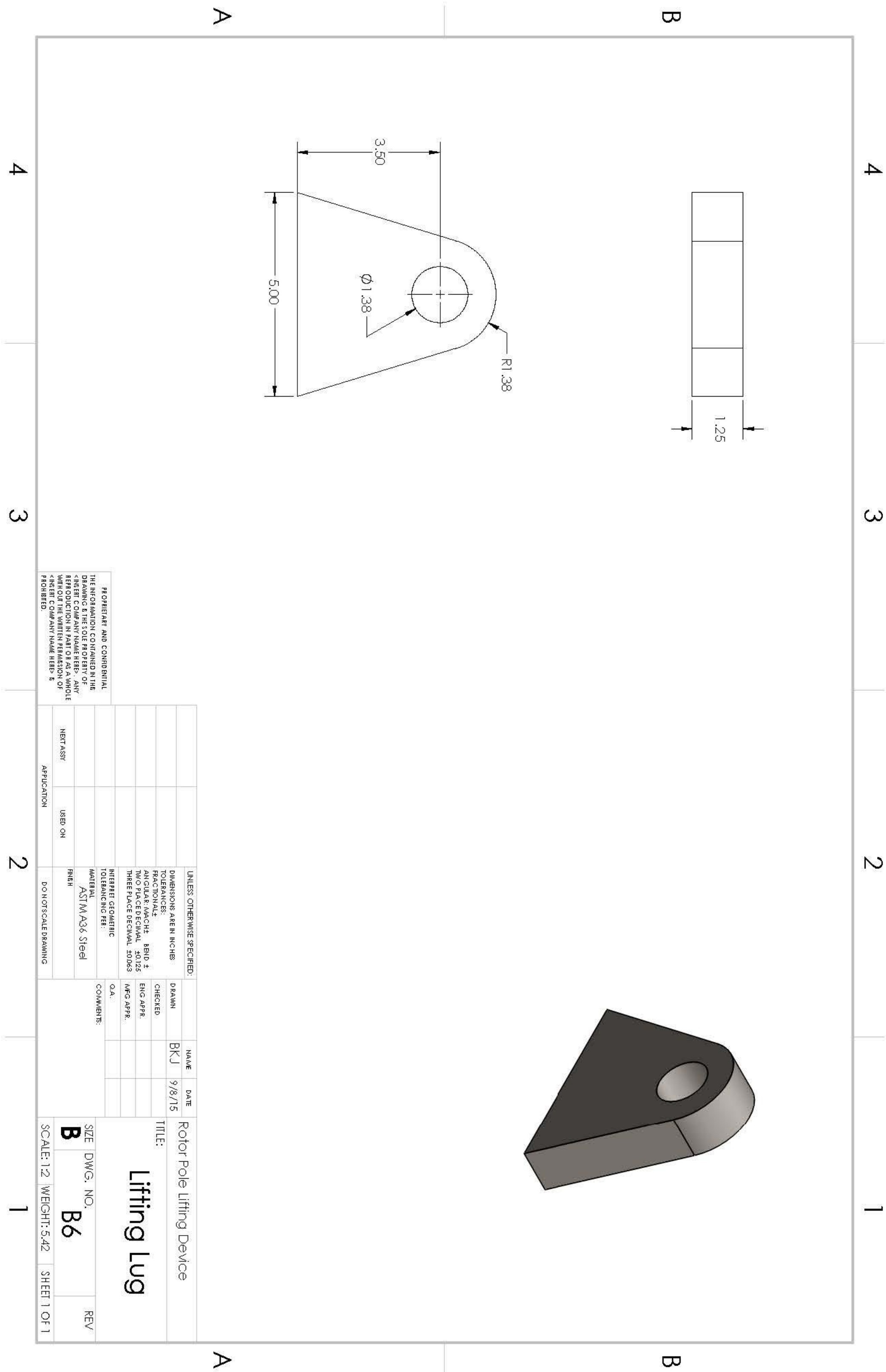


FIGURE B 6: DRAWING OF LIFTING LUG

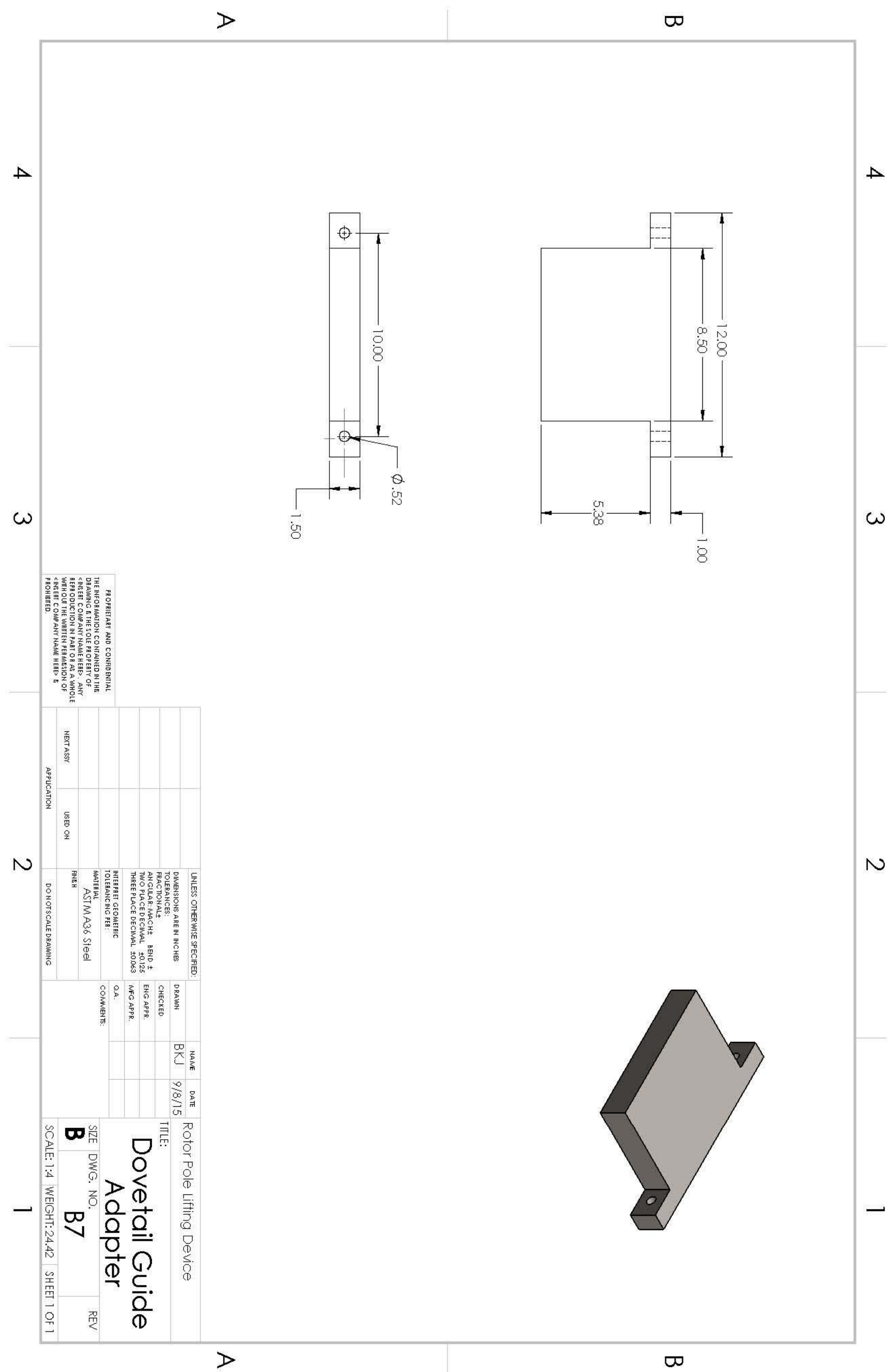


FIGURE B 7: DRAWING OF DOVETAIL GUIDE ADAPTER

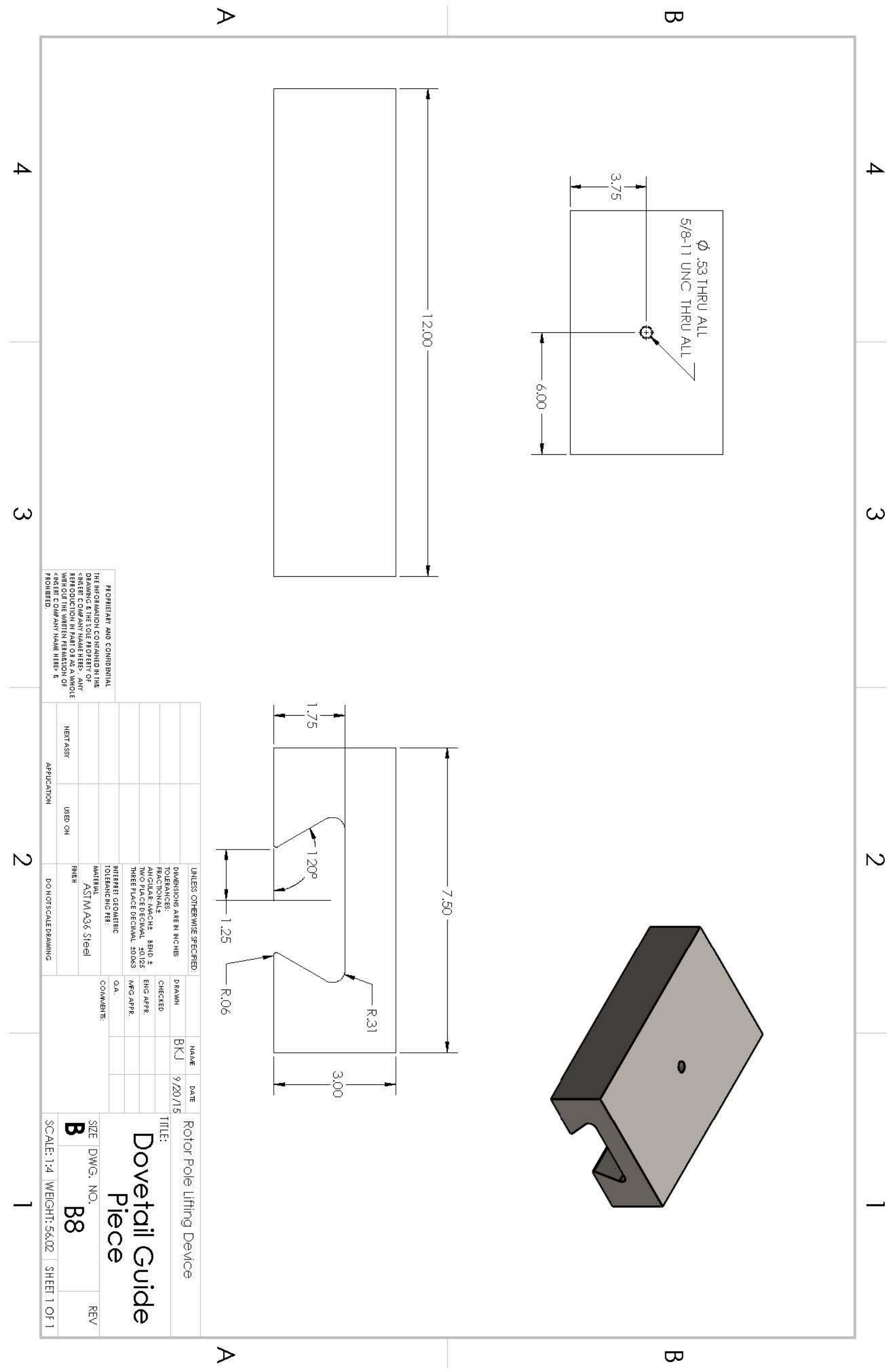


FIGURE B 8: DRAWING OF DOVETAIL GUIDE

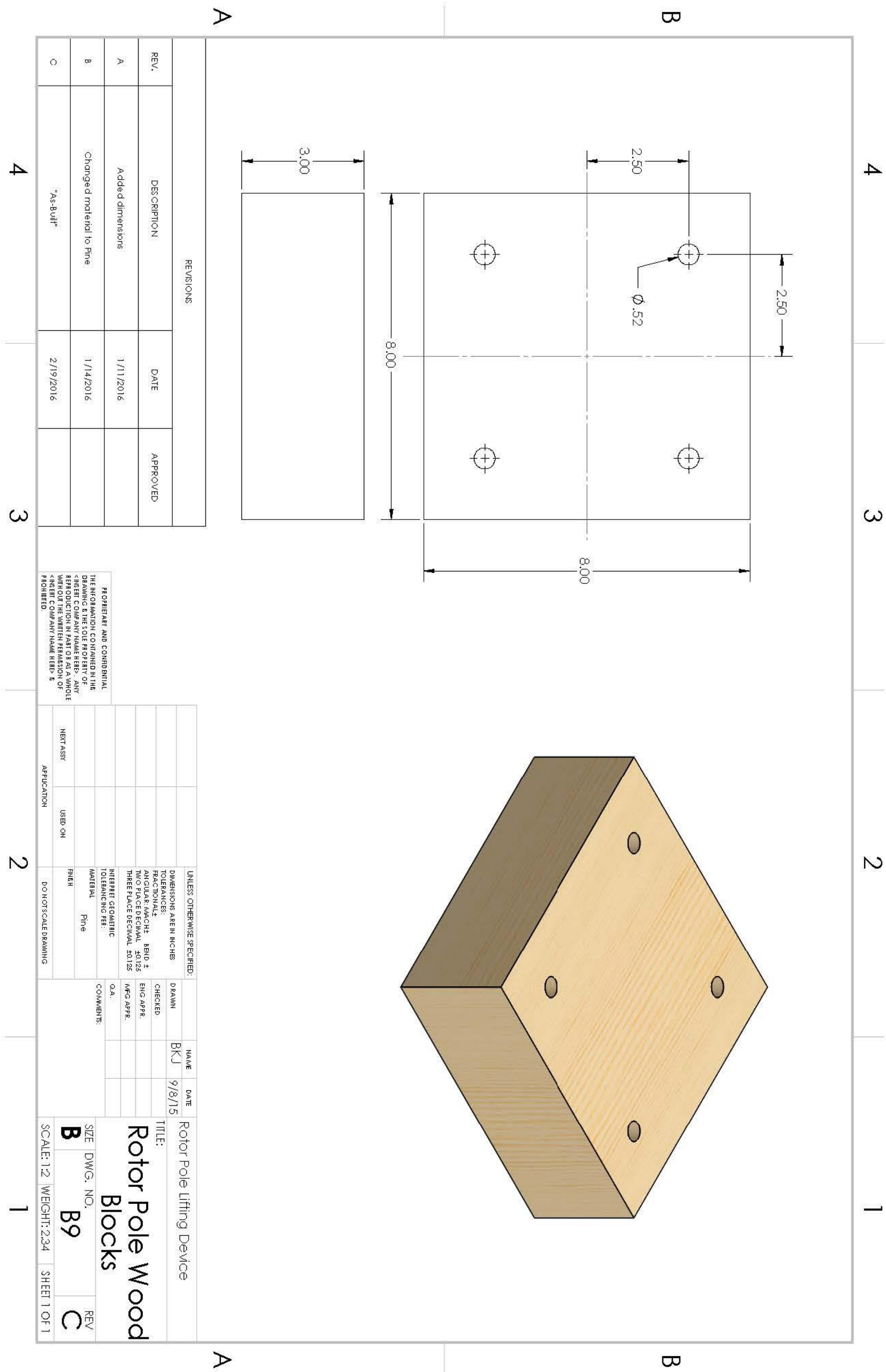


FIGURE B 9: DRAWING OF WOOD BLOCKS

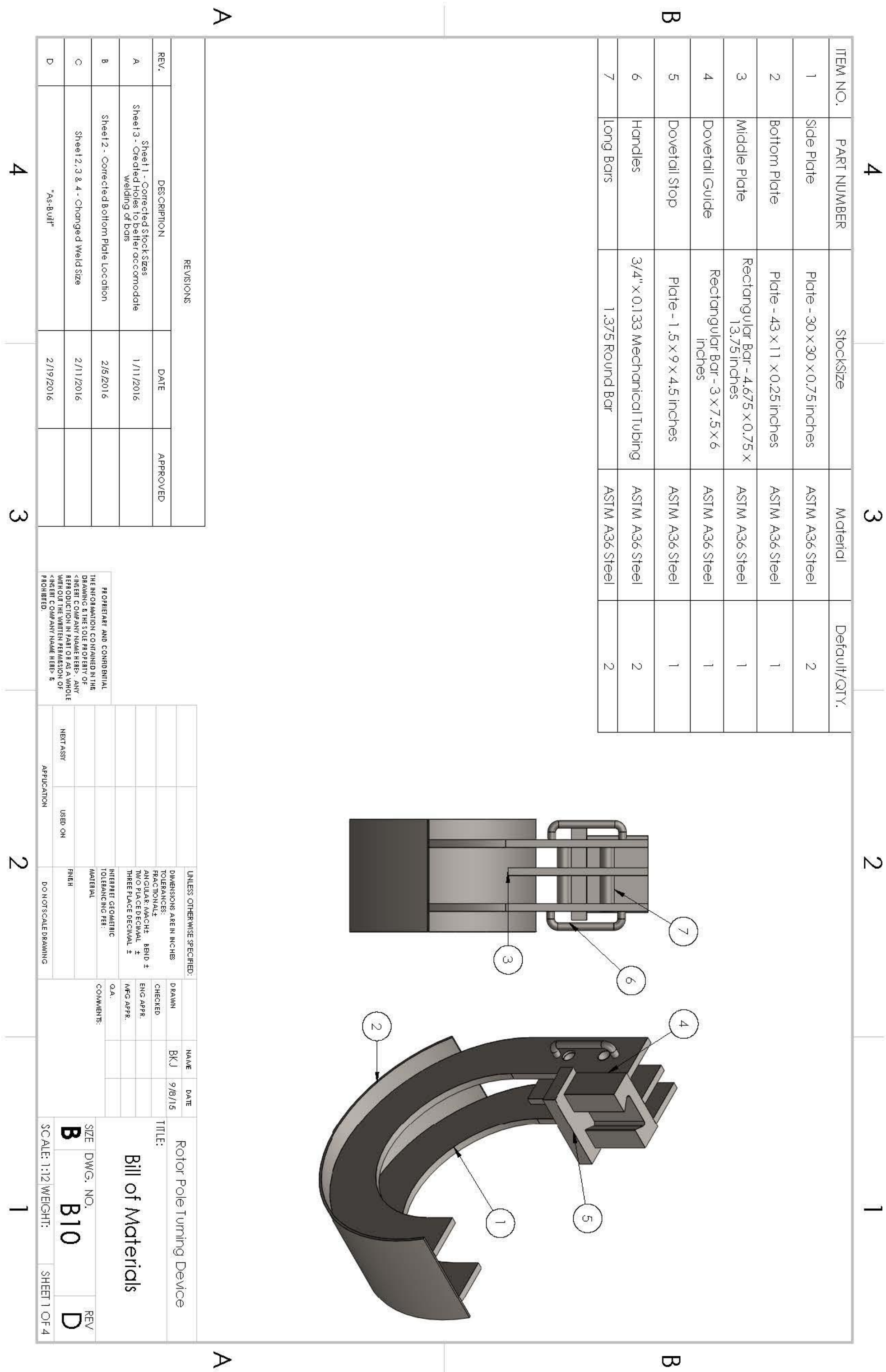


FIGURE B 10: DRAWING OF TURNING DEVICE ASSEMBLY

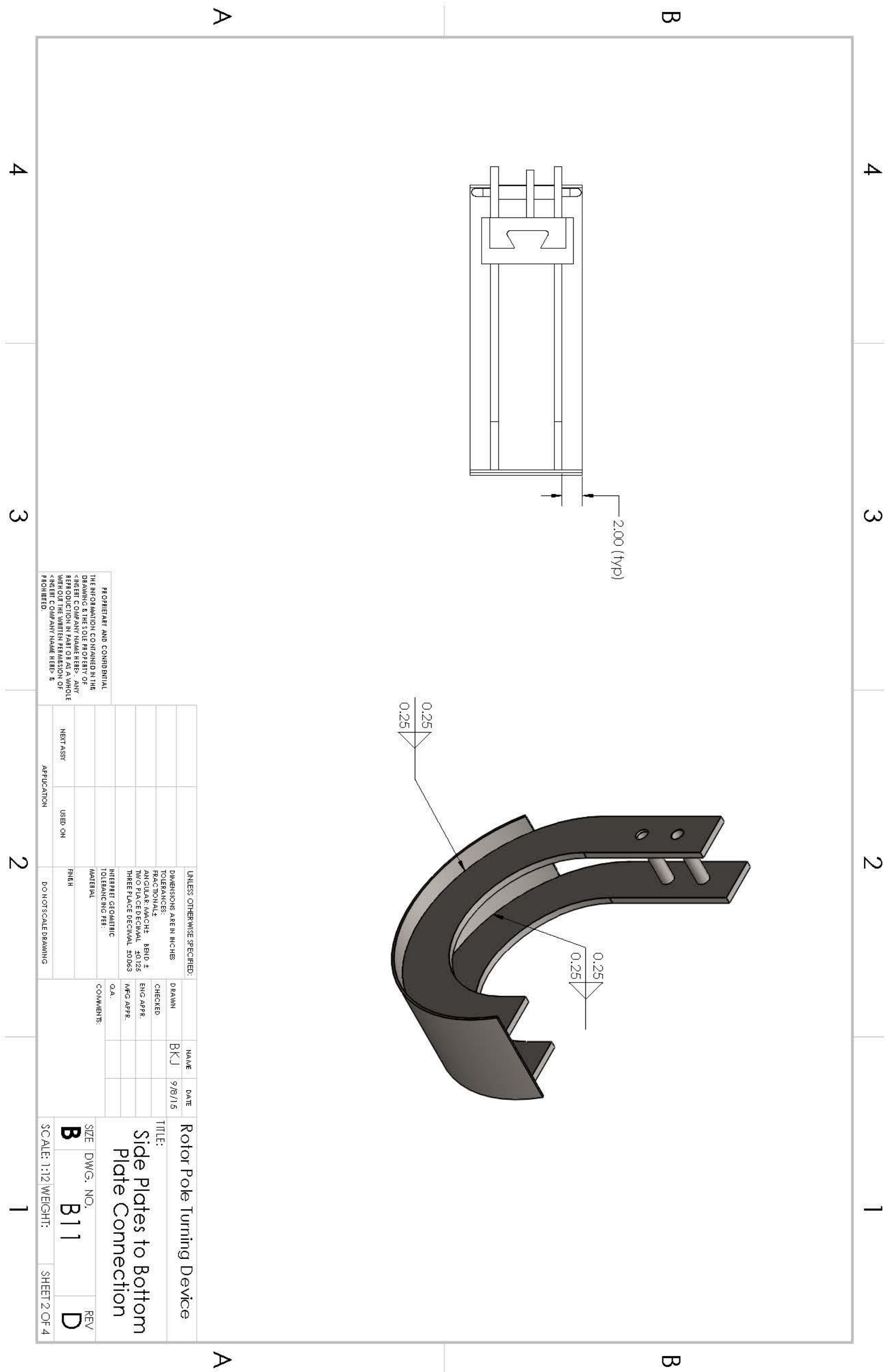


FIGURE B 11: DRAWING OF SIDE PLATES TO TURNING DEVICE BOTTOM PLATE CONNECTION

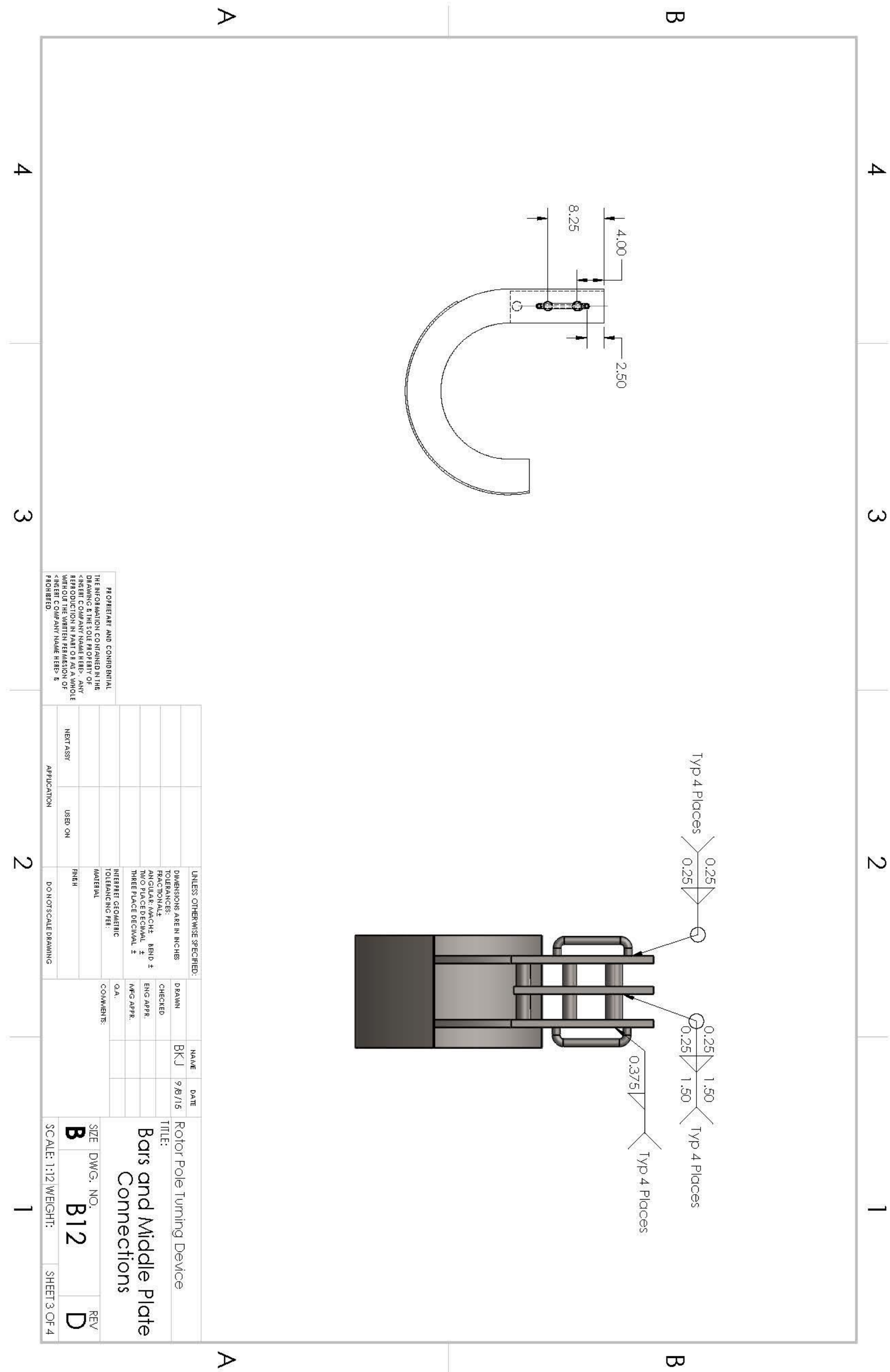


FIGURE B 12: DRAWING OF DOVETAIL GUIDE AND STOP CONNECTIONS

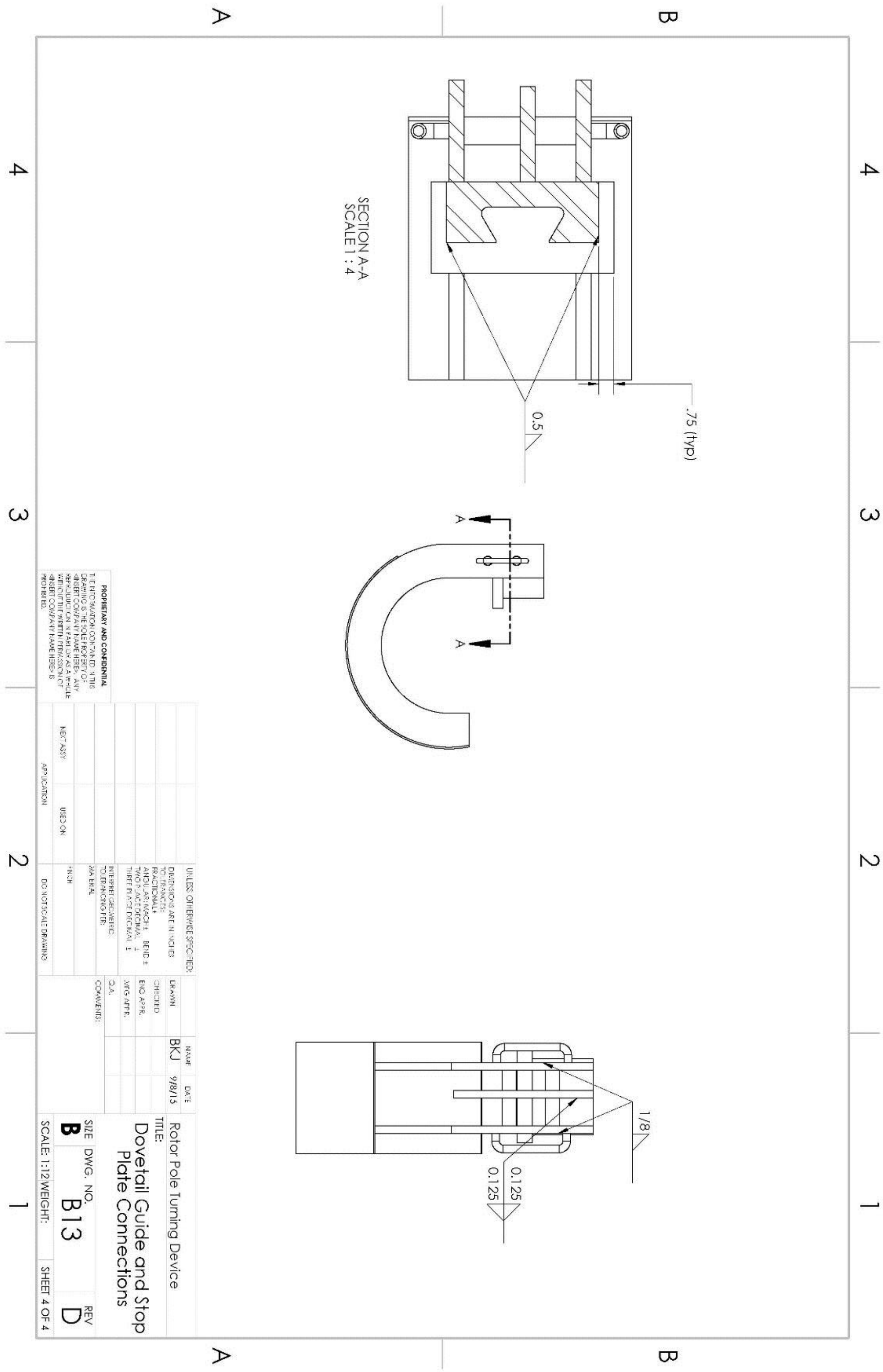


FIGURE B 13: DRAWING OF BARS TO MIDDLE AND SIDE PLATES CONNECTION

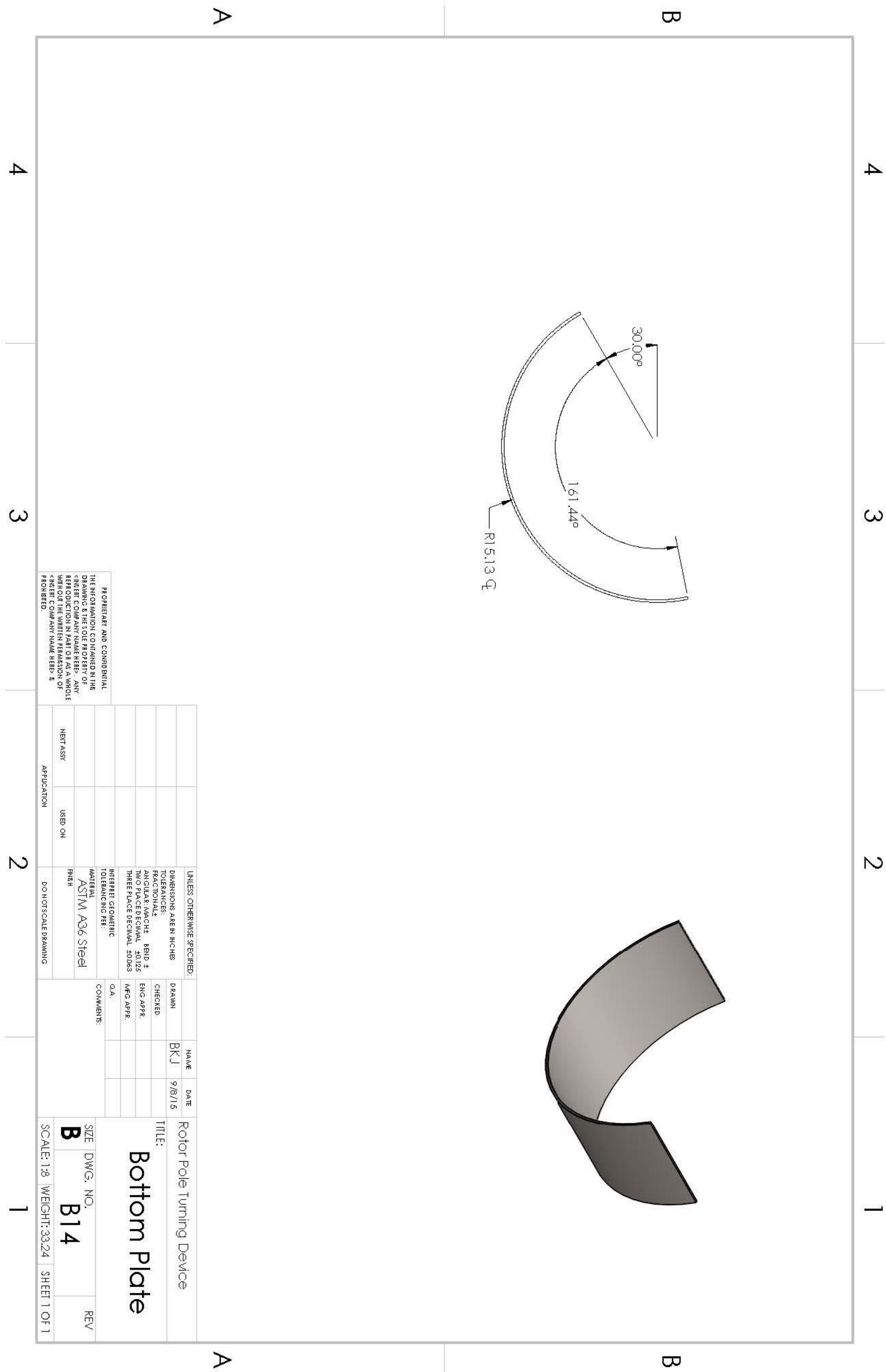
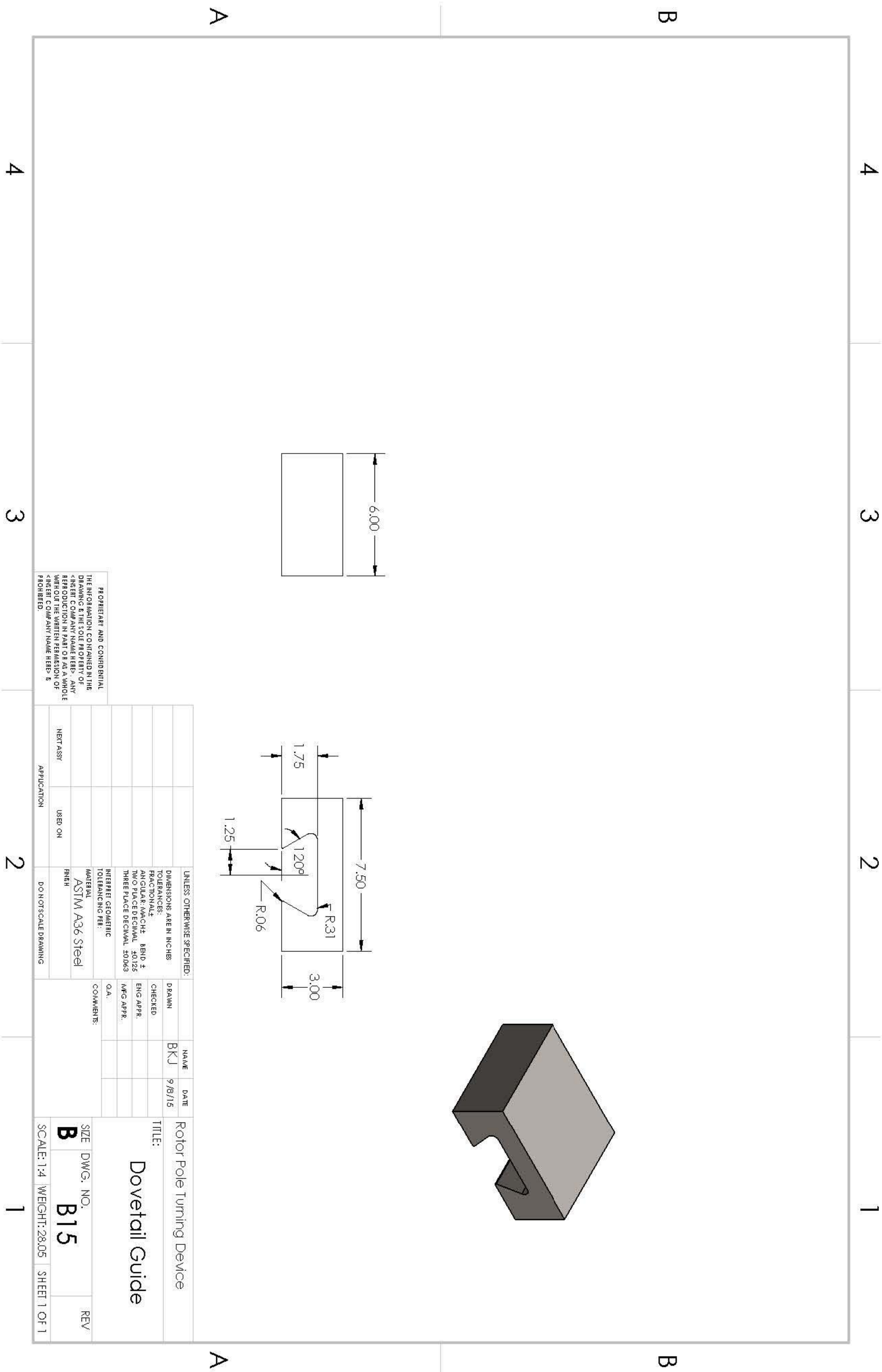


FIGURE B 14: DRAWING OF TURNING DEVICE BOTTOM PLATE



5

FIGURE B 15: DRAWING OF DOVETAIL GUIDE

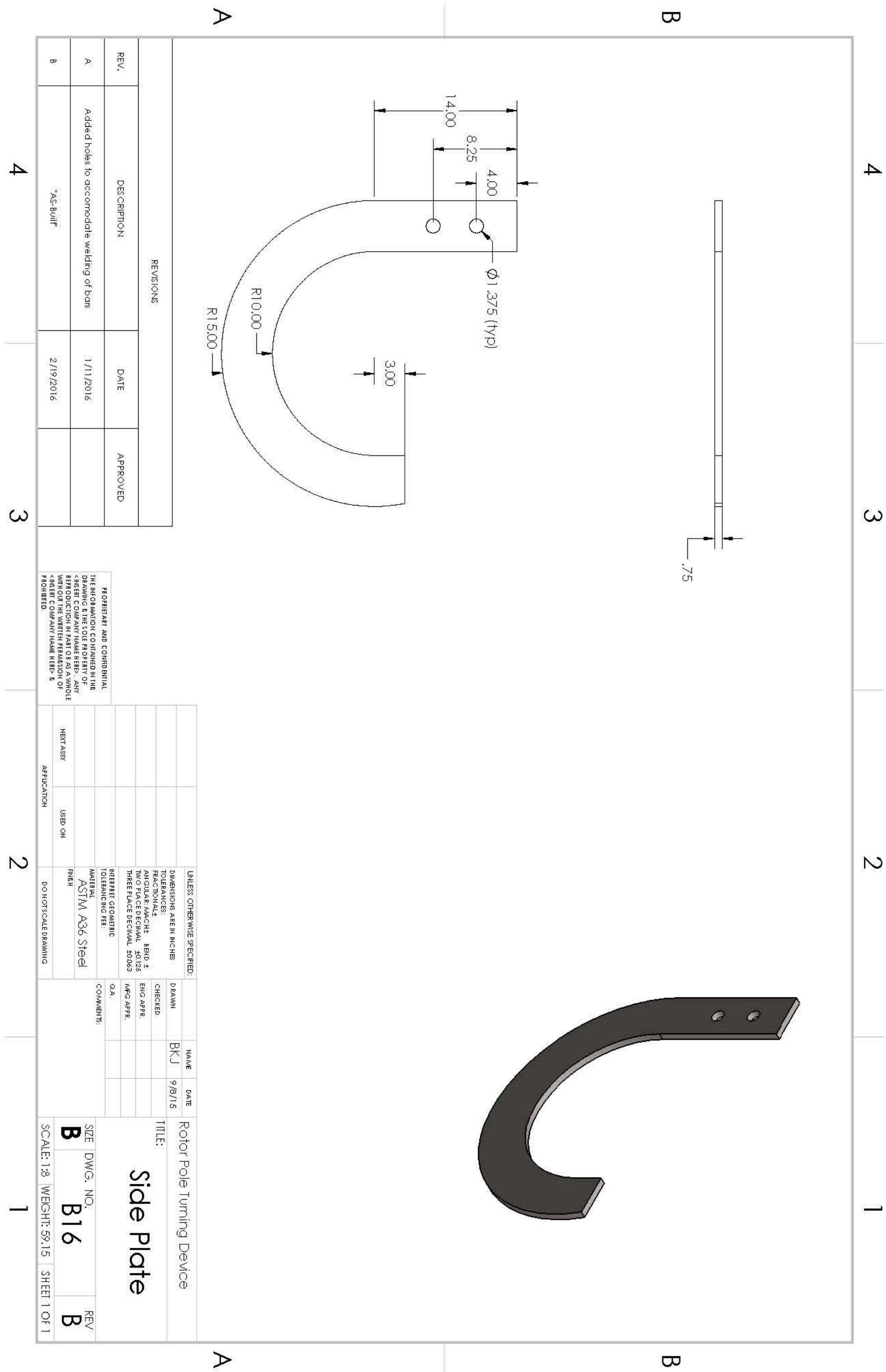


FIGURE B 16: DRAWING OF SIDE PLATE

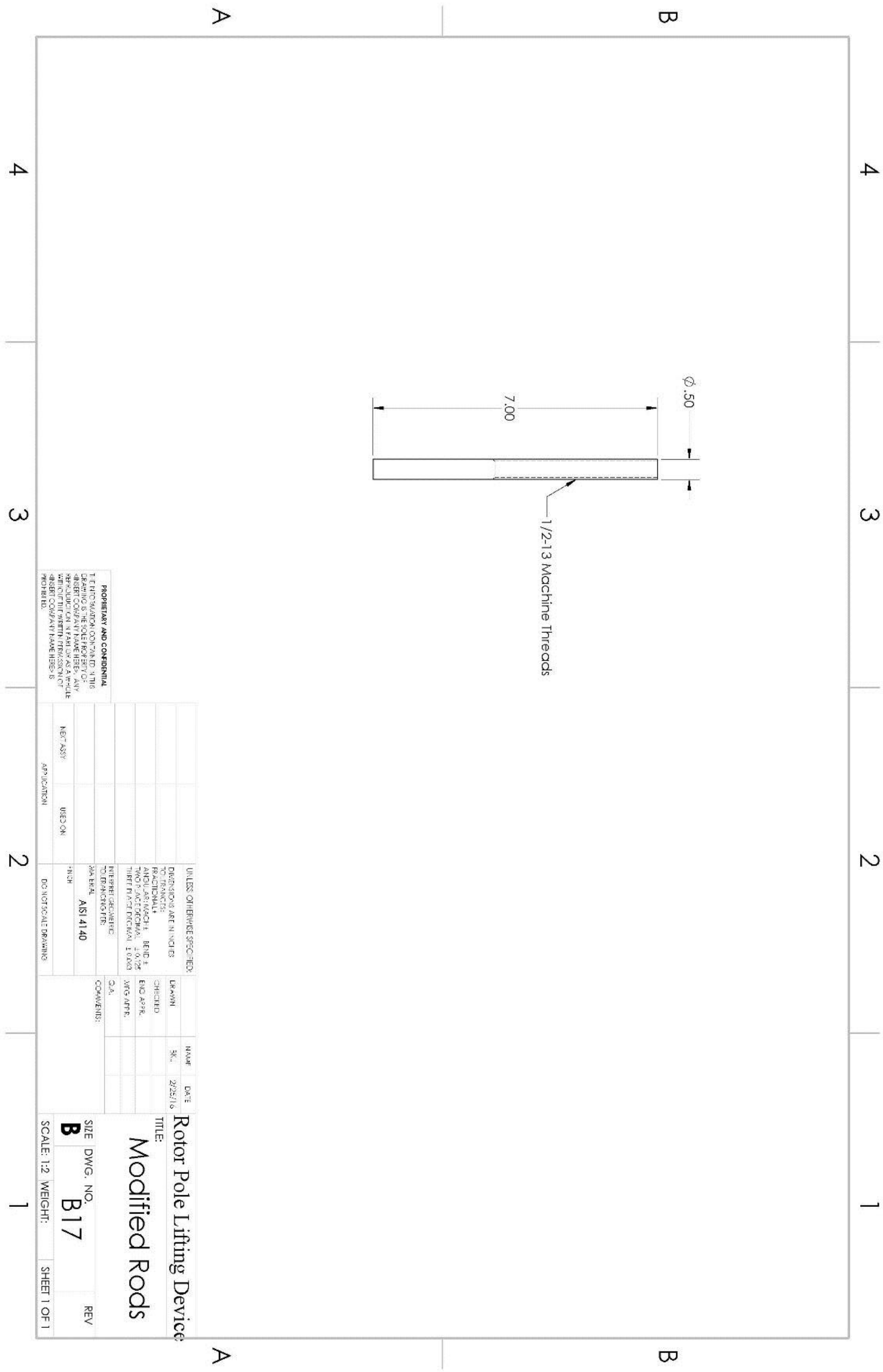


FIGURE B 17: DRAWING OF THREADED ROD

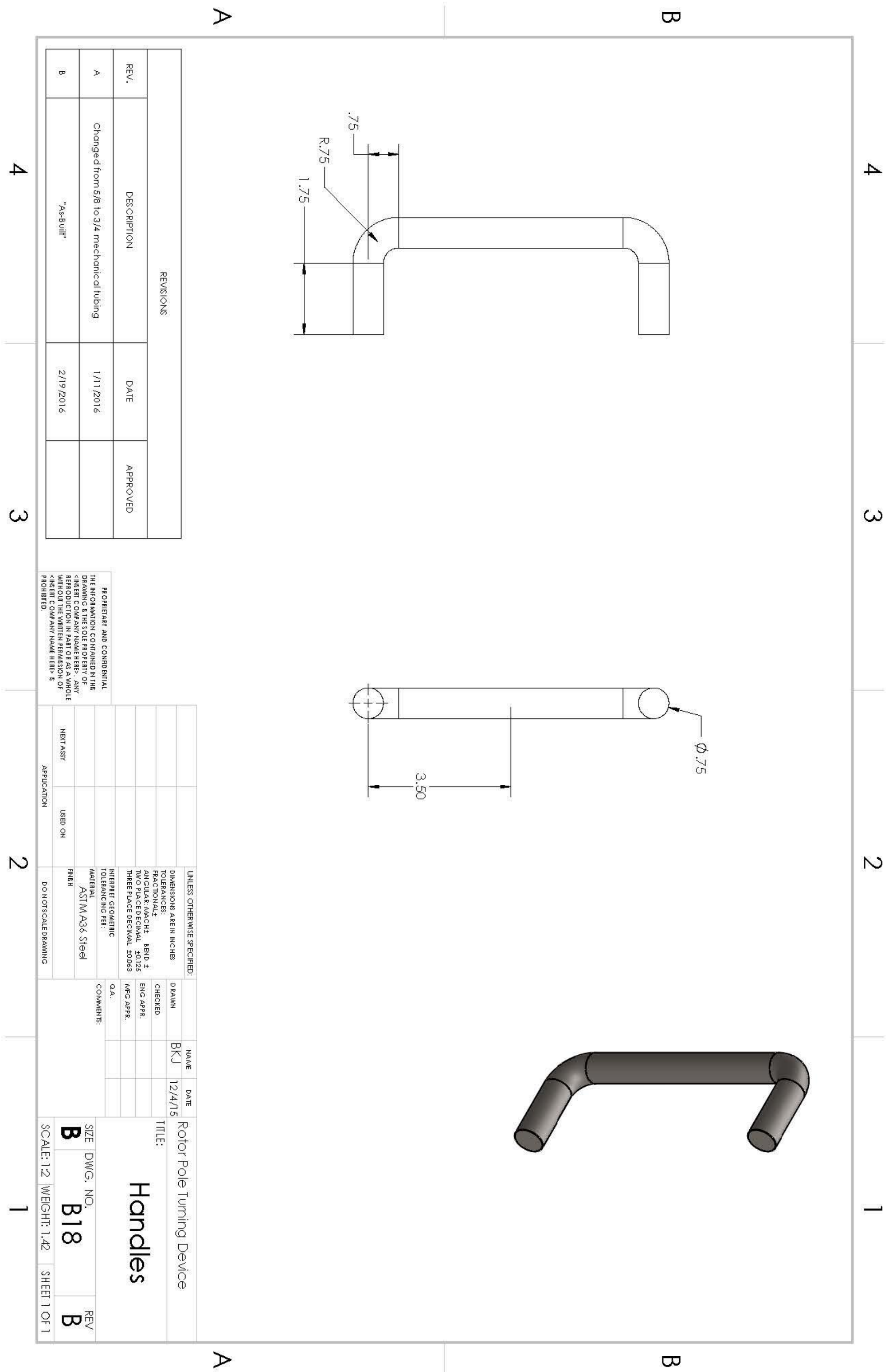


FIGURE B 18: DRAWING OF HANDLES

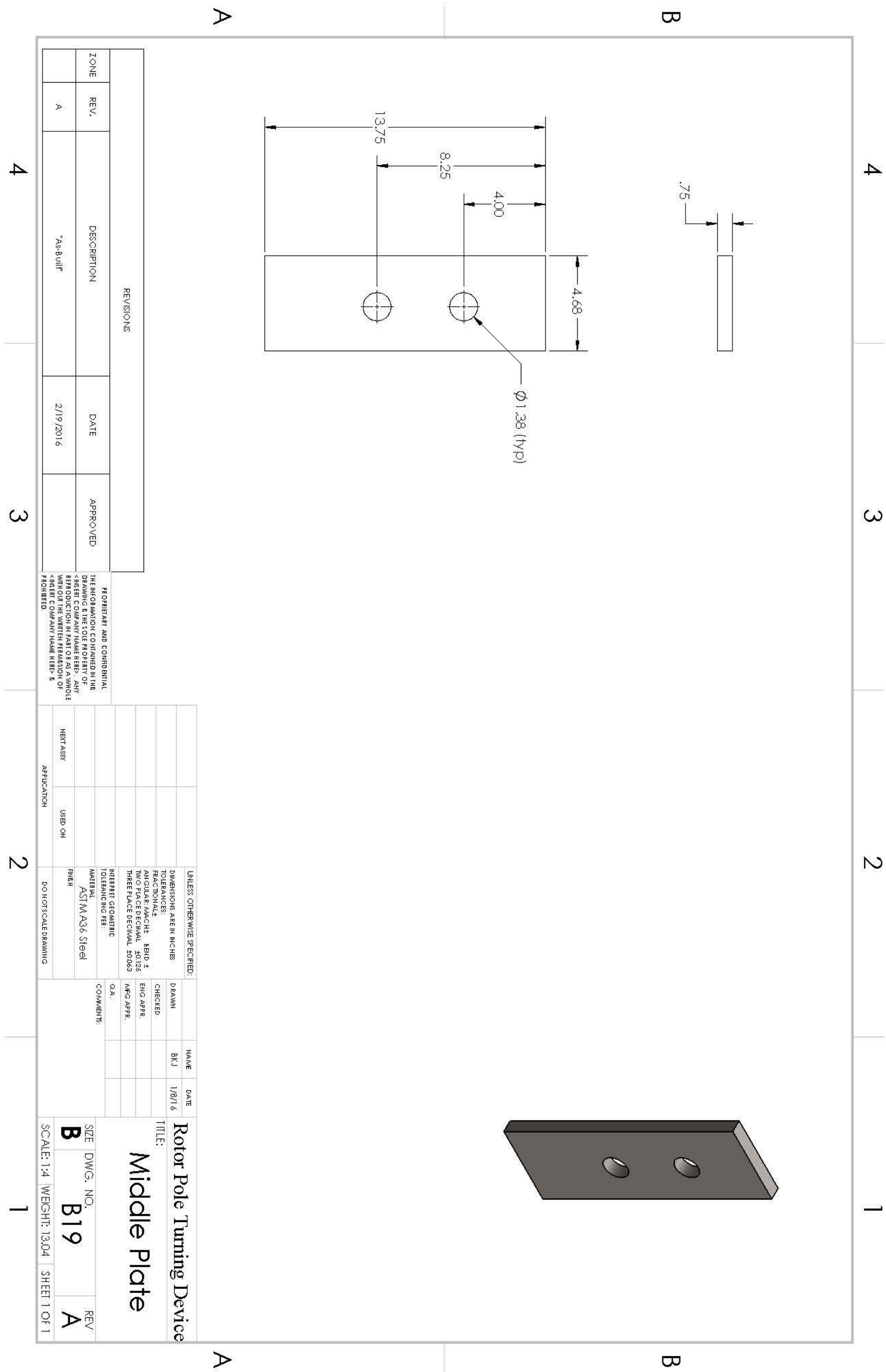


FIGURE B 19: DRAWING OF MIDDLE PLATE

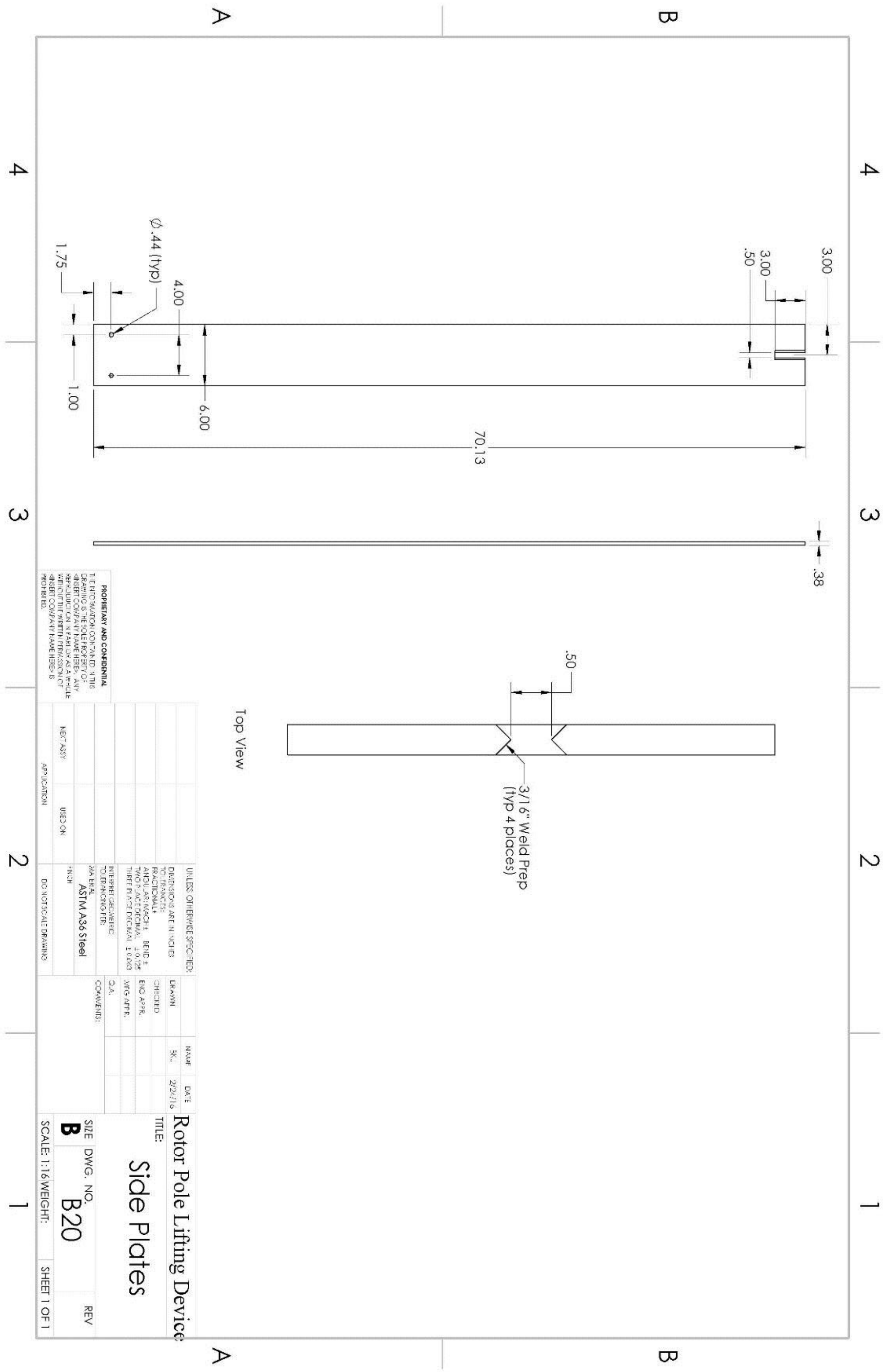


FIGURE B 20 : DRAWING OF SIDE PLATES

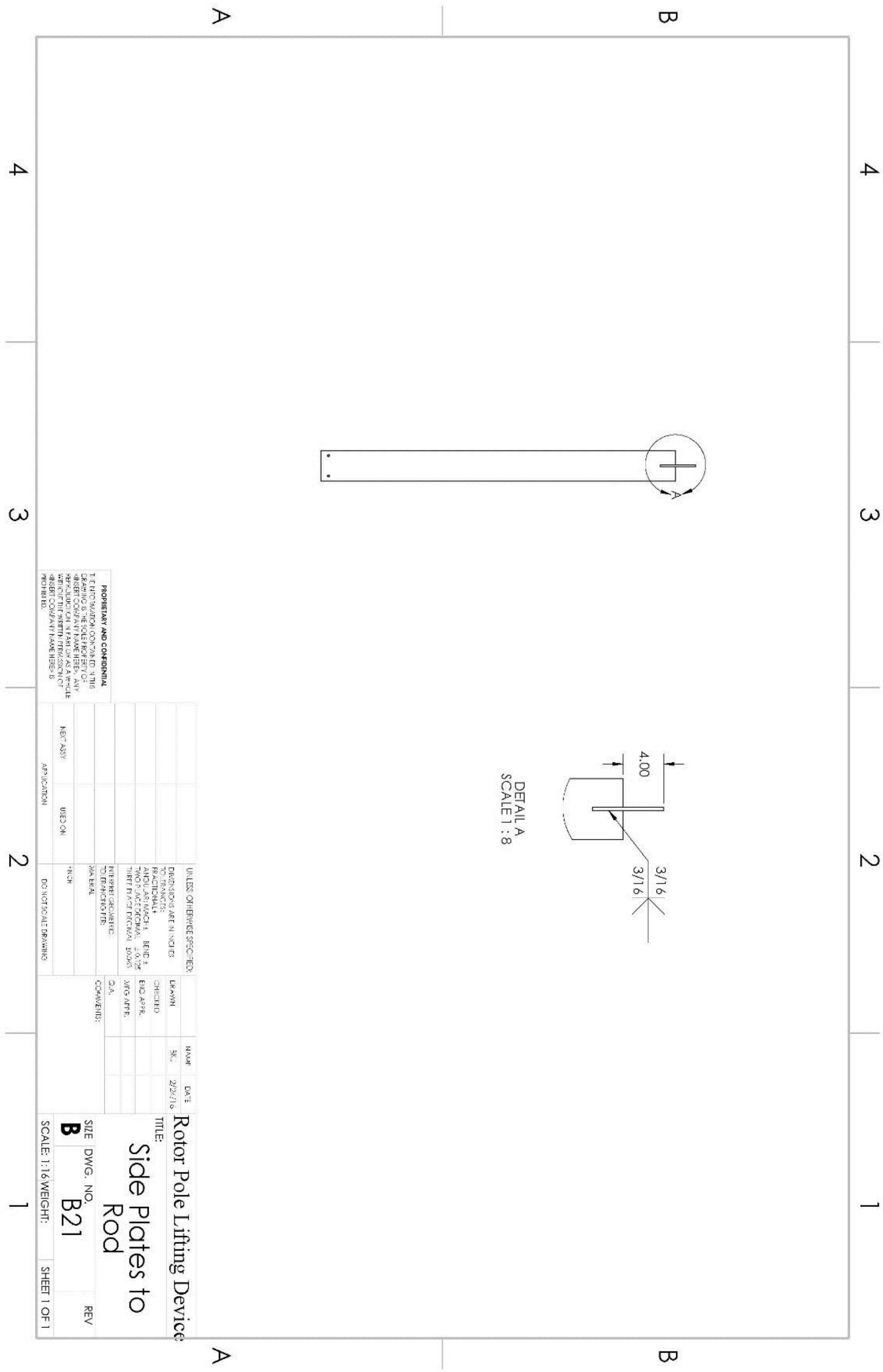


FIGURE B 21: DRAWING OF SIDE PLATE TO ROD WELDS

APPENDIX C – PARTS LIST

Drawing	Description	Stock	Estimated Cost	Actual Cost	Source
Lifting Device					
B5	Top Plate	1 1/2" x 9" x 18 3/8"	$57.05		Moses Lake Steel
B4	Bottom Plate	1 1/2" x 9" x 18 3/8"	$57.05		Moses Lake Steel
	Rods	ASTM B7 3/8 Threaded Rod	$3.38		Moses Lake Steel
B6	Lifting Lug	1 1/4" x 5" x 5"	$22.02		Moses Lake Steel
B8	Dovetail Guide	3" x 7 1/2 " x 12"	$94.50		Moses Lake Steel
B7	Dovetail Adapter	1 1/2" x 12" x 6 3/8"	$57.04		Moses Lake Steel
Turning Device					
B16	Side Plates	3/4" x 30" x 30"	$313.64		Moses Lake Steel
B14	Bottom Plate	107.94" x 11" x 1/4"	$66.91		Moses Lake Steel
	Middle Plate	3/4" x 4 5/8" x 13 3/4"	$13.24		Moses Lake Steel
	Dovetail Stop Plate	1 1/2" x 9" x 4 1/2"	$57.04		Moses Lake Steel
B15	Dovetail Guide	3" x 7 1/2" x 6"	$94.50		Moses Lake Steel
	Bars	1 3/8 Mechanical Tubing	$9.64		Moses Lake Steel
		Subtotal:	$846.01		
		Tax:	$66.83		
		Total:	$912.84		

APPENDIX D – BUDGET

Description	Time (hrs)
Lifting Device	
Top Plate	2
Bottom Plate	1
Rods	0
Lifting Lug	2
Dovetail	4
Dovetail Adapter	1
Weld Lifting Lug to Top Plate	1
Weld Dovetail Adapter to Dovetail	1
Turning Device	
Side Plates	2
Bottom Plate	2
Middle Plate	1
Dovetail Plate	1
Dovetail	3.5
Bars	1
Weld Dovetail Plate to Dovetail	1
Tack Weld	2
Final Weld	2
Magnetic Particle Test on Welds	2
Paint Device	5
Total (hours)	34.5
Total Cost	$4,968

FIGURE D 1: ESTIMATION OF HOURS REQUIRED

QUOTATION

Moses Lake Steel
1502 W Broadway Ave
Moses Lake, WA 98837
P: (800) 765-1741
F: (509) 766-2496

QUOTATION	NUMBER #11528264	PAGE 1	DATE 11/30/2015
SALESPERSON: JUSTIN S			EXPIRES: 12/07/2015
PO#:	NOTES:		CUST ID: GCPUD
ORDERED BY: BAILEY	DELIVERY: DEL		

QUOTED TO:
GRANT COUNTY PUD
PO BOX 878
EPHRATA, WA 98823

SHIP TO:
PRIEST RAPIDS
ATTN: BAILEY

LINE	QTY	ITEM ID/NAME	--- WIDTH ----	--- LENGTH ---	UNITS	PRICE	TOTAL
1	1 PCS	PL-112 1-1/2 A36 PLATE	9"	4' 6"	1 PC	228.1800/PC	228.18
2	1 PCS	PL11448 1-1/4" X 48" HR PLATE (A-36)	5"	5"	1 PC	22.0200/PC	22.02
3	1 PCS	PL-3 3" A-36 PLATE	7.5"	1' 6"	1 PC	189.0000/PC	189.00
4	1 PCS	PL3448 3/4" X 48" HR PLATE (A-36) TRIM TO 36" X 50"	4'	4' 2"	1 PC	313.6400/PC	313.64
5	1 PCS	PL1448 1/4" X 48" HR PLATE (A-36) TRIM TO 11" X 108"	11"	10'	1 PC	66.9100/PC	66.91
6	1 PCS	SCR38 3/8 COLDROLL 1018 ROUND PPSI-19724000		6'	1 PC	3.3800/PC	3.38
7	1 PCS	SF345 3/4 X 5 HR FLAT		1' 2"	1 PC	13.2400/PC	13.24

(CONTINUED)

QUOTATION

Moses Lake Steel
1502 W Broadway Ave
Moses Lake, WA 98837
P: (800) 765-1741
F: (509) 766-2496

	NUMBER	PAGE	DATE
QUOTATION	#11528264	2	11/30/2015
SALESPERSON: JUSTIN S			EXPIRES: 12/07/2015
PO#:	NOTES:		CUST ID: GCPUD
ORDERED BY: BAILEY	DELIVERY: DEL		

QUOTED TO:
GRANT COUNTY PUD
PO BOX 878
EPHRATA, WA 98823

SHIP TO:
PRIEST RAPIDS
ATTN: BAILEY

LINE	QTY	ITEM ID/NAME	--- WIDTH ----	--- LENGTH ---	UNITS	PRICE	TOTAL
8	1 PCS	P~DOM138065 1-3/8 X .065 DOM RND TUBE	1'		1 PC	9.6400/PC	9.64

*** PO NUMBER REQUIRED ***

[END ORDER]

BUYER: CANDUS
PHONE #: (509)754-5088 FAX #: (509)754-6814

TAX ID:	TOTAL:	952.59 LBS	SUBTOTAL	846.01
TERMS: NET 30 DAYS			TAX	66.83
			TOTAL	912.84

FIGURE D 2: QUOTE OF MATERIALS REQUIRED

BUSBY INTERNATIONAL, INC.

QUOTATION 2542

DATE: January 5th 2016

TO: **Grant County PUD**
Attn: Betty Snell
Procurement Officer
PO Box D4 - Beverly, WA 99321
Bsnell@gcpud.org
(509) 793-1503

SHIP TO: Wanapum Maintenance Center

SHIP VIA	SHIP WHEN	TERMS	F.O.B. POINT
	On Or Before February 12th 2016	Net 30	Wanapum Maintenance

QTY	DESCRIPTION	UNIT PRICE	AMOUNT
2	Fabricate Lifting And Turning Devices As Per Drawing And Technical Specifications	$8,253.00	$16,506.00

ALL PRICES ARE IN U.S. DOLLARS

ACCEPTANCE

In accordance with the conditions stated on the front of this form the above quotation is hereby accepted.

By ____________________ **Date** ____________________

If you have any questions concerning this quotation, please call: Steve Standley at (509) 765-1313

12600 Road 3 NE Moses Lake, WA 98837 Phone (509) 765-1313 Fax (509) 765-1985

1/5/2016 3:56 PM

FIGURE D 3: QUOTE OF MANUFACTURING OF TURNING AND LIFTING DEVICES

Grant County
PUBLIC UTILITY DISTRICT

Purchase Order	**CHANGE ORDER**
Purchase Order No.	PO14067
Date	1/7/2016
Revision Number	1

PUD No. 2 of Grant County, WA
PO Box 878
30 C ST SW
Ephrata WA 98823

Vendor: BUIN00

BUSBY INTERNATIONAL INC
12600 RD 3 NE
MOSES LAKE WA 98837

Ship To:

*Address listed with item below.

Contract / Quote No.

^ Changed Since the Previous Revision

	Payment Terms	Confirm With	Page
	NET30	Steve Stanley	1

L/N Item Number / Item Description / Shipping Method	Reference Number	Bin	Req. Date	U/M	Ordered	Unit Price	Ext. Price / Requested by
1 LIFTING AND TURNING DEVICE PER DRAWING AND TECHNICAL SPECIFICATIONS FOB DEST ALLOWE PREVAILING WAGES APPLY			2/12/2016	each	2.00	$8,253.00	$16,506.00 BAYLIE JOHNSON
^2 MODIFICATIONS TO LIFTING AND TURNING DEVICE PER SPEC & DRAWINGS FOB DEST ALLOWE Deliver To: 14353 HIGHWAY 243 S Bldg 5A BEVERLY WA 99321 United States			3/7/2016	JOB	1,705.00	$1.00	$1,705.00 BAILEY JOHNSON

All applicable taxes and freight to be applied.

Subtotal	$18,211.00
^Tax	$1,438.67
Order Total	$19,649.67

Betty Snell 509-793-1503

Authorized

All shipments, shipping papers, invoices and correspondence must be identified with our Purchase Order Number. Overshipments will not be accepted unless authorized by Buyer prior to shipment.

FIGURE D 4: QUOTE OF MODIFICATIONS TO LIFTING DEVICE

APPENDIX E – TECHNICAL SPECIFICATION

TECHNICAL SPECIFICATION

CONTENTS

1. GENERAL TECHNICAL REQUIREMENTS

1.1 INTRODUCTION

1.1.1 PURCHASE ORDER OBJECTIVE

The objective of this purchase order is to manufacture two (2) lifting and turning devices.

1.1.2 SCOPE

1.1.2.1 MANUFACTURE

The scope of this purchase order includes complete manufacture of the devices. Manufacture includes machining and welding processes. All necessary information to manufacture the device is included in the attached drawings.

1.1.2.2 PAINT

Painting will require an adequate prime coat with and top coat of safety yellow paint. Coating shall be Sherwin Williams 640384160 indura alk Y-Base Paint, Safety yellow, acrylic modified alkyd enamel. Coating shall be applied per manufacturer's instructions. Costing shall be free of runs, sags, blisters and mud cracking. The following parts will require paint:

- Bottom Plate
- Top Plate and Lifting Lug subassembly
- Dovetail Guide and Dovetail Guide Adapter subassembly
- Entire turning device assembly

1.2 Schedule

1.2.1 Requirements

1.2.1.1 Welding

The contractor must provide all applicable WPS and PQR documents two (2) weeks prior to any welding processes being conducted. These documents must be approved before welding begins.

1.2.1.2 Non-Destructive Evaluation

The District will provide NDE services on site. The contractor must provide at least 48 hours' notice of need for NDE. Contractor should make an effort to group NDE of parts to minimize travel requirements.

1.2.1.3 Device Completion

The device needs to be completed and delivered to the Wanapum Maintenance Center by end of day January 22, 2016.

1.3 Drawings

1.3.1 Rotor Pole Lifting Device

1.3.1.1	B1	Assembly
1.3.1.2	B2	Dovetail Guide to Adapter Connection
1.3.1.3	B3	Lifting Lug to Top Plate
1.3.1.4	B4	Bottom Plate
1.3.1.5	B5	Top Plate
1.3.1.6	B6	Lifting Lug
1.3.1.7	B7	Dovetail Guide Adapter
1.3.1.8	B8	Dovetail Guide Piece
1.3.1.9	B9	Rotor Pole Wood Blocks
1.3.1.10	B17	Threaded Rod

1.3.2 Rotor Pole Turning Device

1.3.2.1	B10	Bill of Materials
1.3.2.2	B11	Side Plates to Bottom Plate Connection
1.3.2.3	B12	Bars and Middle Plate Connections
1.3.2.4	B13	Dovetail Guide and Stop Plate Connections
1.3.2.5	B14	Bottom Plate
1.3.2.6	B15	Dovetail Guide
1.3.2.7	B16	Side Plate
1.3.2.8	B18	Handles

Modifications Technical Specification

Contents

1. General Technical Requirements

1.1 Introduction

1.1.1 Purchase Order Objective

The objective of this purchase order is to modify two (2) lifting and turning devices.

1.1.2 Scope

1.1.2.1 Manufacture

The scope of this purchase order includes modification of the previously manufactured devices. Manufacture includes machining and welding processes. All necessary information to manufacture the device is included in the attached drawings.

1.1.2.2 Paint

Painting will require an adequate prime coat with and top coat of safety yellow paint. Coating shall be Sherwin Williams 640384160 indura alk Y-Base Paint, Safety yellow, acrylic modified alkyd enamel. Coating shall be applied per manufacturer's instructions. Costing shall be free of runs, sags, blisters and mud cracking. Note: The District will accept ultimate methods (such as powder coating) on a case by case basis. The following parts will require paint:

- Bottom Plate
- Top Plate and Lifting Lug subassembly
- Side Plate and Rod subassembly

1.2 Schedule

1.2.1 Requirements

1.2.1.1 Welding

The contractor must provide all applicable WPS and PQR documents prior to any welding processes being conducted. These documents must be approved before welding begins.

1.2.1.2 Non-Destructive Evaluation

The District will provide NDE services on site. The contractor must provide at least 48 hours' notice of need for NDE. Contractor should make an effort to group NDE of parts to minimize travel requirements.

1.2.1.3 Parts Supplied

The previously manufactured parts that need to be modified will be provided upon approval of contractors quote.

1.2.1.4 Device Completion

The device needs to be completed and delivered to the Wanapum Maintenance Center by end of day March 7, 2016.

1.3 Drawings

1.3.1	B4	Bottom Plate Modifications
1.3.2	B5	Top Plate Modifications
1.3.3	B20	Side Plates
1.3.4	B21	Side Plates to Rod
1.3.5	B22	Modified Assembly
1.3.6	B23	Modified Rods

APPENDIX F – SCHEDULE

Task ID	Task Name	Duration (est)	Duration (actual)	Start	Finish
	Proposal				
1a	Introduction	1	1	Mon 9/28/15	Thu 10/1/15
1b	Design and Analysis	3	3	Mon 10/5/15	Mon 10/12/15
1c	Methods and Construction	5	5	Mon 10/12/15	Mon 10/19/15
1d	Testing Method	5	5	Mon 10/19/15	Mon 10/26/15
1e	Budget	2	2	Mon 10/26/15	Mon 11/2/15
1f	Schedule	5	5	Mon 11/2/15	Mon 11/9/15
1g	Project Management	1	1	Mon 11/9/15	Mon 11/16/15
1h	Discussion	1	1	Mon 11/16/15	Mon 11/23/15
1i	Conclusion	1	1	Mon 11/23/15	Mon 11/30/15
	Subtotal:	24	24	Wed 12/2/16	Wed 12/2/16
	Analysis				
2a	Lifting Device	20	40	Mon 9/28/15	Mon 11/2/15
2b	Turning Device	20	40	Mon 11/2/15	Mon 11/23/15
	Subtotal:	40	80		
	Documentation				
3a	**Lifting Device**	**8**	**14**	Mon 9/28/15	Mon 10/26/15
3b	Bottom Plate	1	1.25	Mon 9/28/15	Thu 10/1/15
3c	Top Plate	1	2.25	Mon 9/28/15	Thu 10/1/15
3d	Lifting Lug	1	1.25	Mon 10/5/15	Mon 10/12/15
3e	Dovetail	1	3.25	Mon 10/5/15	Mon 10/12/15
3f	Dovetail Plate	1	1.25	Mon 10/12/15	Mon 10/19/15
3g	Lifting Lug to Top Plate	1	1.25	Mon 10/12/15	Mon 10/19/15
3h	Wood Blocks	1	2.25	Mon 10/19/15	Mon 10/26/15
3i	Dovetail Plate to Dovetail	1	1.25	Mon 10/19/15	Mon 10/26/15
	Turning Device	**8**	**14**	Mon 11/2/15	Mon 11/30/15
4a	Bottom Plate	1	1.25	Mon 11/2/15	Mon 11/9/15
4b	Middle Plate	1	3.25	Mon 11/2/15	Mon 11/9/15
4c	Side Plates	1	1.25	Mon 11/9/15	Mon 11/16/15
4d	Dovetail Guide	1	1.25	Mon 11/9/15	Mon 11/16/15
4e	Dovetail Plate	1	2.25	Mon 11/16/15	Mon 11/23/15
4f	Bottom Plate to Side Plates	1	1.25	Mon 11/16/15	Mon 11/23/15
4g	Bars to Middle and Side Plates	1	2.25	Mon 11/23/15	Mon 11/30/15
4h	Dovetail Guide to Stopping Plate	1	1.25	Mon 11/23/15	Mon 11/30/15
	Subtotal:	16	28		
	Work Order				
4	Create Parent & Get Approval	1	1	Mon 12/14/15	Mon 12/21/15
5	Create Drawing Child	1	1	Mon 12/21/15	Mon 12/21/15
6	Review Drawings	0	0	Mon 1/4/16	Wed 1/6/16
7	Create Manufacturing Child	1	1	Mon 1/11/16	Mon 1/11/16
8	Review Parts	0	0	Wed 3/9/16	Wed 3/9/16
	Subtotal:	3	3		
	Manufacturing				
9	Order Materials	1	**5**	Wed 1/6/16	Wed 1/6/17
10	**Lifting Device**	**12**	**12**	**Mon 2/1/16**	**Wed 2/10/16**
10a	Bottom Plate	1	1.5	Mon 2/1/16	Mon 2/1/16
10ai	Outside Profile	*0.5*	0.5	Mon 2/1/16	Mon 2/1/16
10aii	Drill Holes	*0.5*	0.75	Mon 2/1/16	Mon 2/1/16
10b	Top Plate	2	1.5	Tue 2/2/16	Tue 2/2/16
10bi	Outside Profile	*1*	0.5	Tue 2/2/16	Tue 2/2/16
10bii	Drill Top Holes	*0.5*	0.5	Tue 2/2/16	Tue 2/2/16
10biii	Drill & Tap Front Holes	*0.5*	0.5	Tue 2/2/16	Tue 2/2/16
10c	Lifting Lug	2	2	Wed 2/3/16	Wed 2/3/16
10ci	Outside Profile	*1*	1	Wed 2/3/16	Wed 2/3/16
10cii	Drill Hole	*1*	1	Wed 2/3/16	Wed 2/3/16
10d	Dovetail	4	6	Thu 2/4/16	Thu 2/4/16
10di	Machine Dovetail	*3.5*	5	Thu 2/4/16	Thu 2/4/16
10dii	Drill & Tap Hole	*0.5*	1	Thu 2/4/16	Thu 2/4/16
10e	Dovetail Adapter	1	1	Mon 2/8/16	Mon 2/8/16
10ei	Outside Profile	*0.5*	0.5	Mon 2/8/16	Mon 2/8/16
10eii	Drill Holes	*0.5*	0.5	Mon 2/8/16	Mon 2/8/16
10f	Weld Lifting Lug to Top Plate	1		Tue 2/9/16	Tue 2/9/16
10g	Weld Dovetail Plate to Dovetail	1		Wed 2/10/16	Wed 2/10/16
11	**Turning Device**	**15.5**	**21**	**Thu 2/11/16**	**Thu 2/25/16**
11a	Bottom Plate	2	1	Thu 2/11/16	Thu 2/11/16
11ai	Bend	*2*	1	Thu 2/11/16	Thu 2/11/16
11b	Middle Plate	1	2	Mon 2/15/16	Mon 2/15/16
11bi	Outside Profile	*1*	2	Mon 2/15/16	Mon 2/15/16
11c	Side Plates	2	3	Tue 2/16/16	Tue 2/16/16
11ci	Cut	*2*	3	Tue 2/16/16	Tue 2/16/16
11d	Dovetail	3.5	5	Wed 2/17/16	Wed 2/17/16
11di	Machine Dovetail	*3.5*	5	Wed 2/17/16	Wed 2/17/16
11e	Dovetail Plate	1	1	Thu 2/18/16	Thu 2/18/16
11ei	Outside Profile	*1*	1	Thu 2/18/16	Thu 2/18/16
11f	Bars	1	2	Mon 2/22/16	Mon 2/22/16
11fi	Cut	*1*	2	Mon 2/22/16	Mon 2/22/16
11g	Weld Dovetail Plate to Dovetail	1	1	Thu 2/25/16	Thu 2/25/16
11h	Tack Weld	2	2	Tue 2/23/16	Tue 2/23/16
11j	Final Weld	2	4	Wed 2/24/16	Wed 2/24/16
12	Magnetic Particle Test on Welds	2	2	Thu 2/25/16	Thu 2/25/16
13	Paint Device	5	5	Mon 2/29/16	Mon 2/29/16
14	Completed Device	27.5	33	Wed 3/9/16	Wed 3/9/16
15	Completed Manufacturing Report	40	40	Wed 3/9/16	Wed 3/9/16
	Subtotal:	75.5	73		
	Testing				
16	Apply Strain Gauges	5	5	Wed 3/23/16	Wed 3/23/16
17	Perform Testing	8	15	Wed 4/6/16	Wed 4/6/16
18	Completed Test Report	10	5	Wed 6/1/16	Wed 6/1/16
	Subtotal:	23	25		
	Total:	210	271		

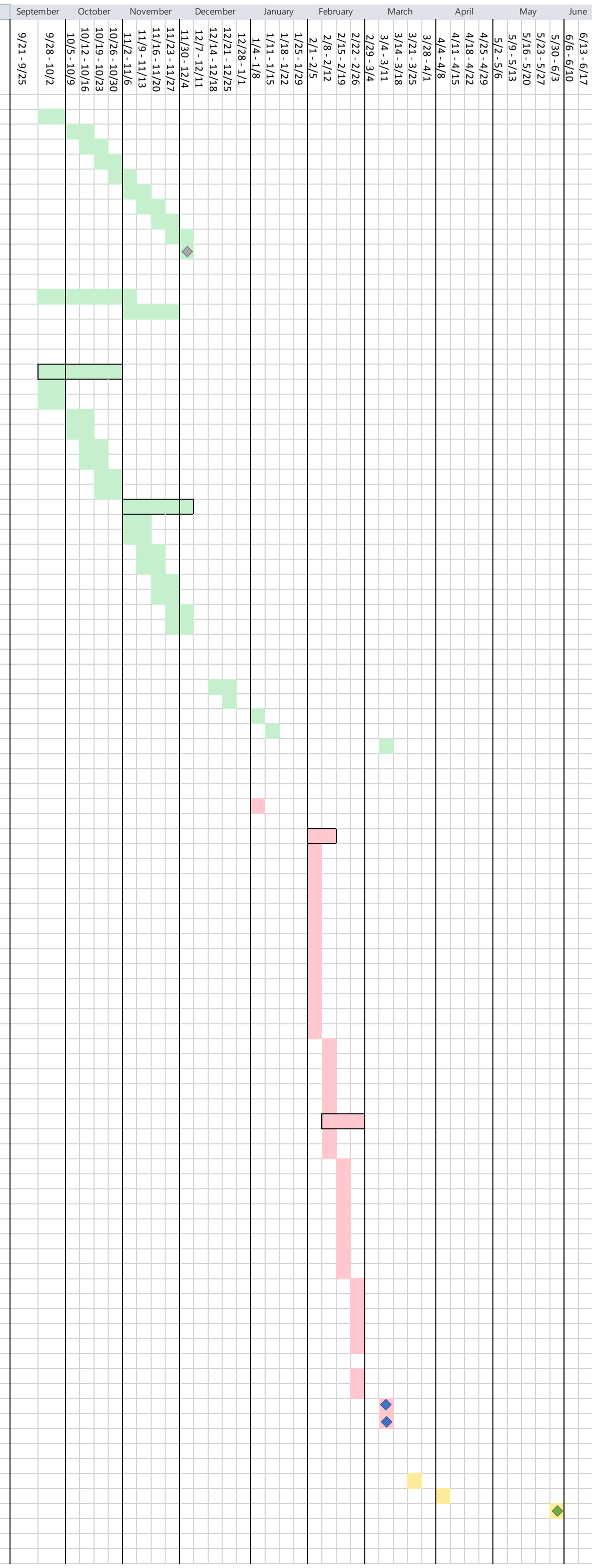


FIGURE E 1: OVERALL SCHEDULE

Task ID	Task Name	Duration (est)	Duration (actual)	Start	Finish
	<u>Proposal</u>				
1a	Introduction	1	1	Mon 9/28/15	Thu 10/1/15
1b	Design and Analysis	3	3	Mon 10/5/15	Mon 10/12/15
1c	Methods and Construction	5	5	Mon 10/12/15	Mon 10/19/15
1d	Testing Method	5	5	Mon 10/19/15	Mon 10/26/15
1e	Budget	2	2	Mon 10/26/15	Mon 11/2/15
1f	Schedule	5	5	Mon 11/2/15	Mon 11/9/15
1g	Project Management	1	1	Mon 11/9/15	Mon 11/16/15
1h	Discussion	1	1	Mon 11/16/15	Mon 11/23/15
1i	Conclusion	1	1	Mon 11/23/15	Mon 11/30/15
	Subtotal:	24	24	Wed 12/2/16	Wed 12/2/16
	<u>Analysis</u>				
2a	Lifting Device	20	40	Mon 9/28/15	Mon 11/2/15
2b	Turning Device	20	40	Mon 11/2/15	Mon 11/23/15
	Subtotal:	40	80		
	<u>Documentation</u>				
3a	**Lifting Device**	**8**	**14**	Mon 9/28/15	Mon 10/26/15
3b	Bottom Plate	1	1.25	Mon 9/28/15	Thu 10/1/15
3c	Top Plate	1	2.25	Mon 9/28/15	Thu 10/1/15
3d	Lifting Lug	1	1.25	Mon 10/5/15	Mon 10/12/15
3e	Dovetail	1	3.25	Mon 10/5/15	Mon 10/12/15
3f	Dovetail Plate	1	1.25	Mon 10/12/15	Mon 10/19/15
3g	Lifting Lug to Top Plate	1	1.25	Mon 10/12/15	Mon 10/19/15
3h	Wood Blocks	1	2.25	Mon 10/19/15	Mon 10/26/15
3i	Dovetail Plate to Dovetail	1	1.25	Mon 10/19/15	Mon 10/26/15
	Turning Device	**8**	**14**	Mon 11/2/15	Mon 11/30/15
4a	Bottom Plate	1	1.25	Mon 11/2/15	Mon 11/9/15
4b	Middle Plate	1	3.25	Mon 11/2/15	Mon 11/9/15
4c	Side Plates	1	1.25	Mon 11/9/15	Mon 11/16/15
4d	Dovetail Guide	1	1.25	Mon 11/9/15	Mon 11/16/15
4e	Dovetail Plate	1	2.25	Mon 11/16/15	Mon 11/23/15
4f	Bottom Plate to Side Plates	1	1.25	Mon 11/16/15	Mon 11/23/15
4g	Bars to Middle and Side Plates	1	2.25	Mon 11/23/15	Mon 11/30/15
4h	Dovetail Guide to Stopping Plate	1	1.25	Mon 11/23/15	Mon 11/30/15
	Subtotal:	16	28		
	<u>Work Order</u>				
4	Create Parent & Get Approval	1	1	Mon 12/14/15	Mon 12/21/15
5	Create Drawing Child	1	1	Mon 12/21/15	Mon 12/21/15
6	Review Drawings	0	0	Mon 1/4/16	Wed 1/6/16
7	Create Manufacturing Child	1	1	Mon 1/11/16	Mon 1/11/16
8	Review Parts	0	0	Wed 3/9/16	Wed 3/9/16
	Subtotal:	3	3		

FIGURE E 2: FALL QUARTER SCHEDULE

Task ID	Task Name	Duration (est)	Duration (actual)	Start	Finish
	Manufacturing				
9	Order Materials	1	**5**	Wed 1/6/16	Wed 1/6/17
10	**Lifting Device**	**12**	**12**	**Mon 2/1/16**	**Wed 2/10/16**
10a	Bottom Plate	1	1.5	Mon 2/1/16	Mon 2/1/16
10ai	Outside Profile	*0.5*	0.5	Mon 2/1/16	Mon 2/1/16
10aii	Drill Holes	*0.5*	0.75	Mon 2/1/16	Mon 2/1/16
10b	Top Plate	2	1.5	Tue 2/2/16	Tue 2/2/16
10bi	Outside Profile	*1*	0.5	Tue 2/2/16	Tue 2/2/16
10bii	Drill Top Holes	*0.5*	0.5	Tue 2/2/16	Tue 2/2/16
10biii	Drill & Tap Front Holes	*0.5*	0.5	Tue 2/2/16	Tue 2/2/16
10c	Lifting Lug	2	2	Wed 2/3/16	Wed 2/3/16
10ci	Outside Profile	*1*	1	Wed 2/3/16	Wed 2/3/16
10cii	Drill Hole	*1*	1	Wed 2/3/16	Wed 2/3/16
10d	Dovetail	4	6	Thu 2/4/16	Thu 2/4/16
10di	Machine Dovetail	*3.5*	5	Thu 2/4/16	Thu 2/4/16
10dii	Drill & Tap Hole	*0.5*	1	Thu 2/4/16	Thu 2/4/16
10e	Dovetail Adapter	1	1	Mon 2/8/16	Mon 2/8/16
10ei	Outside Profile	*0.5*	0.5	Mon 2/8/16	Mon 2/8/16
10eii	Drill Holes	*0.5*	0.5	Mon 2/8/16	Mon 2/8/16
10f	Weld Lifting Lug to Top Plate	1		Tue 2/9/16	Tue 2/9/16
10g	Weld Dovetail Plate to Dovetail	1		Wed 2/10/16	Wed 2/10/16
11	**Turning Device**	**15.5**	**21**	**Thu 2/11/16**	**Thu 2/25/16**
11a	Bottom Plate	2	1	Thu 2/11/16	Thu 2/11/16
11ai	Bend	*2*	1	Thu 2/11/16	Thu 2/11/16
11b	Middle Plate	1	2	Mon 2/15/16	Mon 2/15/16
11bi	Outside Profile	*1*	2	Mon 2/15/16	Mon 2/15/16
11c	Side Plates	2	3	Tue 2/16/16	Tue 2/16/16
11ci	Cut	*2*	3	Tue 2/16/16	Tue 2/16/16
11d	Dovetail	3.5	5	Wed 2/17/16	Wed 2/17/16
11di	Machine Dovetail	*3.5*	5	Wed 2/17/16	Wed 2/17/16
11e	Dovetail Plate	1	1	Thu 2/18/16	Thu 2/18/16
11ei	Outside Profile	*1*	1	Thu 2/18/16	Thu 2/18/16
11f	Bars	1	2	Mon 2/22/16	Mon 2/22/16
11fi	Cut	*1*	2	Mon 2/22/16	Mon 2/22/16
11g	Weld Dovetail Plate to Dovetail	1	1	Thu 2/25/16	Thu 2/25/16
11h	Tack Weld	2	2	Tue 2/23/16	Tue 2/23/16
11j	Final Weld	2	4	Wed 2/24/16	Wed 2/24/16
12	Magnetic Particle Test on Welds	2	2	Thu 2/25/16	Thu 2/25/16
13	Paint Device	5	5	Mon 2/29/16	Mon 2/29/16
14	Completed Device	27.5	33	Wed 3/9/16	Wed 3/9/16
15	Completed Manufacturing Report	40	40	Wed 3/9/16	Wed 3/9/16
	Subtotal:	75.5	73		
	Testing				
16	Apply Strain Gauges	5	5	Wed 3/23/16	Wed 3/23/16
17	Perform Testing	8	15	Wed 4/6/16	Wed 4/6/16
18	Completed Test Report	10	5	Wed 6/1/16	Wed 6/1/16
	Subtotal:	23	25		
	Total:	210	271		

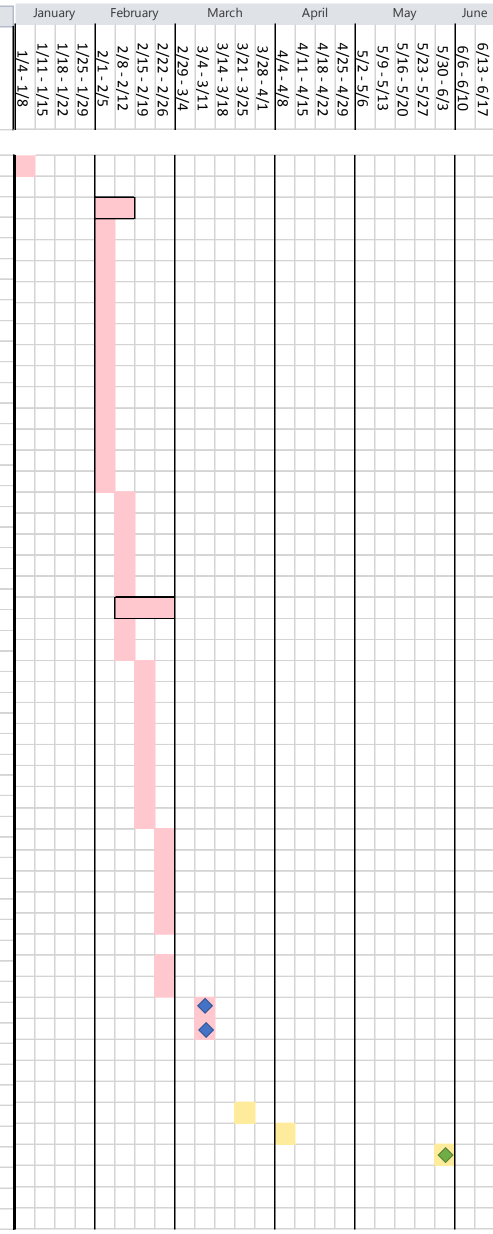


FIGURE E 3: WINTER & SPRING QUARTER SCHEDULE

APPENDIX G - EXPERTISE AND RESOURCES

MANUFACTURING:
Busby International, Inc.

ENGINEERING SUPPORT:
Turbine/Generator Engineering Team

Central Washington University - Mechanical Engineering Technology Staff

TESTING CREW:
Tom Marty, Hydro Mechanic Foreman

Beau Campbell, Hydro Mechanic

Mike Garrett, Hydro Mechanic

APPENDIX H – EVALUATION SHEET

VERTICAL

Axial

Load (lbs)	Actual Strain (µs)	Predicted Strain (µs)	Actual Stress (psi)	Percent Error
1500	-5	11	333	230%
3500	-19	27	778	141%
5000	-18	38	1111	213%
7000	-22	54	1556	244%

Shear

Load (lbs)	Actual Strain (µs)	Predicted Strain (µs)	Actual Stress (psi)	Percent Error
1500	-10	44	1280	441%
3500	-7	103	2987	1471%
5000	-14	147	4267	1051%
7000	-22	206	5973	936%

Top Plate

Load (lbs)	Actual Strain (µs)	Predicted Strain (µs)	Actual Stress (psi)	Percent Error
1200	9	4	109	58.30%
3300	27	10	299	61.77%
5150	46	16	467	64.98%
6800	58	21	617	63.33%

HORIZONTAL

Load (lbs)	Actual Strain (µs)	Predicted Strain (µs)	Actual Stress (psi)	Percent Error
1450	-2	162	58	8077.16%
3700	-4	412	116	10305.35%
7200	-8	802	232	10026.82%

APPENDIX I – TESTING REPORTS

VERTICAL LOAD TEST

Introduction

The rotor pole lifting device for Priest Rapids Dam was designed and analyzed by student intern Baylie Johnson of Grant County Public Utilities District. The device was manufactured by Busby International, Inc. out of Moses Lake, WA. Because this device is going to be used for lifting heavy object over people's heads, it was necessary to do a load test to ensure safety. This load test was performed by student intern Baylie Johnson, hydro mechanic foreman Tom Marty and hydro mechanic Beau Campbell. The test consisted of assembling the device, attaching the device to the crane and the mounting surface, applying load to the device and measuring strain through strain gages in various places. The following report with explain the procedure in more detail, present the data taken and discuss the data.

Method/Approach

The resources needed for this test include the following:

- Priest Rapids Dam Powerhouse Crane
- 2 Slings
- 10,000 pound chain hoist
- 4 Shackles
- 1 Floor mounted shackle
- Access to a floor mount
- Dynamometer
- Torque Wrench
- Camera
- Strain gages
- Strain indicator
- Switch and balance unit
- Extension cord

The device will be mounted to the floor and attached to the crane with a dynamometer between the device and the crane to properly load the device to specified loads. At each load, the strain will be recorded from each strain gage. Three strain gages were used for this test. Two were located on one of the rods, one was oriented axially and the other radially. The third strain gage was located on the top of the top plate.

The rods are what carry load between the top and bottom plates. They are a very sensitive part of the system and that it why they were chosen to be analyzed using strain gages. The orientation of the axial strain gage was chosen because the stress in the rods is axial. The radial strain gage was used because when the gage is stretched axially, the cross section will also change causing stress radially. The predictions for strain in these gages at a the normal working load (3500 pounds total, 1750 pounds per rod) is 546 µs axially and -158 µs radially. The limits of these predictions, based on the tolerance of the dynamometer are 539-554 µs axially and -156 to -161 µs radially.

The loading in the top plate is a bending load, with one upward force in the center of the plate and two downward forces at each end. A strain gage was oriented to detect this bending so that the load transferred could be predicted. It was predicted that the strain at the normal working load would be 11 µs.

Procedure

The following procedure was used to conduct the vertical load test.

1. Lower the 30 ton crane hook from the powerhouse crane.
2. Wrap a sling around the hook and attach a chain hoist to the sling. Ensure the hook of the chain hoist is near the top of its travel.
3. Attach a shackle to the chain hoist hook.
4. Attach a dynamometer to the shackle.
5. Attach another shackle to the bottom side of the dynamometer.
6. Attach a third shackle to the second shackle and to the lifting lug of the device.
7. Lift the top plate to a point where the rods can be inserted. Because there will be no rotor pole, the rods will require nuts on both sides of the top plate to ensure the plate does not fall.
8. Lift the crane until the rods can be put through the bottom plate. Again, nuts must be placed on both side of the bottom plate.
9. Insert a floor mount and use a torque wrench to tighten the mount.
10. Place a sling around the bottom plate between the wood block and the rods.
11. Use a shackle to attach the sling to the floor mount.
12. Record the dynamometer reading without any load applied (this is the weight of the device).
13. Connect the strain gages to the reader and zero the amperage, input the correct gage factor and balance the gages to zero. This means that the load that is contributing to the strain reading is only the difference between the dynamometer reading and the weight of the device.
14. Load the device to a dynamometer reading of approximately 1500 lbs.
15. Record the actual load.
16. Record the strain of each gage.
17. Repeat steps 14 thru 16 for loads of approximately 3000, 5500 and 7000 lbs.
18. Release the load.
19. Lay the device down in a safe and accessible place.
20. Inspect the device for any cracking or deformation. Record anything seen.

Results

Axial Rod Strain

Load	Axial Rod Strain Actual	Axial Rod Strain Predicted	Actual Stress	Percent Error
0	0			
1200	156	187	5432	16.72%
3300	470	515	14939	8.76%
5150	796	804	23314	0.99%
6800	1040	1062	30784	2.03%

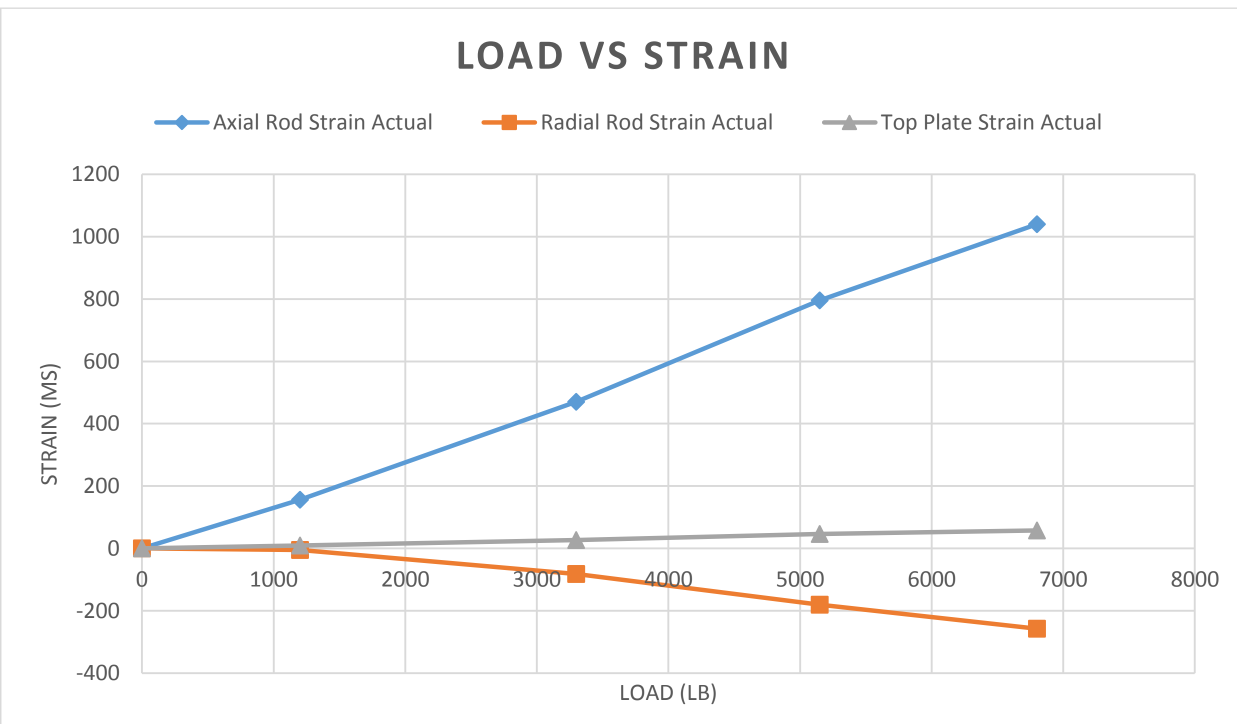
Radial Rod Strain

Load	Radial Rod Strain Actual	Radial Rod Strain Predicted	Actual Stress	Percent Error
0	0			
1200	-5	-54	145	90.80%
3300	-82	-149	2378	45.11%
5150	-180	-233	5220	22.79%
6800	-258	-308	7482	16.19%

Top Plate Strain

Load	Top Plate Strain Actual	Top Plate Strain Predicted	Actual Stress	Percent Error
0	0			
1200	9	4	109	58.30%
3300	27	10	299	61.77%
5150	46	16	467	64.98%
6800	58	21	617	63.33%

All Strain Measurements



Discussion

Axial Rod Strain

The results of the strain recorded from the axially mounted rod strain gage were favorable. The error was relatively small between the actual strain and the predicted strain, 1-17% depending on the load. This amount of error is acceptable. The gages were not mounted in a particularly precise way. This means that the gage could have been crocked and that would have caused error. Also, the accuracy of the dynamometer is only ±100 pounds with a tolerance of ±50 pounds and was located fairly far overhead, so the ability to read the dynamometer with very much accuracy was difficult. Any difference in the load that was applied versus the load that was recorded would cause error between the predicted strain and the actual strain.

The precision of these measurements was not required to be very high. Even at 6800 pounds of applied load, the stress experienced by the rod is less than one fifth of the ultimate stress of the material. This means that the safety factor is far more than five to one, given that 6800 pounds is almost twice the working load of the device.

Radial Rod Strain

Radial rod strain was not something that was necessarily worried about, it was just a check for the axial rod strain. The error of these strain measurements is much higher than those for axial rod strain, anywhere between 14 and 74% higher. This is very likely caused by the predicted strains that are less than 310 µs. You can see that the percent error decreases as the strain increases. For example, the error at 1200 pounds of load is 91% whereas the error at a 6800 pound load is 16%, which is approximately the same as the highest error seen in the axial rod strain gage. Other factors that possibly caused error include those stated to be present in the axial rod strain measurements.

Although these errors were high, in some cases more than 90% higher than predicted, this data is sufficient to prove that the stresses in the rods are low enough to prove the safety of the device.

Top Plate Strain

The top plate strain data also shows that the stresses are so low that it will not fail in an overload case. The error of this data is also high, up to 65%. This is likely for the same reasons stated in the discussion about the axial rod strain. The strain gage could be crocked or not applied completely correctly or the error could be caused by the tolerance of the dynamometer.

Conclusion

Although the error between the predicted strain and the measured strain gets to be quite high, up above 90%, the resulting data of the vertical load test is sufficient enough to prove that this device can be safely used overhead with a safety factor in all tested parts of more than 5. The device can be loaded to twice its rated loading without failing. Failure in this case is defined as the yielding of the parts of this device. Modification of this device is not required.

Acknowledgments

Thank you to Tom Marty, Grant County PUD hydro mechanic foreman and Beau Campbell, GCPUD hydro mechanic.

HORIZONTAL LOAD TEST

Introduction:

The rotor pole lifting device for Priest Rapids Dam was designed and analyzed by student intern Baylie Johnson of Grant County Public Utilities District. The device was manufactured by Busby International, Inc. out of Moses Lake, WA. Because this device is going to be used for lifting heavy object over people's heads, it was necessary to do a load test to ensure safety. This load test was performed by student intern Baylie Johnson, hydro mechanics Mike Garrett and Beau Campbell. The test consisted of configuring the device, attaching the device to the crane and a pole, applying load to the device and measuring strain through a strain gage. The following report with explain the procedure in more detail, present the data taken and discuss the data.

Method/Approach

The resources needed for this test include the following

- Priest Rapids Dam Powerhouse Crane
- Two swivel eyes
- Six shackles
- 10,000 pound Dynamometer
- Five slings
- Two horizontal lifting devices
- Camera
- Strain gages
- Strain indicator
- Switch and balance unit
- Extension cord

Both top plate/dovetail subassemblies were placed on either side of a rotor pole. They were then attached to a crane and lifted. There was one strain gage placed on the dovetail adapter plate to record any bending in the plate.

When the rotor pole is being tilted to or from a horizontal position the load is being carried in the dovetail. We wanted to test for this load to ensure safety. Based on a distance from the strain gage to the midpoint of dovetail contact, the strain read by the strain gage should have been 195 µs.

Procedure

1. Lower the 30 ton crane hook from the power house crane.
2. Assemble both top plates with the dovetails.
3. Insert swivel eyes into the threaded holes in the dovetail.
4. Place the dovetail/top plate combination on each side of a rotor pole laying horizontally.
5. Attach a sling to the crane hook with the loops down.
6. Connect the loops to a dynamometer with a shackle.
7. Attach another shackle to the bottom side of the dynamometer.

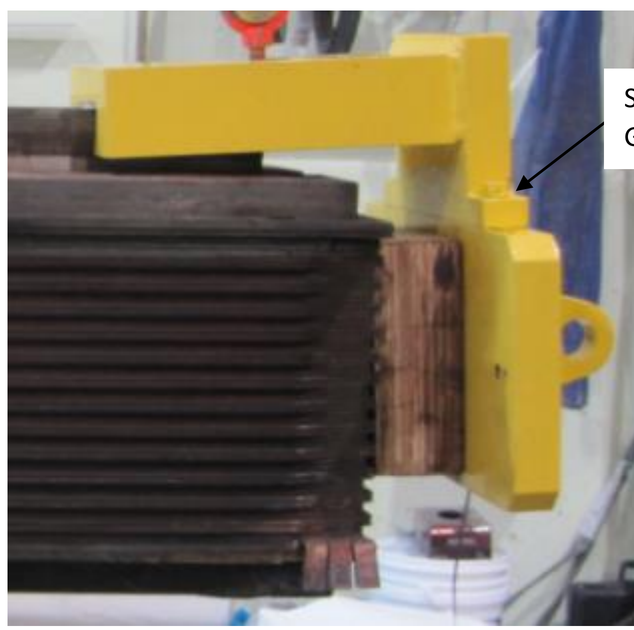
8. Attach two slings on the shackle on the bottom side of the dynamometer.
9. Attach a shackle to each swivel eye on the dovetails.
10. Attach one of the slings hanging from the crane to each swivel eye shackle.
11. Connect the strain gages to the reader and zero the amperage, input the correct gage factor and balance the gages to zero. This means that the load that is contributing to the strain reading is only the difference between the dynamometer reading and the weight of the device.
12. Raise the crane until a load of approximately 1500 pounds is applied. Record the actual dynamometer reading.
13. Record the strain gage measurement.
14. Repeat steps 12 and 13 once the rotor pole is no longer supported by the ground.
15. Attach the horizontal lifting devices (provided by GCPUD) to a second pole.
16. Attach shackles to the horizontal lifting devices.
17. Wrap two slings around the first rotor pole and attach each to a horizontal lifting device.
18. Lift the second pole until it is no longer touching the ground.
19. Record the dynamometer reading and strain measurement.
20. Lower and detach the poles.

Results

Load (lbs)	Actual Strain (µs)	Predicted Strain (µs)	Actual Stress (psi)	Percent Error
1450	-2	162	58	8077.16%
3700	-4	412	116	10305.35%
7200	-8	802	232	10026.82%

Discussion

The results of this load test were not as they were predicted. The smallest error was more than 8000%. This error most likely came from the fact that the fit between the dovetails was very poor. This caused the dovetail to tilt, as shown in the image to the right. The tilting took a lot of the stress away from the point of measurement.



Conclusion

Ultimately, this test did not provide usable results. The fit between the dovetails is so poor that the strain in the point of measurement became eight to ten thousand percent lower than predicted. However, the strain read at this location shows that it will not be a point of failure in the case of overload.

Acknowledgments

Thank you to Priest Rapids Dam hydro mechanics Beau Campbell and Mike Garrett for conducting the test.

APPENDIX J – RESUME/VITA

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Professional Profile

- Good teamwork skills
- Management experience
- Quality work
- Computer competency
- Quick learning ability
- SolidWorks Certified

Professional Experience

Heartland Automotive, Inc. dba Jiffy Lube, Spokane and Bellingham, WA
January 2011 to June 2014
Assistant General Manager

Responsibilities:

- Opening and closing the store
- Getting things done in the most effective manor
- Managing the team

O'Reilly Auto Parts, Ellensburg, WA
July 2014 to Present
Parts Specialist

Responsibilities:

- Helping customers
- Inventory management
- Cleaning

Grant County Public Utilities District, Beverly, WA
June 2015 to Present
Student Engineering Intern

Responsibilities:

- Assisting Engineers
- Completely Project Proposals

Education

Central Washington University, Bellingham, WA
Pursing a Bachelor's in Mechanical Engineering Technology
Currently Enrolled

Spokane Community College, Spokane, WA
Associate of Arts Degree
September 2010 to June 2012

References

Available Upon Request