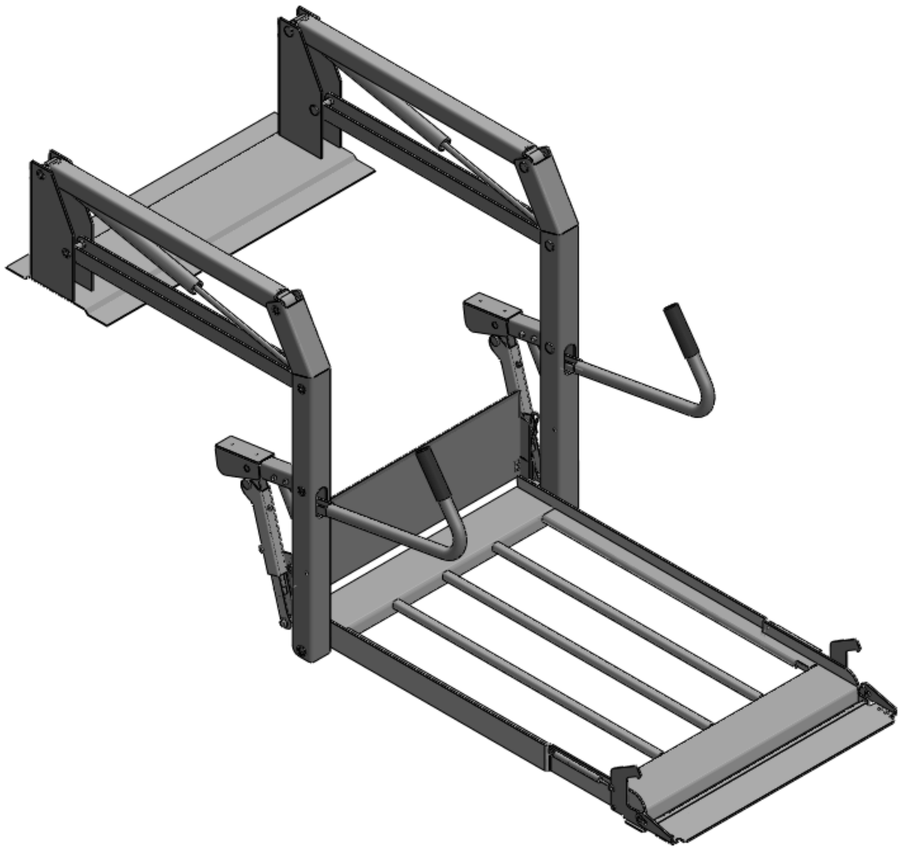
Project – Wheel Chair Lift



Engineering Project & Report B

Professor: Rob Schaaf

Name: Kwangmyung Lee

Student #: 7483712

Date: 2019. July.22

Abstract

This report shows design, material, displacement, safety and analysis regarding wheelchair lift. It primarily focused on force and stress analysis to verify that the wheelchair lift specified is safe and acceptable for use. In force analysis, possible human motion and maximum force location along with the movement of the lift were considered. Two displacements were selected to implement force analysis. These locations were chosen because they are the positions that introduce the highest stress conditions. Based on these two locations, displacement was decided and then force analysis was implemented according to the data from the displacement analysis. In the stress analysis, all parts were analyzed with manual calculation. In that case, several assumptions were used to simplify and overcome limitations. Some parts were divided into several sectional areas, and the areas again were divided into several elements. This improved the accuracy of the safety factors while staying conservative in regards to worst-case conditions. From this analysis, the Wheelchair lift was confirmed to be safe for operation.

Contents

1.0 Introduction

A wheelchair lift is a device for people using a wheelchair to facilitate to get in a car or move to a different level of a floor. The proposal focuses on the wheelchair lift used in cars, which deals with the movement mechanism and stress analysis based on the maximum load to verify safety. Safety factor, which is three, is following the Americans with Disabilities Act standard. The Braunability model NCL 1000FIB3454-2 was selected, and which is measured and remodelled. The drawings showing assemblies and single parts are provided separately from the report.

Force and stress analysis is a major part of the report. Except for the FBD system, all forces are organized with linear equations in other FBDs. The equations were converted to a matrix and solved with a matrix calculator. Possible locations which are likely to have the highest stress were selected and analyzed. In conclusion, it verifies the wheelchair lift is within the given safety factor.

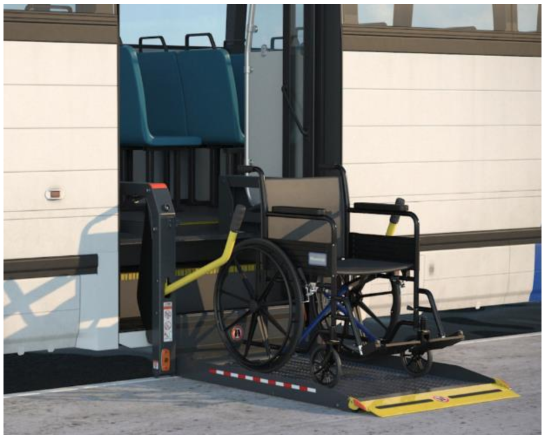


Figure 1. Wheel Chair Lift

1.1 History/Background

In the United States, the Americans with Disabilities Act of 1990 (ADA) required that all new mass transit vehicles placed into service after July 1, 1993, be accessible to persons in wheelchairs, and until the 2000s, this requirement was most commonly met by the inclusion of a wheelchair lift. In 1993, 29,033 transit buses in the U.S. were equipped with a wheelchair lift or ramps, 52 percent of all U.S. transit buses.

1.2 Project Goals

The main goal of this project is to evaluate the current design and verify safety by modelling and calculating several types of stress on each part.

1.3 Market Research

The global wheelchair lift market is expected to generate revenues of around $2.6 billion by 2023 and is anticipated to grow at a CAGR of approximately 10% during the forecast period. The global wheelchair lift market by automotive lifts are classified in to occupied (single-post split platform, standard dual-post platform, and under vehicle lifts (UVLs)) and unoccupied lifts (outside lifts, inside lifts, and hybrid lifts). The occupied lifts dominated more than half of the market share in 2017 and are projected to grow at CAGR of around 11% during the forecast period. Occupied lifts are the most preferred option as they offer wheelchair users ease of access while entering the vehicle. The leading vendors operating in this segment are BraunAbility and VMI. Standard dual-post platform lifts and UVLs have more stability compared to a single-post split platform. The development of efficient chairlifts that offer ease of mobility and that can handle heavier loads with two arms to support will transform the market over the next few years.

1.4 Project Breakdown

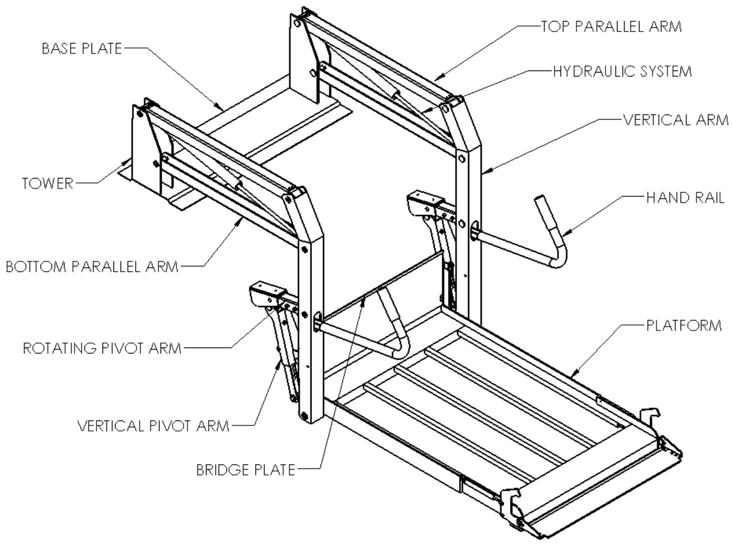


Figure 2. Project Breakdown

1. Base Plate
2. Tower
3. Hydraulic System
4. Top Parallel Arm
5. Bottom Parallel Arm
6. Vertical Arm
7. Handrail
8. Rotating Pivot Arm
9. Vertical Pivot Arm
10. Platform
11. Bridge Plate
12. Pin

1.5 Assembly Information

1.5.1 Base Plate – Installed on a vehicle to connect the vehicle to towers, and which supports the towers not to damage the vehicle

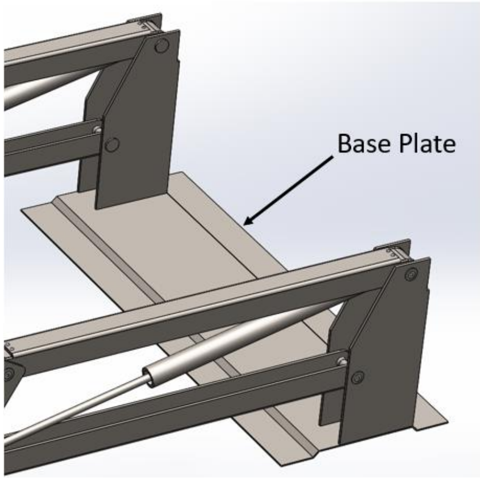


Figure 3. Base Plate

1.5.2 Tower – Connects a base plate to top and bottom parallel arms

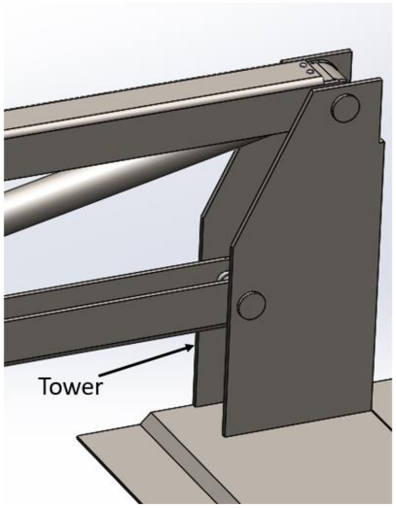


Figure 4. Tower

1.5.3 Hydraulic Cylinders -Telescoping cylinders convert hydraulic pressure into platform lifting force.

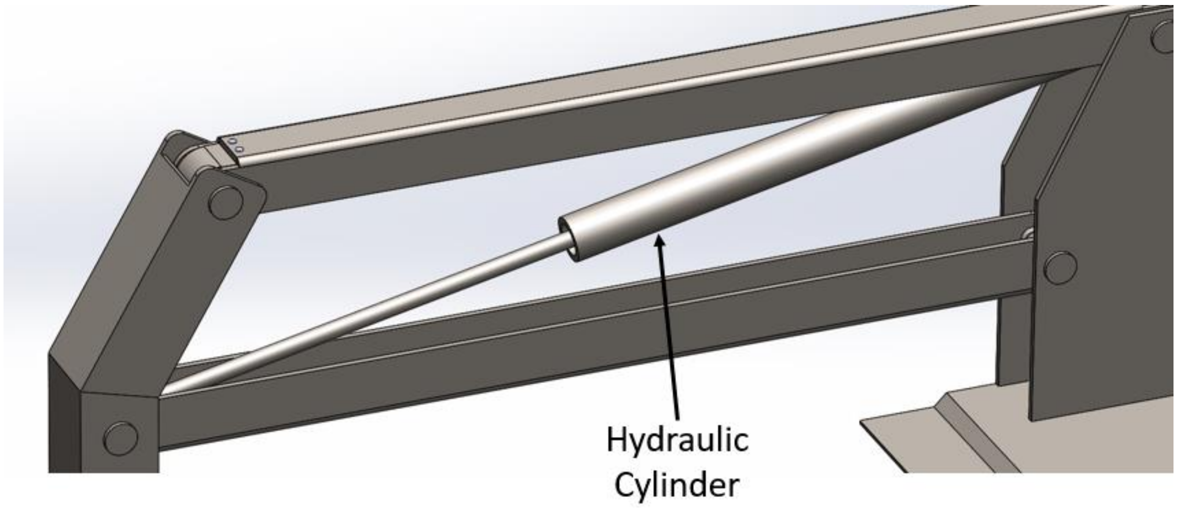


Figure 5. Hydraulic Cylinder

1.5.4 Top Parallel Arm – Upper arm which connects a tower to a vertical arm

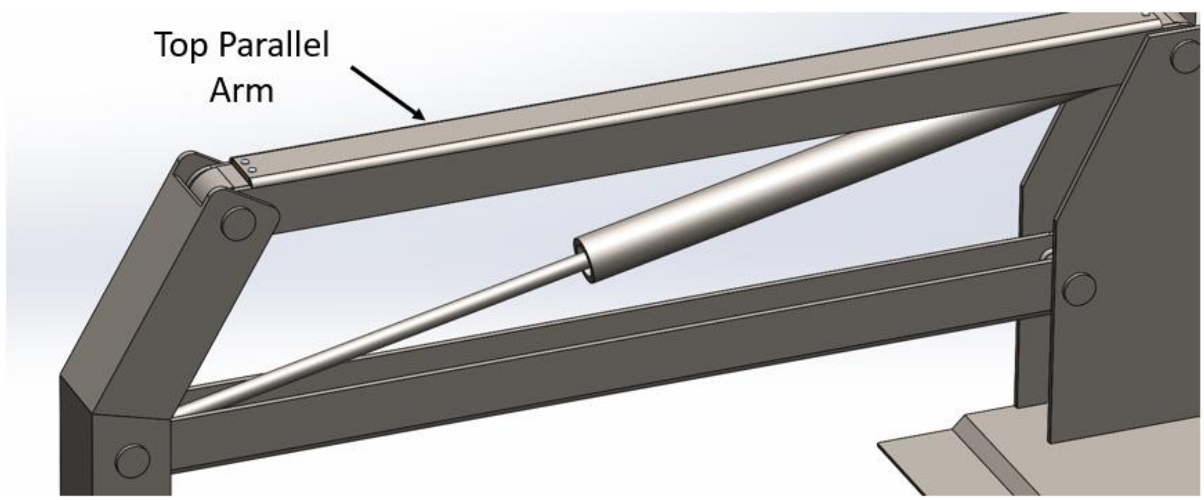


Figure 6. Top Parallel Arm

1.5.5 Bottom Parallel Arm – Bottom arm which connects a tower to a vertical arm

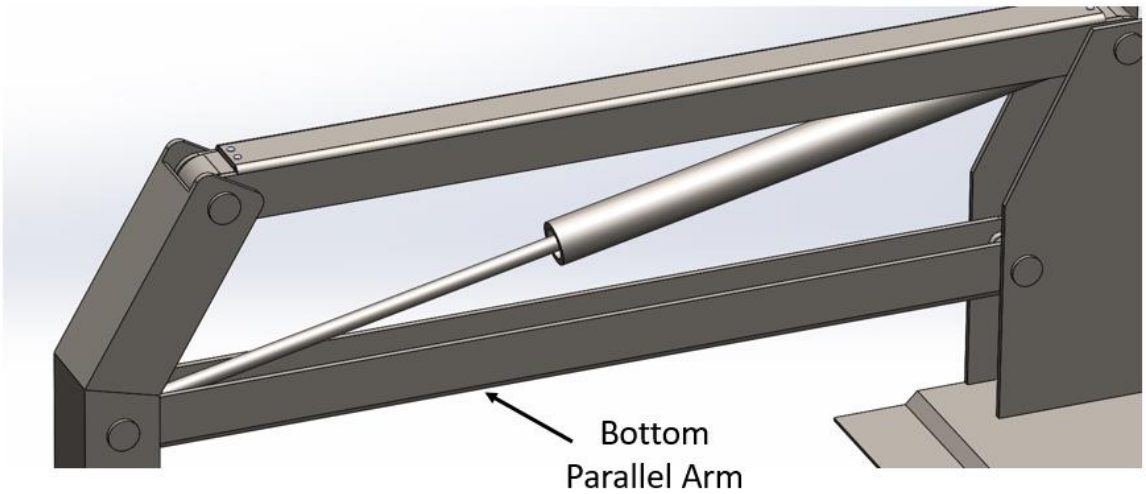


Figure 7. Bottom Parallel Arm

1.5.6 Vertical Arm – Supports a platform, handrail and horizontal pivot arm not to rotate

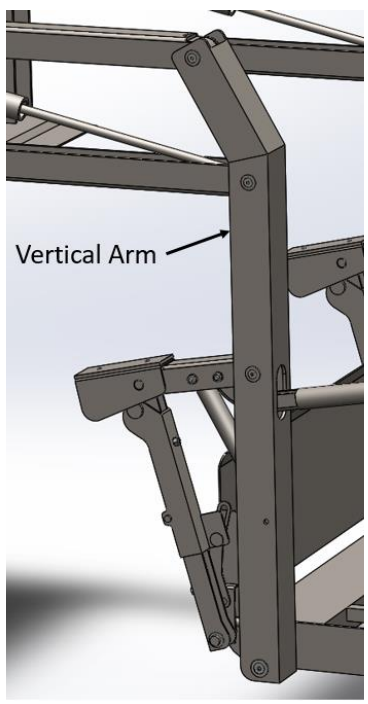


Figure 8. Vertical Arm

1.5.7 Handrail - Provide a hand-hold for platform occupant.

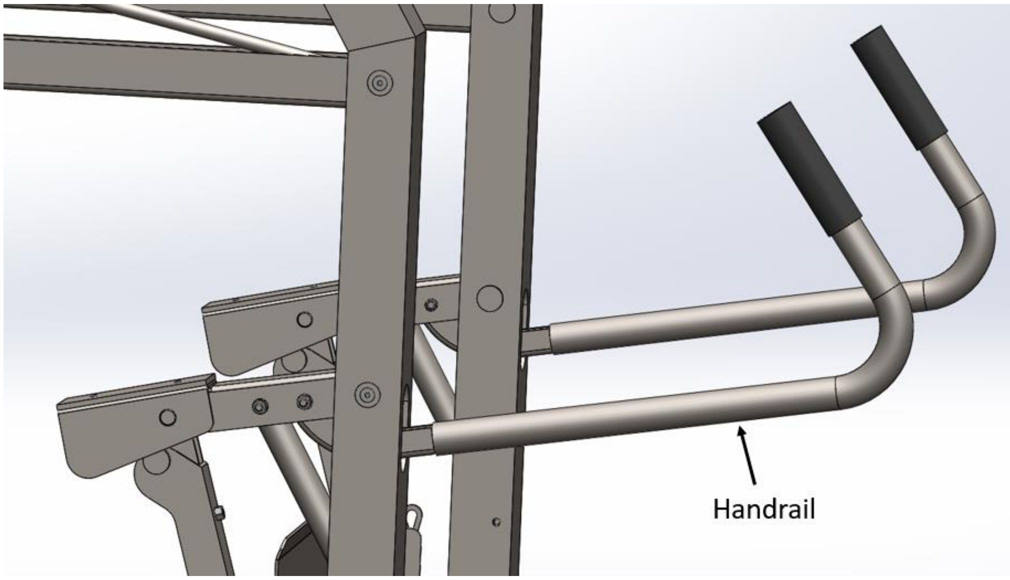


Figure 9. Handrail

1.5.8 Horizontal Pivot Arm – Connects a vertical arm to vertical pivot arm, prevents handrail from rotating

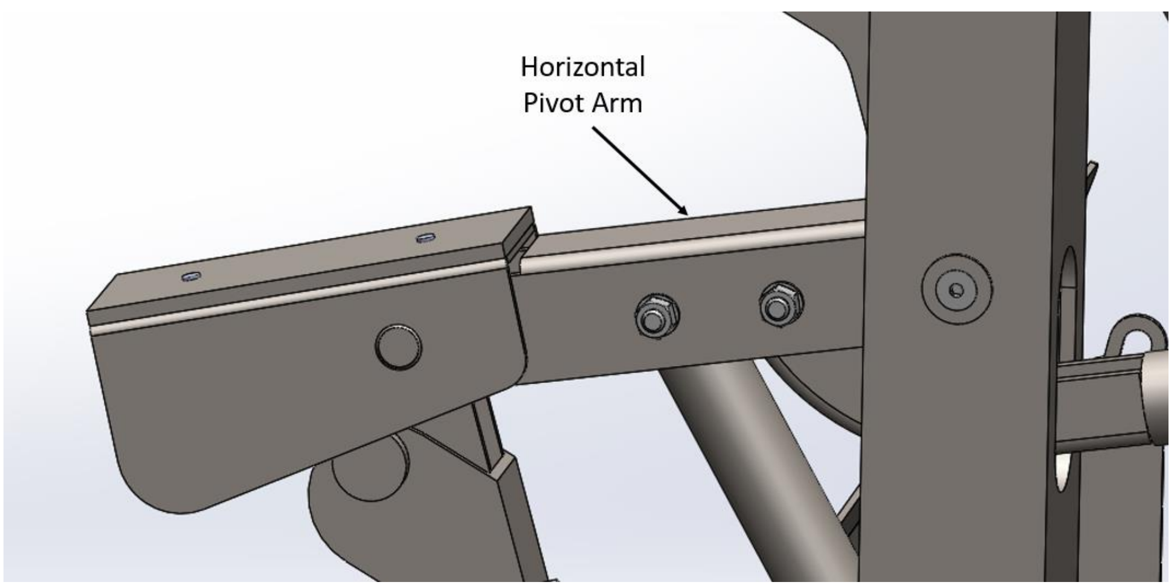


Figure 10. Horizontal Pivot Arm

1.5.9 Vertical Pivot Arm – Controls a bridge plate to rotate and supports a horizontal pivot arm

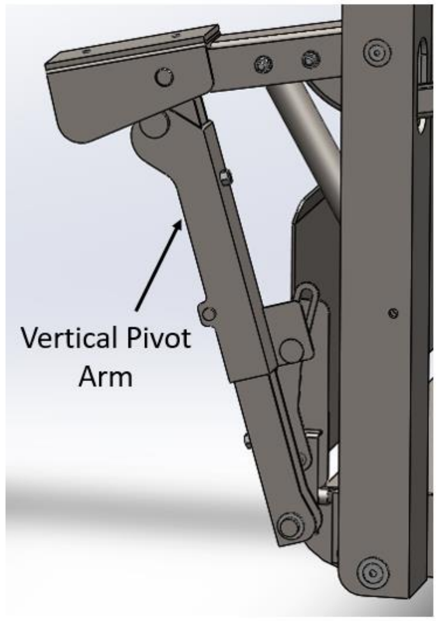


Figure 11. Vertical Pivot Arm

1.5.10 Platform - Area of a lift where wheelchair and occupant are situated during "Up" and "Down" motions.

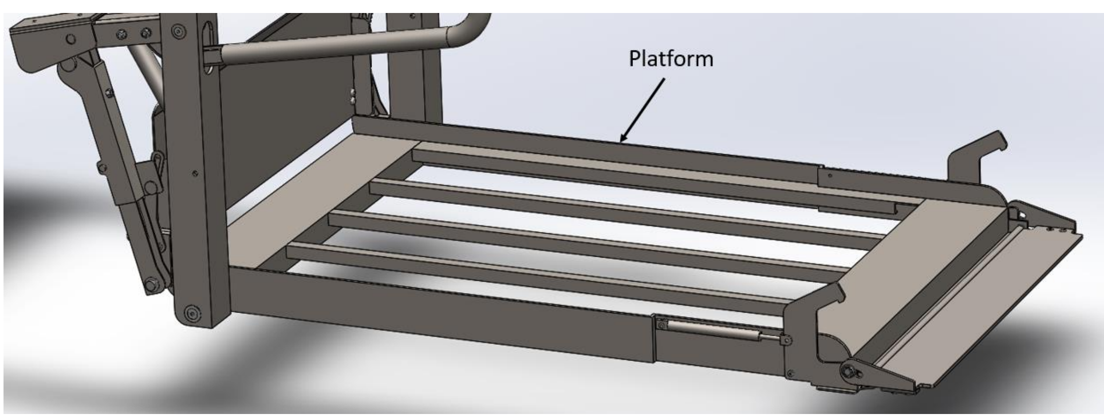


Figure 12. Platform

1.5.11 Bridge Plate - Plate that bridges the gap between platform and vehicle when the platform is at floor height. Acts as a barrier to confine wheelchair to the platform during "Up" and "Down" motions.

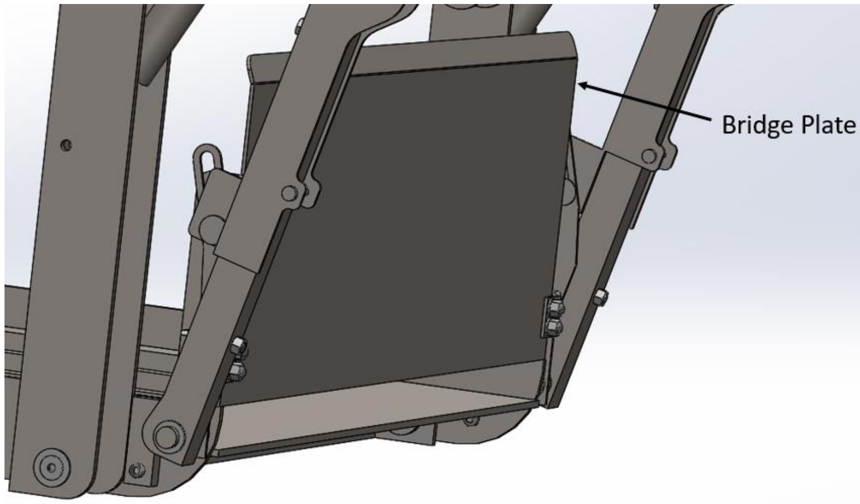


Figure 13. Bridge Plate

1.5.12 Pin - Secures the position of two or more parts of a machine relative to each other.

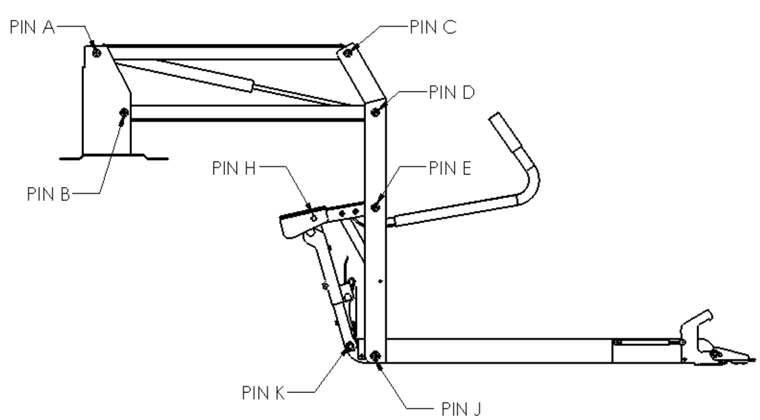


Figure 14. Pin Location

1.6 Operation

1.6.1 Lifting Down – Once the lift is down, the platform begins to unfold.

Figure 15.Lifting Down Step 1

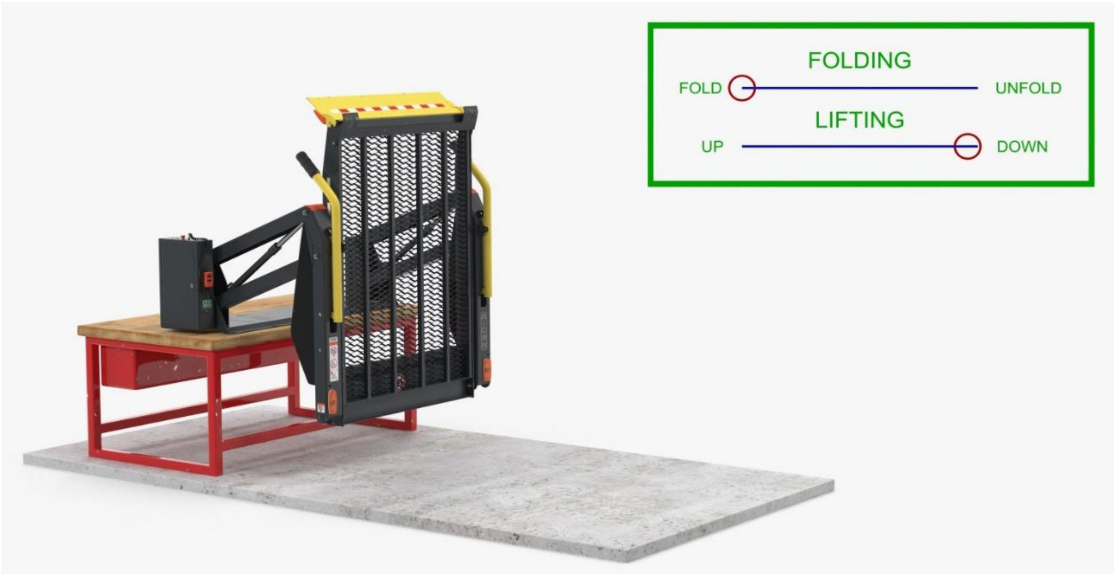


Figure 16. Lifting Down Step 2

Figure 17. Lifting Down Step 3

1.6.2 Lifting Up - Once the platform is folded, the lift starts to move up.

Figure 18. Lifting Up Step 1

Figure 19. Lifting Up Step 2

Figure 20. Lifting Up Step 3

1.7 Specifications

- **Model** – Braunability NCL 1000FIB3454-2
- **Dimension**

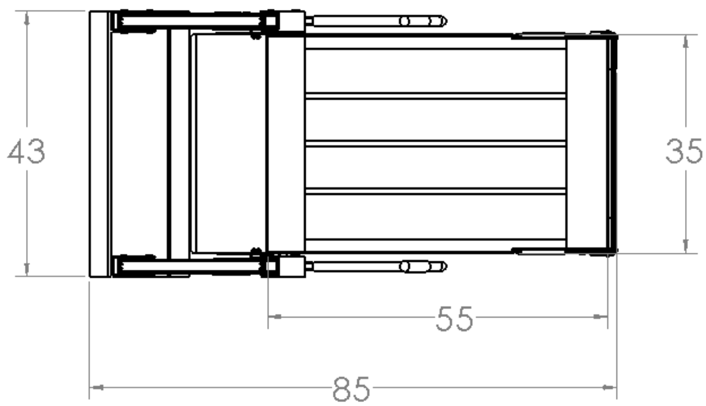


Figure 21. Top View

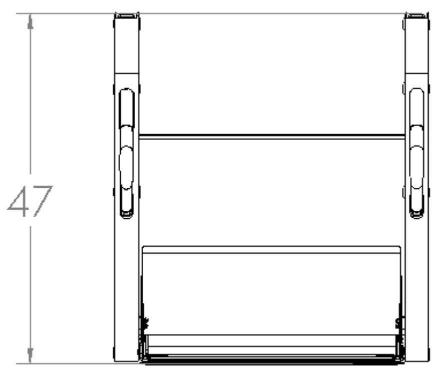


Figure 22. Side View

Stationary Frame width [in]	Height [in]	Overall length [in]	Usable Platform width [in]	Usable Platform length [in]	Cycle Time [sec]
43	47	85	35	55	45

- **General Specification**

Power	Motor Rating @12 Volts DC	Maximum Load	Manual Back - Up	Manual Back - Down	Weight
Electrohydraulic	65 amp avg/cycle, 1250 psi	1000 lbs	Hand pump	Pressure relieve valve	400 lbs

1.8 Safety Instructions

- Do not load more than allowed maximum load.
- Have the machine checked at least every six months
- When the roll stop is fully down, then move the wheelchair.

1.9 Scope

- Base plate, tower and hydraulic system are excluded.
- Top parallel arm, bottom parallel arm, vertical arms, handrails, rotating pivot arm, vertical pivot arm, platform, bridge plate and pins are included.

1.10 Safety Factor

Safety Factor is three, which is following the Americans with Disabilities Act Standard.

2.0 Discussion

2.1 Force Analysis

2.1.1 Introduction

The wheelchair lift has several parts moving independently, which causes difficulty to calculate every force applied to each part. Therefore, two critical positions were selected, which are “Lift-Up” and “Lift-Down.” The following figures show components and connection points of wheelchair lift.

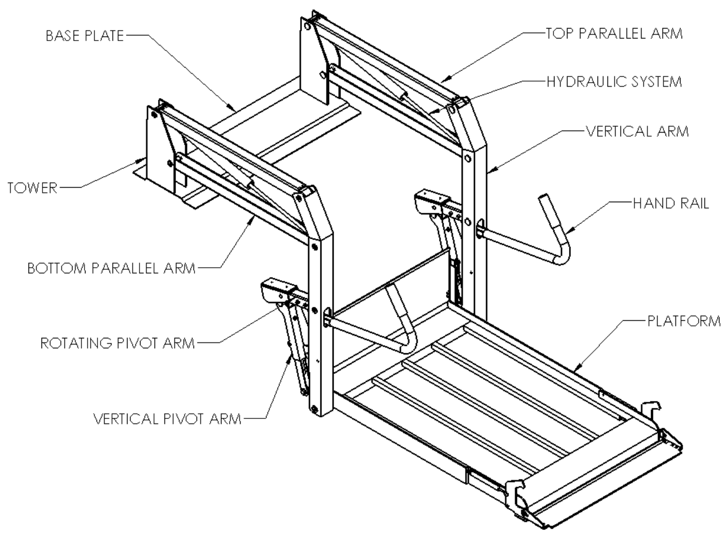


Figure 23. Components Names

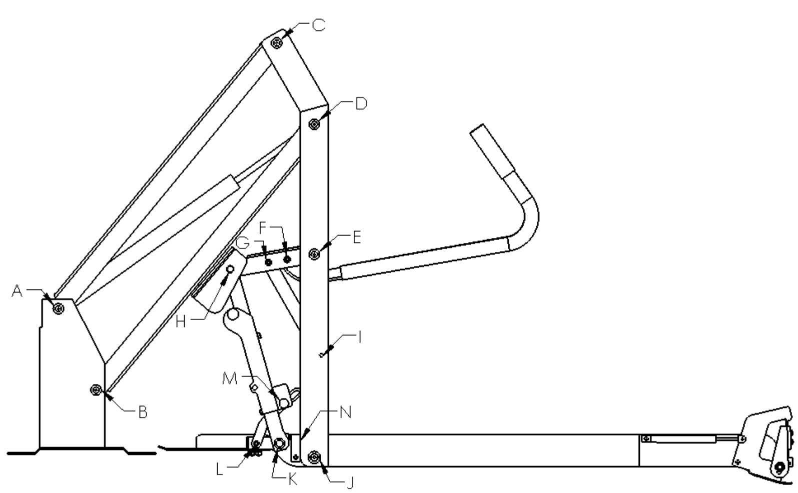


Figure 24. Connected Points

2.1.2 Lift Up

2.1.2.1 FBD System

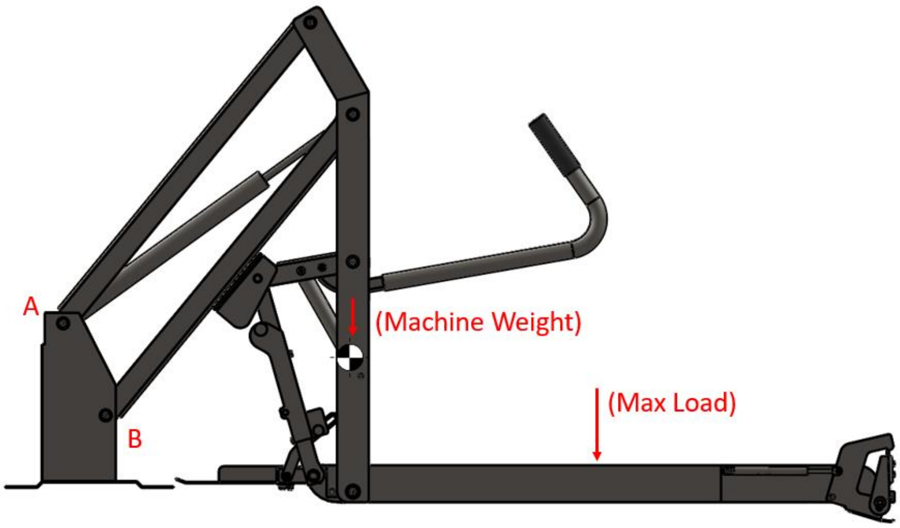


Figure 25. Applied Load

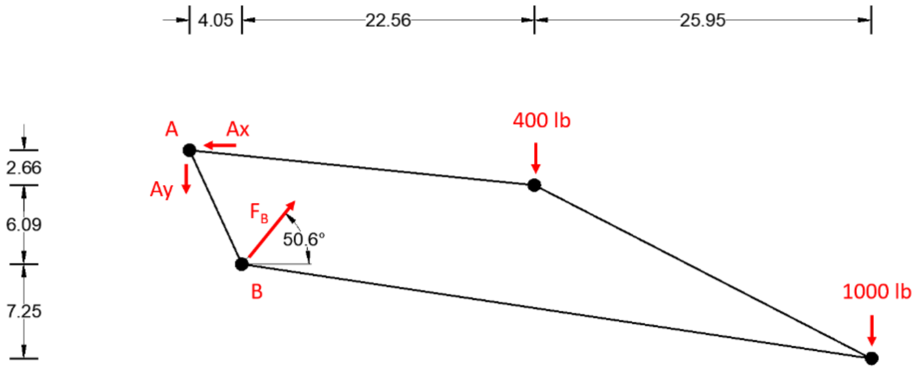


Figure 26. FBD System

$$\circlearrowleft \sum M_A = 0$$

$$0 = -400 \times 26.61 - 1000 \times 52.56 + cos\,50.6 \times F_B \times 8.75 + sin\,50.6 \times F_B \times 4.05$$

$$F_B = \frac{400 \times 26.61 + 1000 \times 52.56}{\cos 50.6 \times 8.75 + \sin 50.6 \times 4.05}$$

$$F_B = 7278.66\ lb \angle 50.6°$$

$\rightarrow \sum F_X = 0$

$0 = -A_X + \cos 50.6 \times F_B$

$A_X = \cos 50.6 \times 7278.66$

$A_X = 4619.99\ lb \leftarrow$

$\uparrow \sum F_Y = 0$

$0 = -A_Y - 400 - 1000 + \sin 50.6 \times F_B$

$A_Y = -400 - 1000 + \sin 50.6 \times 7278.66$

$A_Y = 4224.46\ lb \downarrow$

2.1.2.2 FBD Pin A

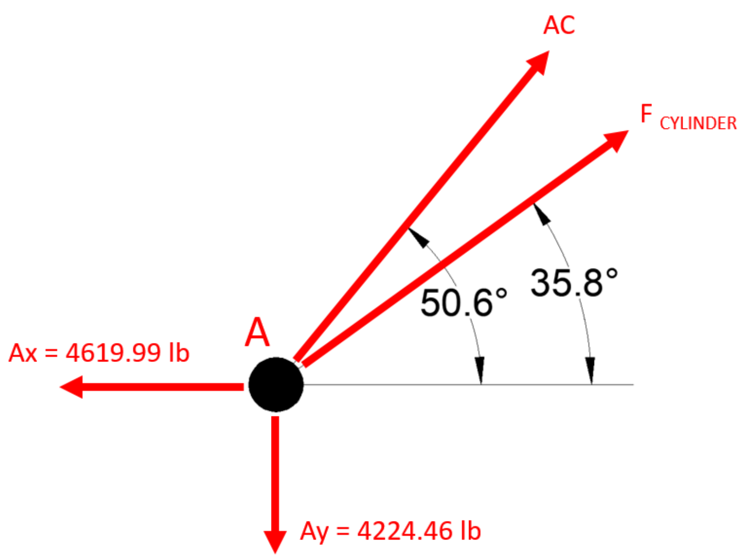


Figure 27. FBD Pin A

$\rightarrow \sum F_X = 0$

$0 = \cos 50.6 \times AC + \cos 35.8 \times F_{CYLINDER} - 4619.99$

$\cos 50.6 \times AC + \cos 35.8 \times F_{CYLINDER} = 4619.99$

$\uparrow \sum F_Y = 0$

$0 = \sin 50.6 \times AC + \sin 35.8 \times F_{CYLINDER} - 4224.46$

$\sin 50.6 \times AC + \sin 35.8 \times F_{CYLINER} = 4224.46$

There are two linear equations and two unknown values. Therefore, it is solvable with a calculator which has a linear equation function. Member AC, which is a top parallel arm, is a two-force member.

$AC = 2833.51\ lb\ (Tension)$

$F_{CYLINDER} = 3478.73\ lb\ (Tension)$

2.1.2.3 FBD Top Parallel Arm

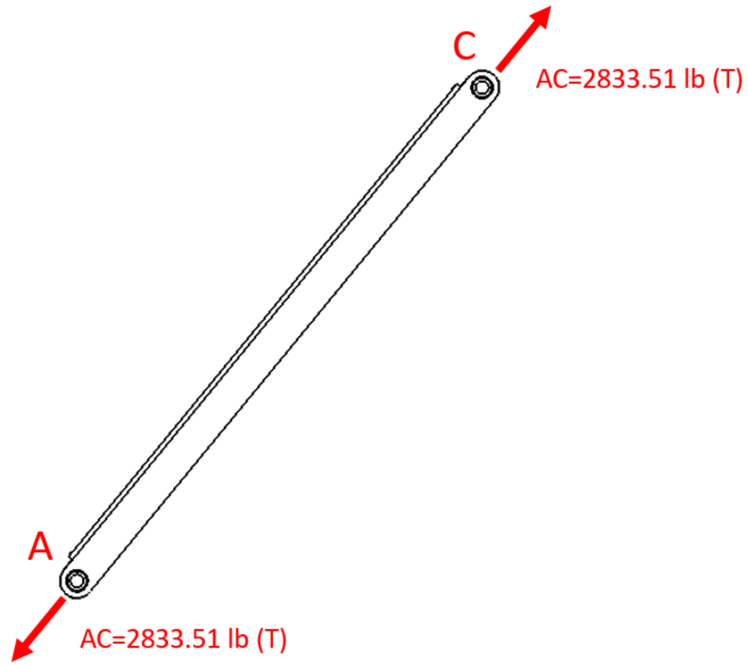


Figure 28. FBD Top Parallel Arm

Tension applies to two-force member AC.

2.1.2.4 FBD Pin B

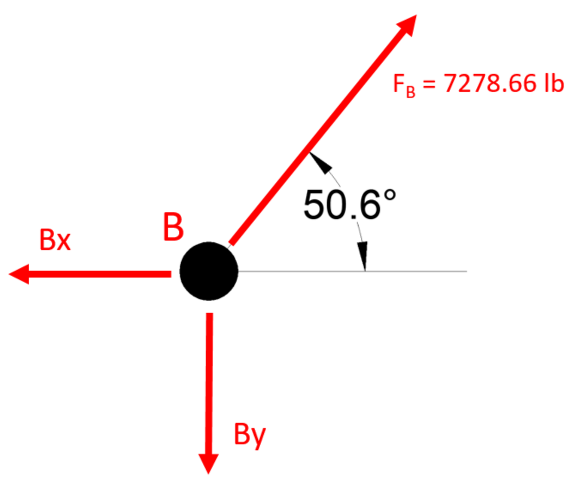


Figure 29. FBD Pin B

$\rightarrow \sum F_X = 0$

$0 = -B_X + \cos 50.6 \times 7278.66$

$B_X = \cos 50.6 \times 7278.66$

$B_X = 4619.99\ lb \leftarrow$

$\uparrow \sum F_Y = 0$

$0 = -B_Y + \sin 50.6 \times 7278.66$

$B_Y = \sin 50.6 \times 7278.66$

$B_Y = 5624.46\ lb \downarrow$

Member BD, which is a bottom parallel arm, is a two-force member. Compression applies to member BD.

$BD = \sqrt{{B_X}^2 + {B_Y}^2} = \sqrt{4619.99^2 + 5624.46^2}$

$BD = 7278.66\ lb\ (Compression)$

2.1.2.5 FBD Bottom Parallel Arm

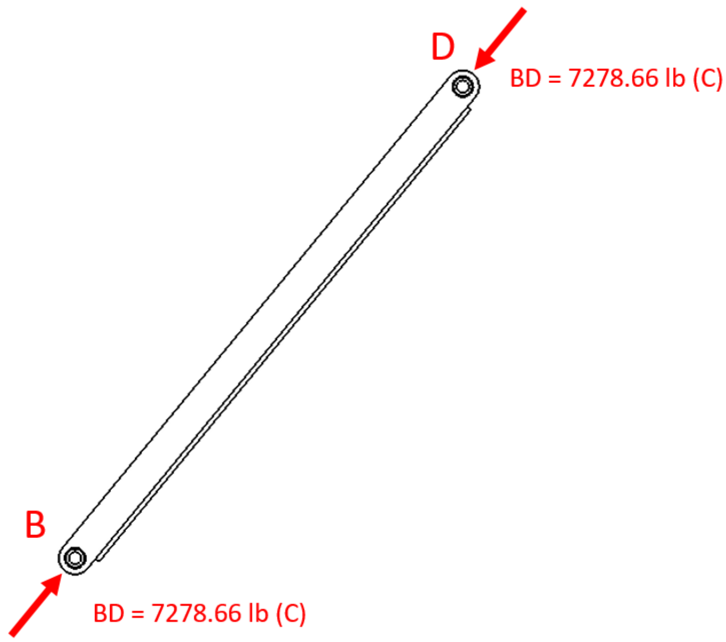


Figure 30. FBD Bottom Parallel Arm

2.1.2.6 FBD Pin C

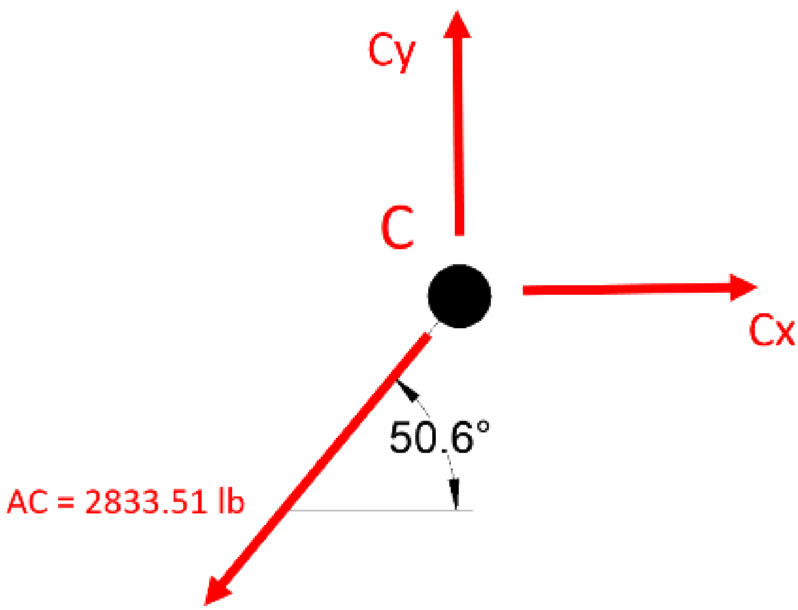


Figure 31. FBD Pin C

$\rightarrow \sum F_X = 0$

$0 = C_X - \cos 50.6 \times 2833.51$

$C_X = \cos 50.6 \times 2833.51$

$C_X = 1798.52\ lb \rightarrow$

$\uparrow \sum F_Y = 0$

$0 = C_Y - \sin 50.6 \times 2833.51$

$\mathrm{C_Y} = \sin 50.6 \times 2833.51$

$\mathrm{C_Y} = 2189.55\ lb \uparrow$

2.1.2.7 FBD Pin D

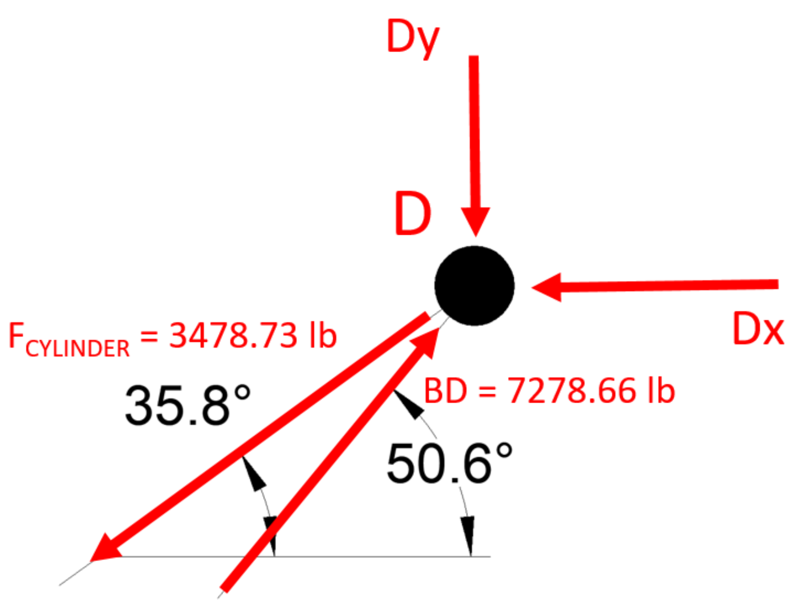


Figure 32. FBD Pin D

$\rightarrow \sum F_X = 0$

$0 = -D_X + \cos 50.6 \times 7278.66 - \cos 35.8 \times 3478.73$

$D_X = \cos 50.6 \times 7278.66 - \cos 35.8 \times 3478.73$

$D_X = 1798.52\ lb \leftarrow$

$\uparrow \sum F_Y = 0$

$0 = -D_Y + \sin 50.6 \times 7278.66 - \sin 35.8 \times 3478.73$

$\mathrm{D_Y} = \sin 50.6 \times 7278.66 - \sin 35.8 \times 3478.73$

$\mathrm{D_Y} = 3589.56\ lb \downarrow$

Up until this point, calculations have no error. Therefore, the values calculated until this phase were used to analyze stress calculation for Pin A, B, C, D, top parallel arm and bottom parallel arm.

2.1.2.8 FBD Bridge Plate

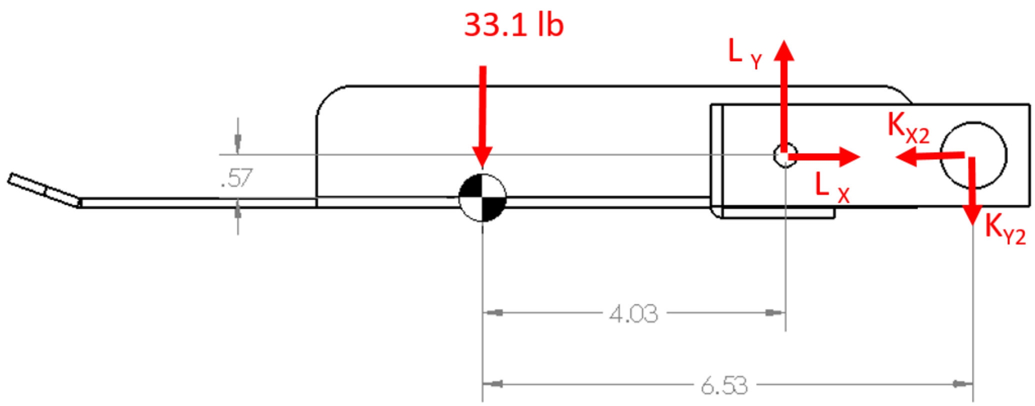


Figure 33. FBD Bridge Plate

$\rightarrow \sum F_X = 0$

$0 = L_X - K_{X2}$

$L_X - K_{X2} = 0$

$\uparrow \sum F_Y = 0$

$0 = -K_{Y2} + L_Y - 33.1$

$-K_{Y2} + L_Y = 33.1$

$\circlearrowleft \sum M_L = 0$

$0 = 33.1 \times 4.03 - 2.05 \times K_{Y2}$

$2.5 \cdot K_{Y2} = 133.393$

2.1.2.9 FBD Handrail

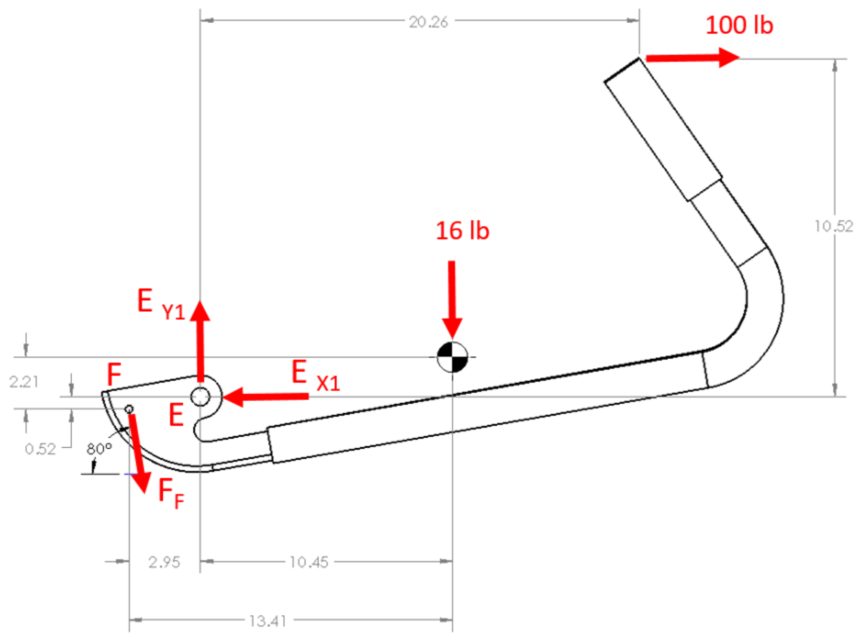


Figure 34. FBD Handrail

100 lb is an external load due to the people holding the handrail.

$\rightarrow \sum F_X = 0$

$0 = -E_{X1} + \cos 80 \times F_F + 100$

$-E_{X1} + 0.1736 \cdot F_F = -100$

$\uparrow \sum F_Y = 0$

$0 = E_{Y1} - 16 - \sin 80 \times F_F$

$E_{Y1} - 0.9848 \cdot F_F = 16$

$\circlearrowleft \sum M_E = 0$

$0 = -16 \times 10.45 + cos80 \times F_F \times 0.52 + \sin 80 \times F_F \times 2.95 - 100 \times 10.52$

$$F_F = \frac{16 \times 10.45 + 100 \times 10.52}{\cos 80 \times 0.52 + \sin 80 \times 2.95}$$

$F_F = 407.013\ lb$

2.1.2.10 FBD Horizontal Pivot Arm

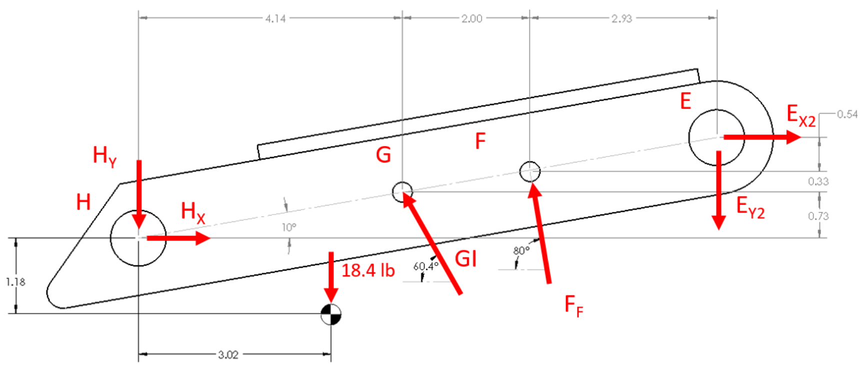


Figure 35. FBD Horizontal Pivot Arm

The location of a center of gravity and weight contains a horizontal pivot arm and member GI. That is the reason why the center of gravity looks like to locate out of the center of the part.

$\rightarrow \sum F_X = 0$

$0 = H_X - \cos 60.4 \times G_I - \cos 80 \times F_F + E_{X2}$

$H_X - 0.4939 \cdot G_I - 0.1736 \cdot F_F + E_{X2} = 0$

$\uparrow \sum F_Y = 0$

$0 = -H_Y - 18.4 + \sin 60.4 \times GI + \sin 80 \times F_F - E_{Y2}$

$-H_Y + 0.8695 \cdot GI + 0.9848 \cdot F_F - E_{Y2} = 18.4$

$\circlearrowleft \sum M_H = 0$

$$0 = -18.4 \times 3.02 + \cos 60.4 \times GI \times 0.73 + \sin 60.4 \times GI \times 4.14 + \cos 80 \times F_F \times 1.06 + \sin 80 \times F_F \times 6.14 - 1.6 \times E_{X2} - 9.07 \times E_{Y2}$$

$3.96 \cdot GI + 6.23 \cdot F_F - 1.6 \cdot E_{X2} - 9.07 \cdot E_{Y2} = 55.568$

2.1.2.11 FBD Vertical Pivot Arm

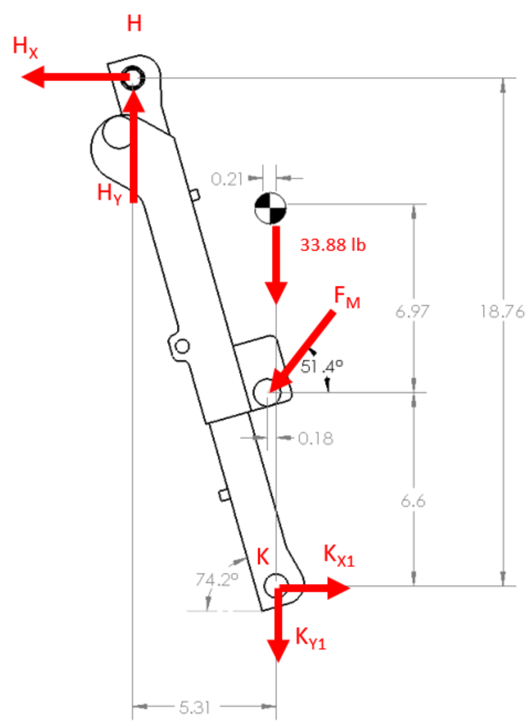


Figure 36. FBD Vertical Pivot Arm

$\rightarrow \sum F_X = 0$

$0 = -H_X - \cos 51.4 \times F_M + K_{X1}$

$-H_X - 0.6239 \cdot F_M + K_{X1} = 0$

$\uparrow \sum F_Y = 0$

$0 = H_Y - 33.88 - \sin 51.4 \times F_M - K_{Y1}$

$H_Y - 0.7815 \cdot F_M - K_{Y1} = 33.88$

$\circlearrowleft \sum M_K = 0$

$0 = 18.76 \times H_X - 5.31 \times H_Y + 33.88 \times 0.21 + 6.6 \times \cos 51.4 \times F_M + 0.18 \times \sin 51.4 \times F_M$

$18.76 \cdot H_X - 5.31 \cdot H_Y + 4.26 \cdot F_M = -7.1148$

2.1.2.12 FBD Slot

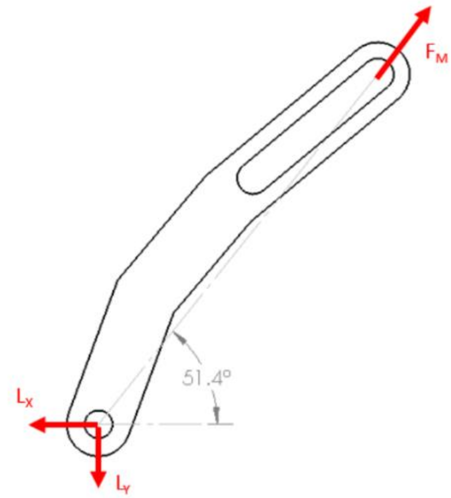


Figure 37. FBD Slot

Tension applies to a slot. It means the slot can be assumed as a two-force member when the lift is up.

$\rightarrow \sum F_X = 0$

$0 = \cos 51.4 \times F_M - L_X$

$0.6239 \cdot F_M - L_X = 0$

$\uparrow \sum F_Y = 0$

$0 = \sin 51.4 \times F_M - L_Y$

$0.7815 \cdot F_M - L_Y = 0$

2.1.2.13 FBD Vertical Arm

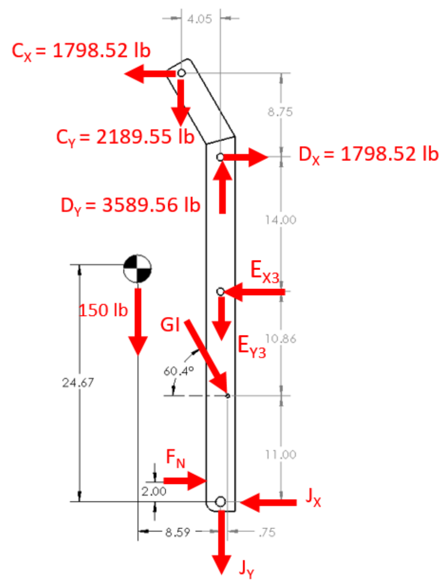


Figure 38. FBD Vertical Arm

The weight contains a vertical arm, hydraulic cylinder, top parallel arm and bottom parallel arm.

$\rightarrow \sum F_X = 0$

$0 = -C_X + D_X - E_{X3} + \cos 60.4 \times GI + F_N - J_X$

$-C_X + D_X - E_{X3} + 0.4939 \cdot GI + F_N - J_X = 0$

$\uparrow \sum F_Y = 0$

$0 = -C_Y + D_Y - E_{Y3} - 150 - \sin 60.4 \times GI - J_Y$

$-C_Y + D_Y - E_{Y3} - 0.8695 \cdot GI - J_Y = 150$

$\circlearrowleft \sum M_E = 0$

$$0 = 22.75 \times C_X + 4.05 \times C_Y - 14 \times D_X - \sin 60.4 \times GI \times 0.75 + \cos 60.4 \times GI \times 10.86 + 19.86 \times F_N - 21.86 \times J_X + 150 \times 8.59$$

$$22.75 \cdot C_X + 4.05 \cdot C_Y - 14 \cdot D_X + 4.712 \cdot GI + 19.86 \cdot F_N - 21.86 \cdot J_X = -1288.5$$

2.1.2.14 FBD Platform

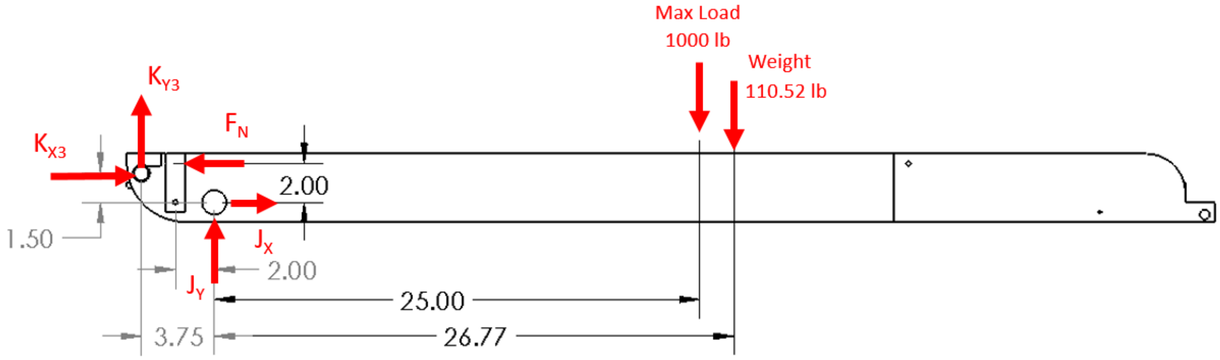


Figure 39. FBD Platform

$\rightarrow \sum F_X = 0$

$$0 = K_{X3} - F_N + J_X$$

$$K_{X3} - F_N + J_X = 0$$

$\uparrow \sum F_Y = 0$

$$0 = K_{Y3} + J_Y - 1000 - 110.52$$

$$K_{Y3} + J_Y = 1110.52$$

$\circlearrowleft \sum M_J = 0$

$0 = -3.75 \times K_{Y3} - 1.5 \times K_{X3} + 2 \times F_N - 1000 \times 25 - 110.52 \times 26.77$

$-3.75 \cdot K_{Y3} - 1.5 \cdot K_{X3} + 2 \cdot F_N = 27958.62$

2.1.2.15 Additional Equation

Both point E and K are connected with three components. The sum of forces acting on these points has to be zero. Therefore, the following additional equations are required to make an equilibrium state.

$-E_{X1} + E_{X2} - E_{X3} = 0$

$E_{Y1} - E_{Y2} - E_{Y3} = 0$

$K_{X1} - K_{X2} + K_{X3} = 0$

$-K_{Y1} - K_{Y2} + K_{Y3} = 0$

2.1.2.16 Result

From FBD Bridge Plate to FBD Platform, equations were input into the matrix. However, there were two redundant equations and it caused minor errors, but it is still allowable. The appendix shows the used matrix. The following table shows the direction and magnitude of forces applied to each point.

Table 1. Calculated Forces

Location & Direction	Force (lbs)	Location & Direction	Force (lbs)
C_X	1815.81	H_Y	150.15
C_Y	2193.40	J_X	14063.17
D_X	1787.88	J_Y	1050.88
D_Y	3588.79	K_{X1}	78.73
E_{X1}	170.27	K_{Y1}	10.01
E_{Y1}	415.37	K_{X2}	112.90
E_{X2}	94.37	K_{Y2}	54.02
E_{Y2}	288.54	K_{X3}	49.65
E_{X3}	75.90	K_{Y3}	60.41
E_{Y3}	127.60	L_X	97.42
F_F	404.75	L_Y	94.88
GI	76.07	F_M	131.34
H_X	12.25	F_N	14129.43

2.1.3 Lift Down

2.1.3.1 FBD System

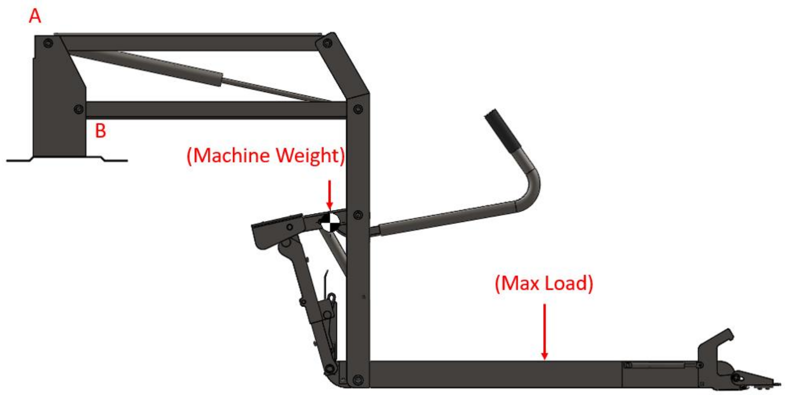


Figure 40. Applied Load

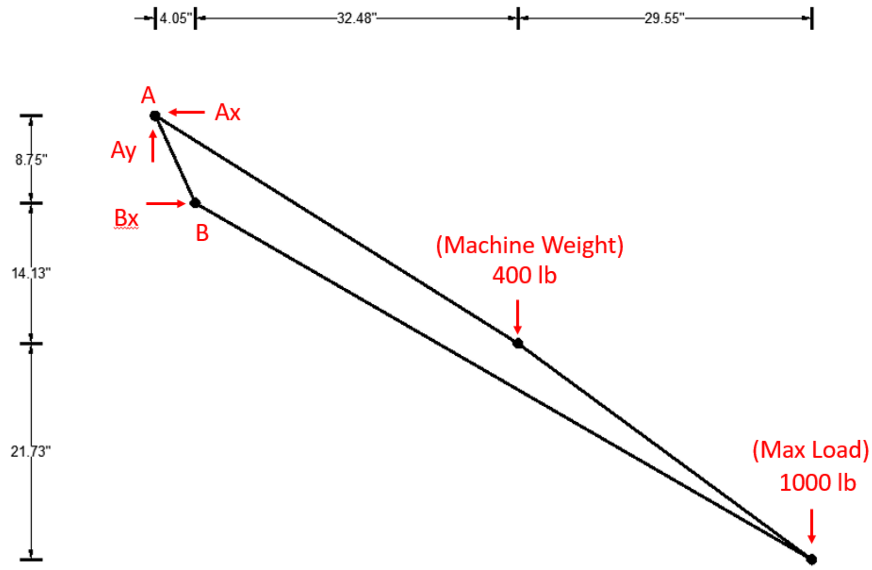


Figure 41. FBD System

$\circlearrowleft \sum M_A = 0$

$0 = B_X \times 8.75 - 400 \times 36.53 - 1000 \times 66.08$

$$B_X = \frac{400 \times 36.53 + 1000 \times 66.08}{8.75}$$

$B_X = 9221.94\ lb \rightarrow$

$\rightarrow \sum F_X = 0$

$0 = -A_X + B_X$

$A_X = B_X$

$A_X = 9221.94\ lb \leftarrow$

$\uparrow \sum F_Y = 0$

$0 = A_Y - 400 - 1000$

$A_Y = 400 + 1000$

$A_Y = 1400\ lb \uparrow$

2.1.3.2 FBD Pin A

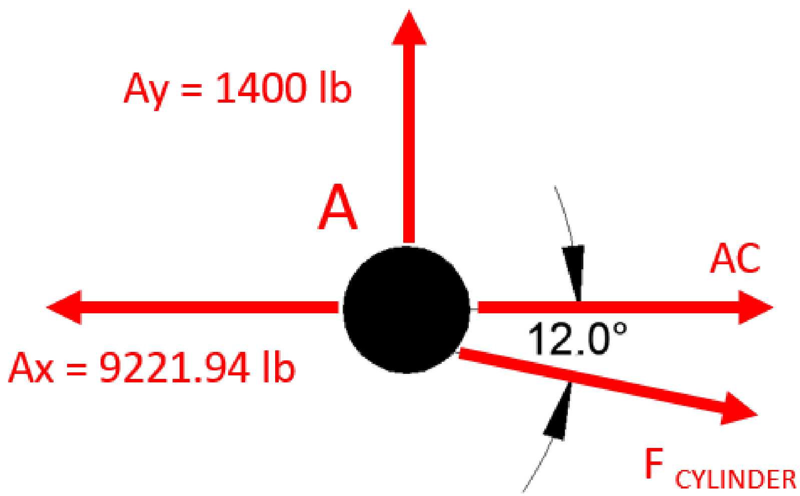


Figure 42. FBD Pin A

$\uparrow \sum F_Y = 0$

$0 = 1400 - \sin 12 \times F_{CYLINDER}$

$F_{CYLINER} = \dfrac{1400}{\sin 12}$

$F_{CYLINDER} = 6733.63\ lb\ (Tension)$

$\rightarrow \sum F_X = 0$

$0 = AC + \cos 12 \times F_{CYLINDER} - 9221.94$

$AC + \cos 12 \times 6733.63 - 9221.94 = 0$

$AC = 9221.94 - \cos 12 \times 6733.63$

$AC = 2635.46\ lb(Tension)$

Member AC, which is a top parallel arm, is a two-force member. Tension applies to a member AC.

2.1.3.3 FBD Member AC

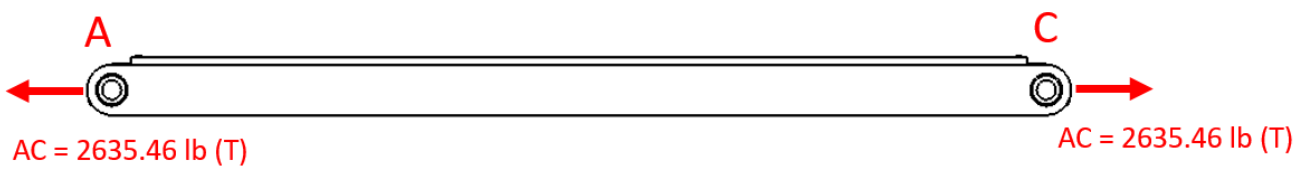


Figure 43. FBD Top Parallel Arm

2.1.3.4 FBD Pin B

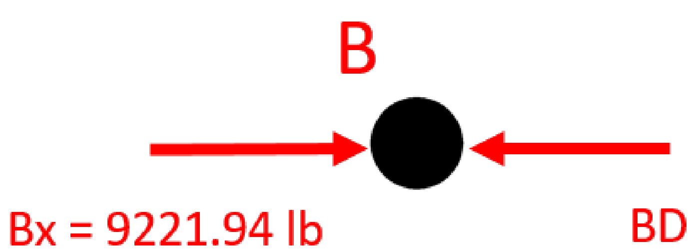


Figure 44. FBD Pin B

$\rightarrow \sum F_X = 0$

$0 = 9221.94 - BD$

$BD = 9221.94\ lb\ (Compression)$

Member BD, which is a bottom parallel arm, is a two-force member. Compression applies to member BD.

2.1.3.5 FBD Top Parallel Arm

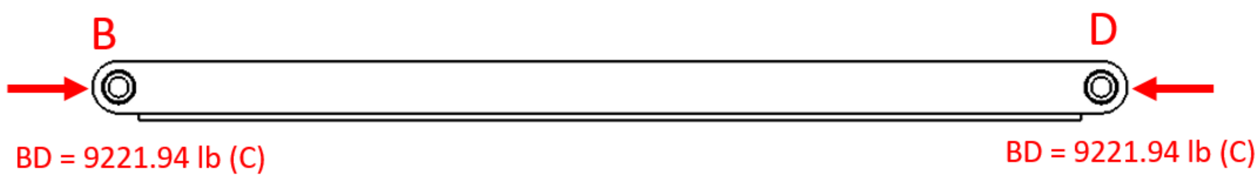


Figure 45. FBD Bottom Parallel Arm

2.1.3.6 FBD Pin C

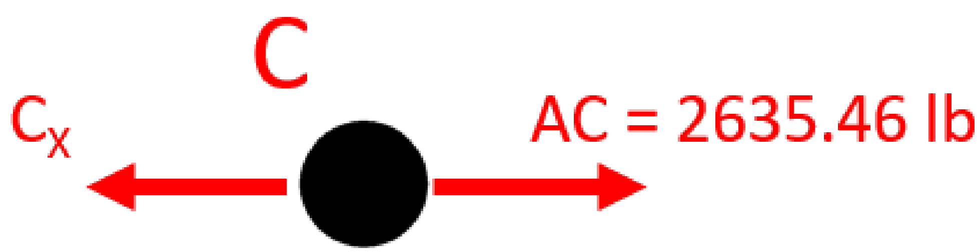


Figure 46. FBD Pin C

$\rightarrow \sum F_X = 0$

$0 = -C_X + 2635.46$

$C_X = 2635.46\ lb\ \leftarrow$

2.1.3.7 FBD Pin D

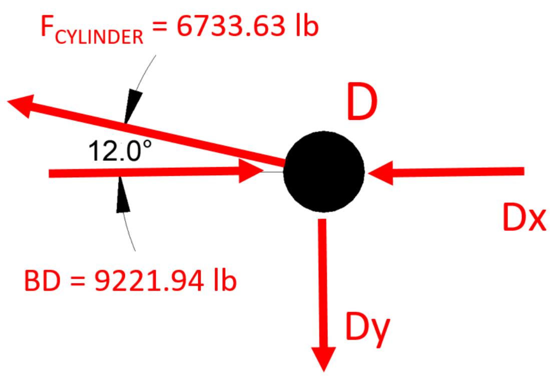


Figure 47. FBD Pin D

$\rightarrow \sum F_X = 0$

$0 = -D_X - \cos 12 \times 6733.63 + 9221.94$

$D_X = -\cos 12 \times 6733.63 + 9221.94$

$D_X = 2635.46\ lb \leftarrow$

$\uparrow \sum F_Y = 0$

$0 = -D_Y + \sin 12 \times 6733.63$

$\mathrm{D_Y} = \sin 12 \times 6733.63$

$D_Y = 1400\ lb\ \downarrow$

Up until this point, calculations have no error. Therefore, the values calculated until this phase were used to analyze stress calculation for Pin A, B, C, D, top parallel arm and bottom parallel arm.

2.1.3.8 FBD Bridge Plate

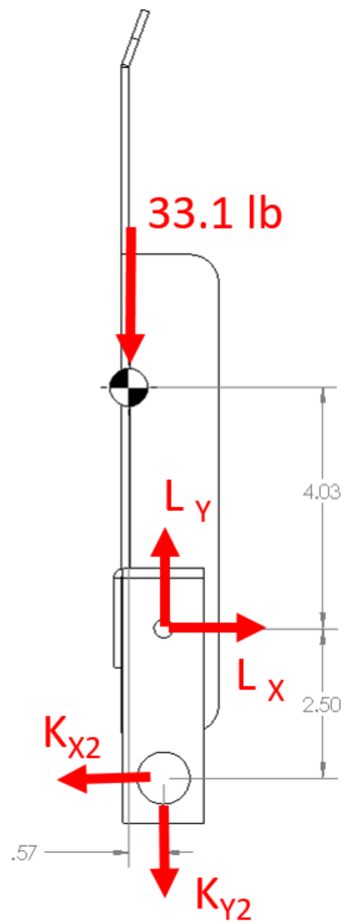


Figure 48. FBD Bridge Plate

$\rightarrow \sum F_X = 0$

$0 = L_X - K_{X2}$

$L_X - K_{X2} = 0$

$\uparrow \sum F_Y = 0$

$0 = -K_{Y2} + L_Y - 33.1$

$-K_{Y2} + L_Y = 33.1$

$\circlearrowleft \sum M_L = 0$

$0 = 33.1 \times 0.57 - 2.5 \times K_{X2}$

$2.5 \cdot K_{X2} = 18.867$

2.1.3.9 FBD Handrail

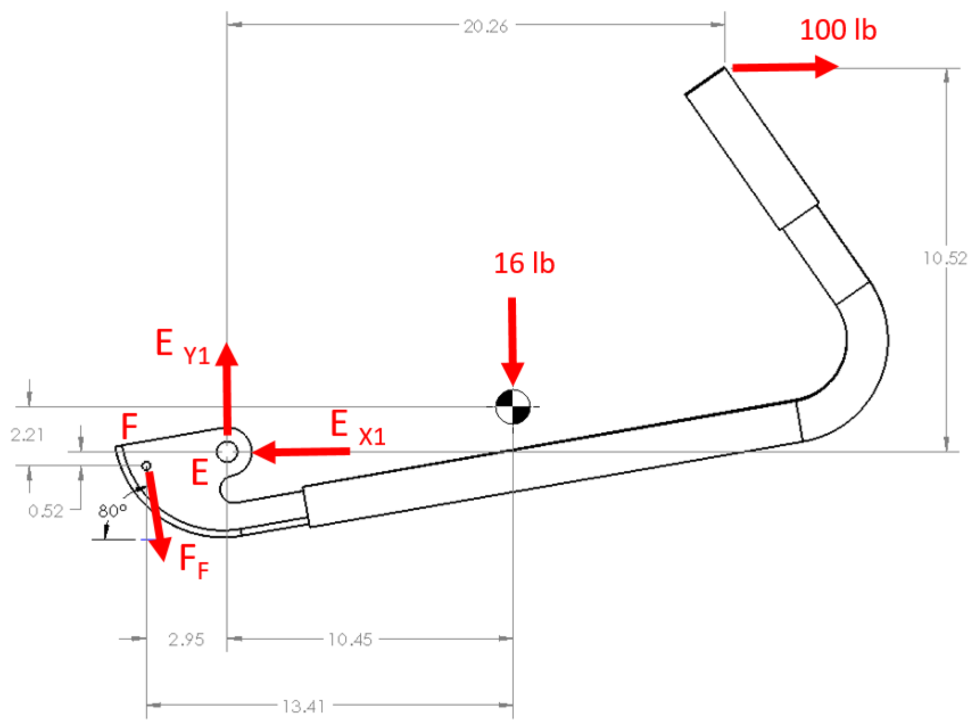


Figure 49. FBD Handrail

100 lb is an external load due to the people holding the handrail.

$\rightarrow \sum F_X = 0$

$0 = -E_{X1} + \cos 80 \times F_F + 100$

$-E_{X1} + 0.1736 \cdot F_F = -100$

$\uparrow \sum F_Y = 0$

$0 = E_{Y1} - 16 - \sin 80 \times F_F$

$E_{Y1} - 0.9848 \cdot F_F = 16$

$\circlearrowleft \sum M_E = 0$

$0 = -16 \times 10.45 + cos80 \times F_F \times 0.52 + \sin 80 \times F_F \times 2.95 - 100 \times 10.52$

$$F_F = \frac{16 \times 10.45 + 100 \times 10.52}{\cos 80 \times 0.52 + \sin 80 \times 2.95}$$

$F_F = 407.013\ lb$

2.1.3.10 FBD Horizontal Pivot Arm

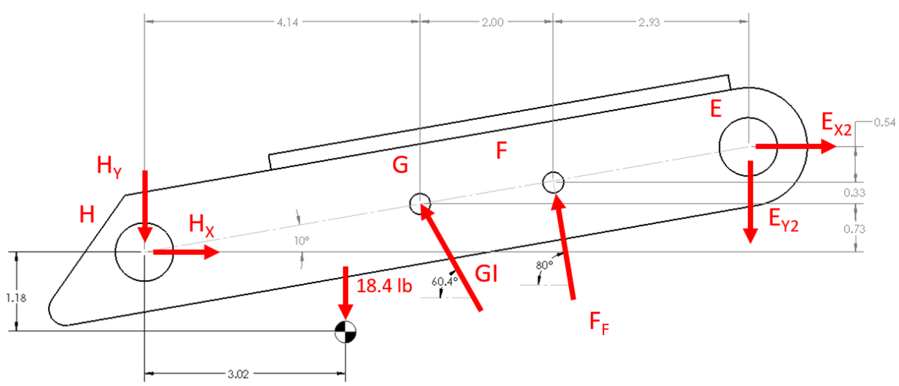


Figure 50. FBD Horizontal Pivot Arm

The location of a center of gravity and weight contains a horizontal pivot arm and member GI. That is the reason why the center of gravity looks like to locate out of the center of the part.

$\rightarrow \sum F_X = 0$

$0 = H_X - \cos 60.4 \times G_I - \cos 80 \times F_F + E_{X2}$

$H_X - 0.4939 \cdot G_I - 0.1736 \cdot F_F + E_{X2} = 0$

$\uparrow \sum F_Y = 0$

$0 = -H_Y - 18.4 + \sin 60.4 \times GI + \sin 80 \times F_F - E_{Y2}$

$-H_Y + 0.8695 \cdot GI + 0.9848 \cdot F_F - E_{Y2} = 18.4$

$\circlearrowleft \sum M_H = 0$

$$0 = -18.4 \times 3.02 + \cos 60.4 \times GI \times 0.73 + \sin 60.4 \times GI \times 4.14 + \cos 80 \times F_F \times 1.06 + \sin 80 \times F_F \times 6.14 - 1.6 \times E_{X2} - 9.07 \times E_{Y2}$$

$3.96 \cdot GI + 6.23 \cdot F_F - 1.6 \cdot E_{X2} - 9.07 \cdot E_{Y2} = 55.568$

2.1.3.11 FBD Vertical Pivot Arm

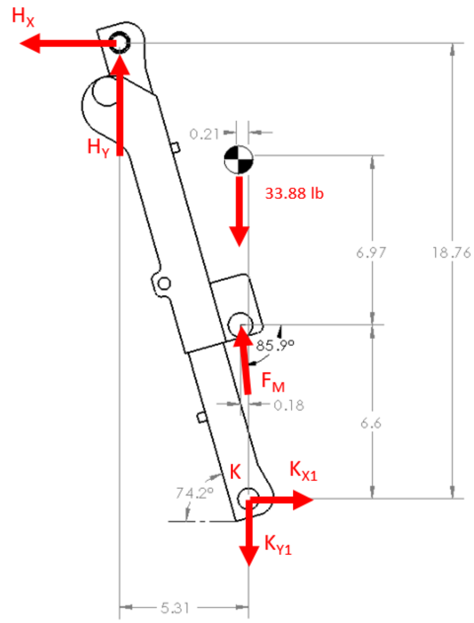


Figure 51. FBD Vertical Pivot Arm

$\rightarrow \sum F_X = 0$

$0 = -H_X - \cos 85.9 \times F_M + K_{X1}$

$-H_X - 0.0715 \cdot F_M + K_{X1} = 0$

$\uparrow \sum F_Y = 0$

$0 = H_Y - 33.88 - \sin 85.9 \times F_M - K_{Y1}$

$H_Y - 0.9974 \cdot F_M - K_{Y1} = 33.88$

$\circlearrowleft \sum M_K = 0$

$0 = 18.76 \times H_X - 5.31 \times H_Y + 33.88 \times 0.21 + 6.6 \times \cos 85.9 \times F_M - 0.18 \times \sin 85.9 \times F_M$

$18.76 \cdot H_X - 5.31 \cdot H_Y + 0.2923 \cdot F_M = -7.1148$

2.1.3.12 FBD Slot

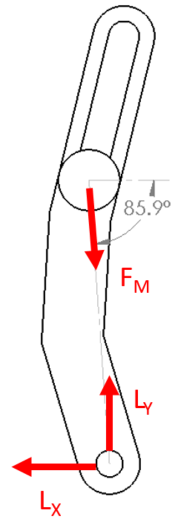


Figure 52. FBD Slot

Compression applies to a slot. It means the slot can be assumed as a two-force member when the lift is down.

$$\rightarrow \sum F_X = 0$$

$$0 = \cos 85.9 \times F_M - L_X$$

$$0.0715 \cdot F_M - L_X = 0$$

$$\uparrow \sum F_Y = 0$$

$$0 = -\sin 85.9 \times F_M + L_Y$$

$$-0.9974 \cdot F_M + L_Y = 0$$

2.1.3.13 FBD Vertical Arm

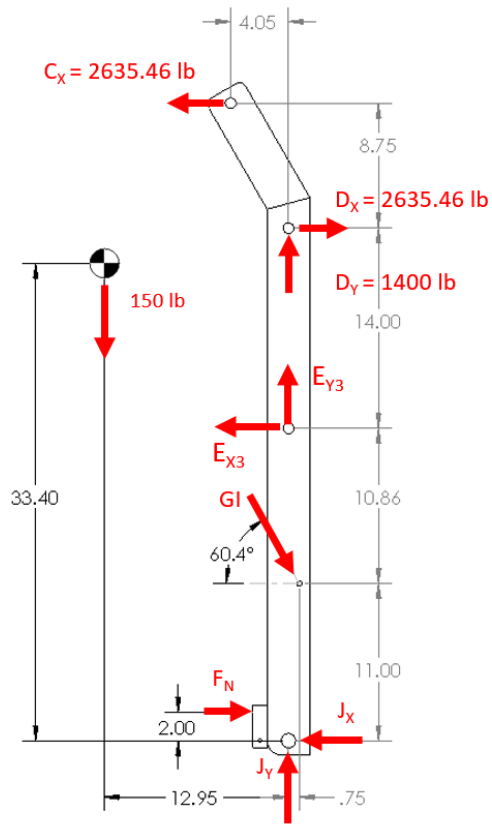


Figure 53. FBD Vertical Arm

The weight contains a vertical arm, hydraulic cylinder, top parallel arm and bottom parallel arm.

$\rightarrow \sum F_X = 0$

$0 = -C_X + D_X - E_{X3} + \cos 60.4 \times GI + F_N - J_X$

$-C_X + D_X - E_{X3} + 0.4939 \cdot GI + F_N - J_X = 0$

$\uparrow \sum F_Y = 0$

$0 = D_Y + E_{Y3} - 150 - \sin 60.4 \times GI + J_Y$

$D_Y + E_{Y3} - 0.8695 \cdot GI + J_Y = 150$

$\circlearrowleft \sum M_E = 0$

$$0 = 22.75 \times C_X - 14 \times D_X - \sin 60.4 \times GI \times 0.75 + \cos 60.4 \times GI \times 10.86 + 19.86 \times F_N - 21.86 \times J_X + 150 \times 12.95$$

$$22.75 \cdot C_X - 14 \cdot D_X + 4.712 \cdot GI + 19.86 \cdot F_N - 21.86 \cdot J_X = -1942.5$$

2.1.3.14 FBD Platform

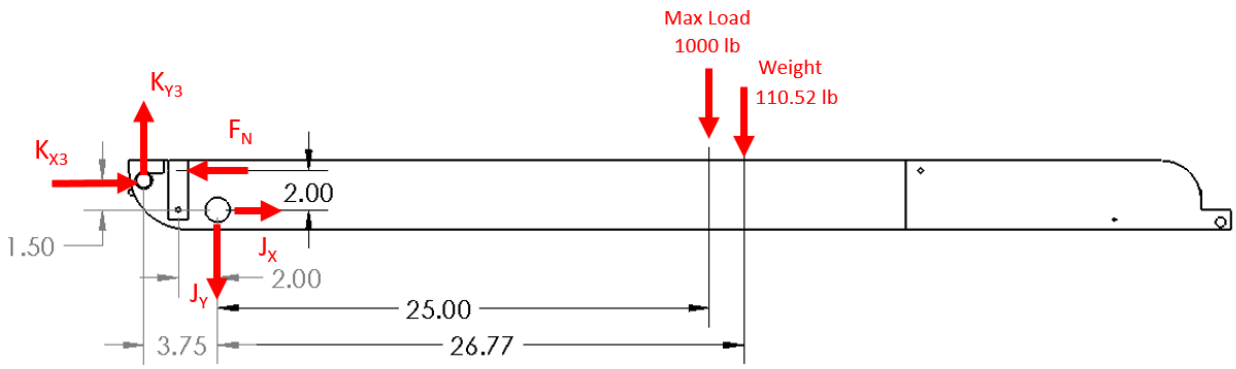


Figure 54. FBD Platform

$\rightarrow \sum F_X = 0$

$$0 = K_{X3} - F_N + J_X$$

$$K_{X3} - F_N + J_X = 0$$

$\uparrow \sum F_Y = 0$

$$0 = K_{Y3} - J_Y - 1000 - 110.52$$

$$K_{Y3} - J_Y = 1110.52$$

$\circlearrowleft \sum M_J = 0$

$0 = -3.75 \times K_{Y3} - 1.5 \times K_{X3} + 2 \times F_N - 1000 \times 25 - 110.52 \times 26.77$

$-3.75 \cdot K_{Y3} - 1.5 \cdot K_{X3} + 2 \cdot F_N = 27958.62$

Bluebit Matrix calculator gives unrealistic high value when this equation is used. Therefore, the following equation is used to remove the error. It causes rotate motion of the platform, but not affect other components. The forces in the platform will be redistributed in the stress analysis section to make close to the equilibrium state.

$2 \cdot F_N = 27958.62$

2.1.3.15 Additional Equation

Both point E and K are connected with three components. The sum of forces acting on these points has to be zero. Therefore, the following additional equations are required to make an equilibrium state.

$-E_{X1} + E_{X2} - E_{X3} = 0$

$E_{Y1} - E_{Y2} + E_{Y3} = 0$

$K_{X1} - K_{X2} + K_{X3} = 0$

$-K_{Y1} - K_{Y2} + K_{Y3} = 0$

2.1.3.16 Result

From FBD Bridge Plate to FBD Platform, equations were input into the matrix. However, there were two redundant equations and it caused minor errors, but it is still allowable. The appendix shows the used matrix. The following table shows the direction and magnitude of forces applied to each point.

Table 2. Calculated Forces

Location & Direction	Force (lbs)	Location & Direction	Force (lbs)
C_X	2644.55	H_Y	1375.23
C_Y	0.00	J_X	14408.04
D_X	2626.37	J_Y	178.90
D_Y	1396.15	K_{X1}	418.09
E_{X1}	161.57	K_{Y1}	978.59
E_{Y1}	420.68	K_{X2}	7.55
E_{X2}	953.63	K_{Y2}	318.54
E_{Y2}	1216.53	K_{X3}	419.63
E_{X3}	801.15	K_{Y3}	1293.27
E_{Y3}	791.99	L_X	16.64
F_F	407.01	L_Y	355.49
GI	2545.35	F_M	359.84
H_X	383.27	F_N	13979.31

2.2 Stress Analysis

2.2.1 Top Parallel Arm (Member AC)

2.2.1.1 General Information

Figure 55. Member AC

Member AC is a two-force member and maximum force is acting when the lift is up. From force analysis, the maximum force 2833.51 lb is applied to the member, which is tension. However, there are two components. Therefore, 1416.75 lb is applied to each member.

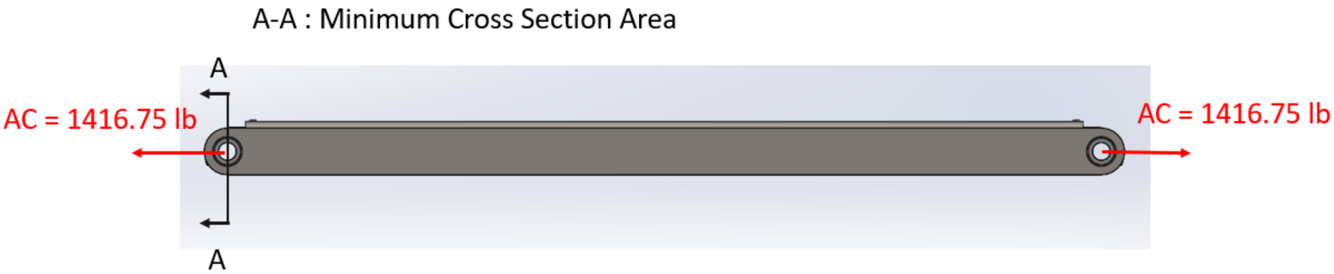


Figure 56. Applied Force on Member AC

2.2.1.2 Section Property

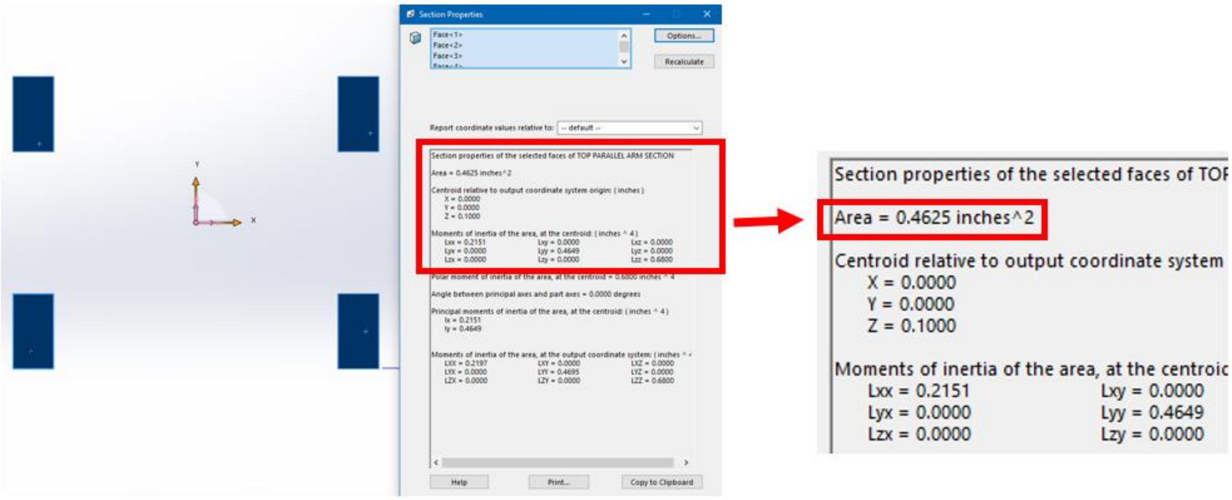


Figure 57. Cross-Section Property

2.2.1.3 Axial Stress

$$\sigma_{Nom} = \frac{F}{A}$$

$$= \frac{1416.76}{0.4625}$$

$$= 3063.26\, psi$$

Where, (1 Mott, p. 23)

$\sigma_{Nom} = Nominal\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

Selected Material: 1020 Annealed, Su = 57ksi, Sy = 43ksi (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{3060} = 14.0$$

2.2.1.4 Conclusion

The selected material is 1020 annealed. Only axial stress is applied to a member, the safety factor from which is 14.03. Therefore, the part is safety.

2.2.2 Bottom Parallel Arm (Member BD)

2.2.2.1 General Information

Figure 58.Member BD

Member BD is a two-force member and the maximum force is acting when the lift is down. From force analysis, the maximum force 9221.94 lb is applied to the member, which is compression. However, there are two components. Therefore, 4610.97 lb is applied to each member.

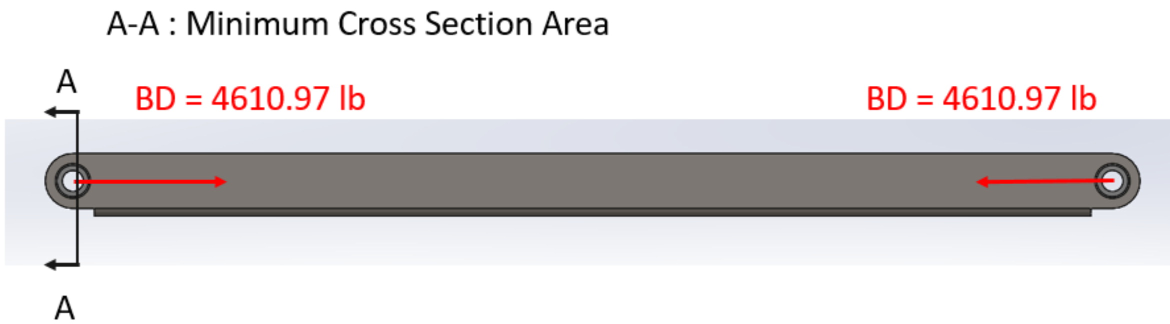


Figure 59.Applied Force on Member BD

2.2.2.2 Section Property

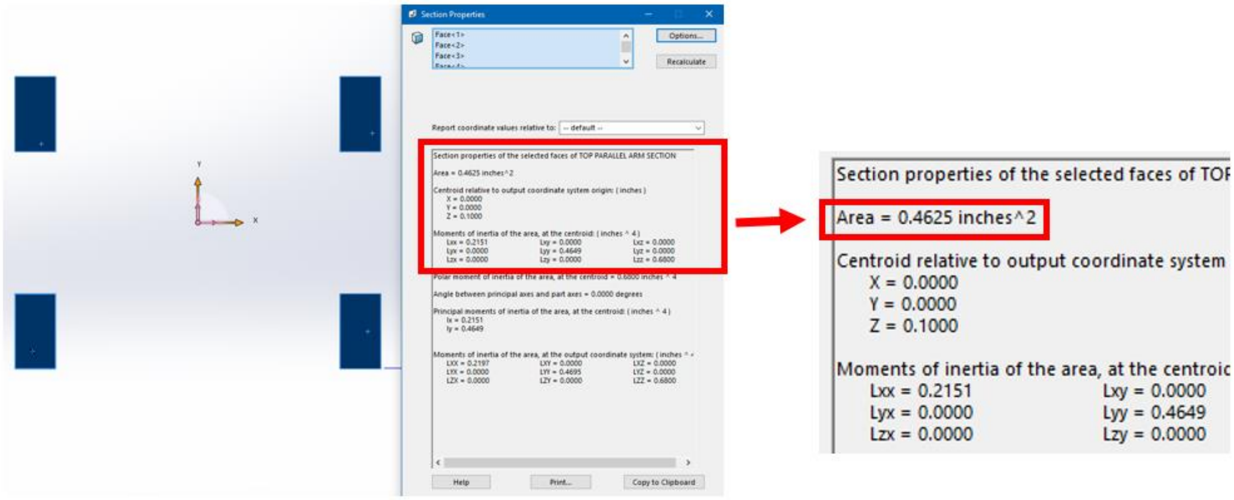


Figure 60. Cross-Section Property

2.2.2.3 Stress Analysis

$$\boldsymbol{\sigma_{Nom}} = \frac{\boldsymbol{F}}{\boldsymbol{A}}$$

$$= \frac{4610.97}{0.4625}$$

$$= 9969.66\, psi$$

Where, (1 Mott, p. 23)

$\sigma_{Nom} = Nominal\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

Selected Material: 1020 Annealed , Su = 57ksi, Sy = 43ksi (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{9970} = 4.31$$

2.2.2.4 Conclusion

The selected material is 1020 annealed. Only axial stress is applied to a member, the safety factor from which is 4.31. Therefore, the part is safety.

2.2.3 Horizontal Pivot Arm

2.2.3.1 General Information

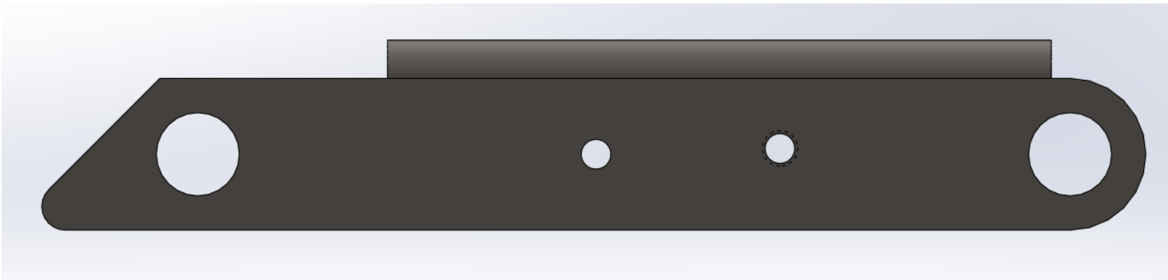


Figure 61.Horizontal Pivot Arm

Horizontal pivot arm connects a vertical arm to vertical pivot arm and supports a handrail not to rotate. The member is tilted ten degrees when force was analyzed. Therefore, it is required to rotate ten-degree opposite direction to perform the stress analysis. In addition to that, two members support the forces, which means only half of the forces are applied to the component.

Table 3. Revised Forces

Location	Force (lb)	Half Force (lb)
E_{X2}	953.63	476.81
E_{Y2}	1216.53	608.26
F_F	407.01	203.51
GI	2545.35	1272.67
H_X	383.27	191.64
H_Y	1375.23	687.61

2.2.3.2 Force Revision

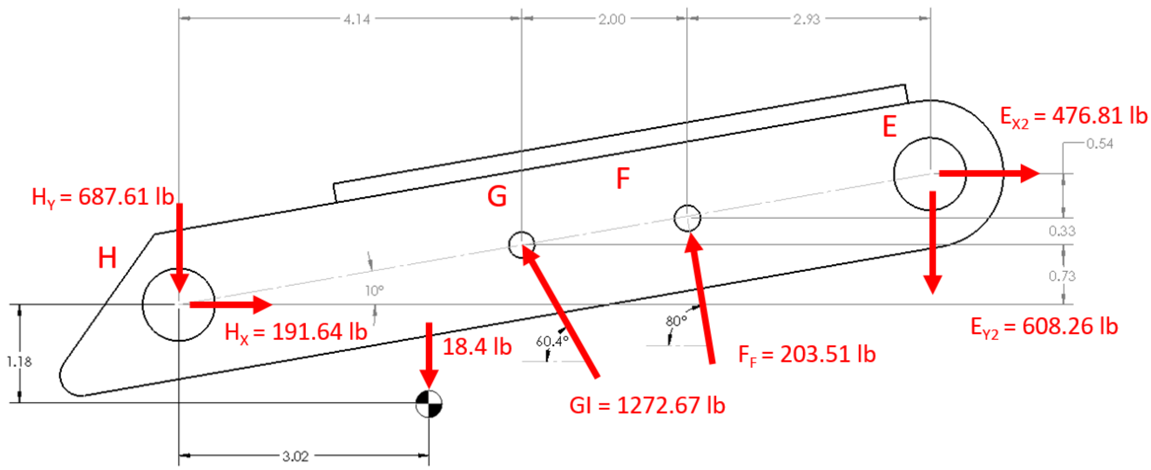


Figure 62. Applied Forces on Tilted Member

$$H_Y' = H_Y \times \cos 10 + H_X \times \sin 10$$

$$= 687.61 \times \cos 10 + 191.64 \times \sin 10$$

$$= 710.44\ lb$$

$$H_X' = -H_Y \times \sin 10 + H_X \times \cos 10$$

$$= -687.61 \times \sin 10 + 191.64 \times cos 10$$

$$= 69.33\ lb$$

$$Weight_X = 18.4 \times \sin 10 = 3.2\ lb$$

$$Weight_Y = 18.4 \times \cos 10 = 18.12\ lb$$

$$GI_X = GI \times \cos 60.4 = 1272.67 \times \cos 60.4 = 628.62\ lb$$

$$GI_Y = GI \times \sin 60.4 = 1272.67 \times \sin 60.4 = 1106.58\ lb$$

$GI'_X = GI_X \times \cos 10 - GI_Y \times \sin 10$

$= 628.62 \times \cos 10 - 1106.58 \times \sin 10$

$= 426.92\ lb$

$GI'_Y = GI_X \times \sin 10 + GI_Y \times \cos 10$

$= 628.62 \times \sin 10 + 1106.58 \times \cos 10$

$= 1198.93\ lb$

$F'_Y = F_F \times \sin(80 + 10) = 203.51 \times \sin 90$

$= 203.51\ lb$

$E'_{X2} = E_{X2} \times \cos 10 - E_{Y2} \times \sin 10$

$= 476.81 \times \cos 10 - 608.26 \times \sin 10$

$= 363.94\ lb$

$E'_{Y2} = E_{X2} \times \sin 10 + E_{Y2} \times \cos 10$

$= 476.81 \times \sin 10 + 608.26 \times \cos 10$

$= 681.82\ lb$

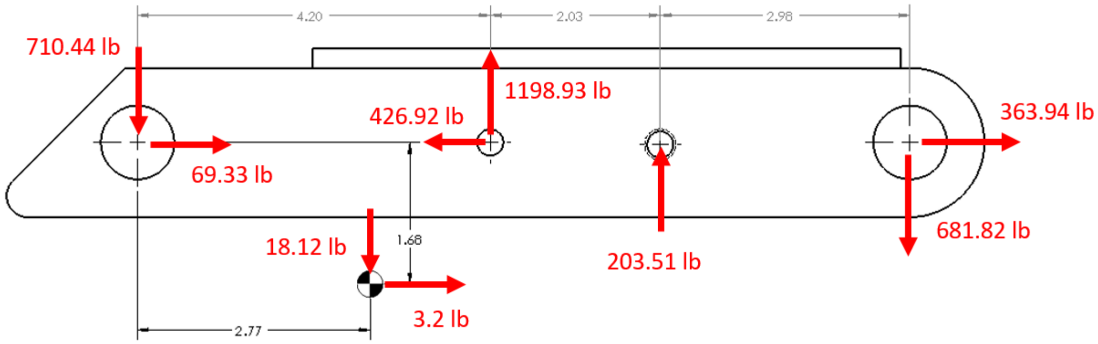


Figure 63. Revised Forces

2.2.3.3 Shear Force and Bending Moment

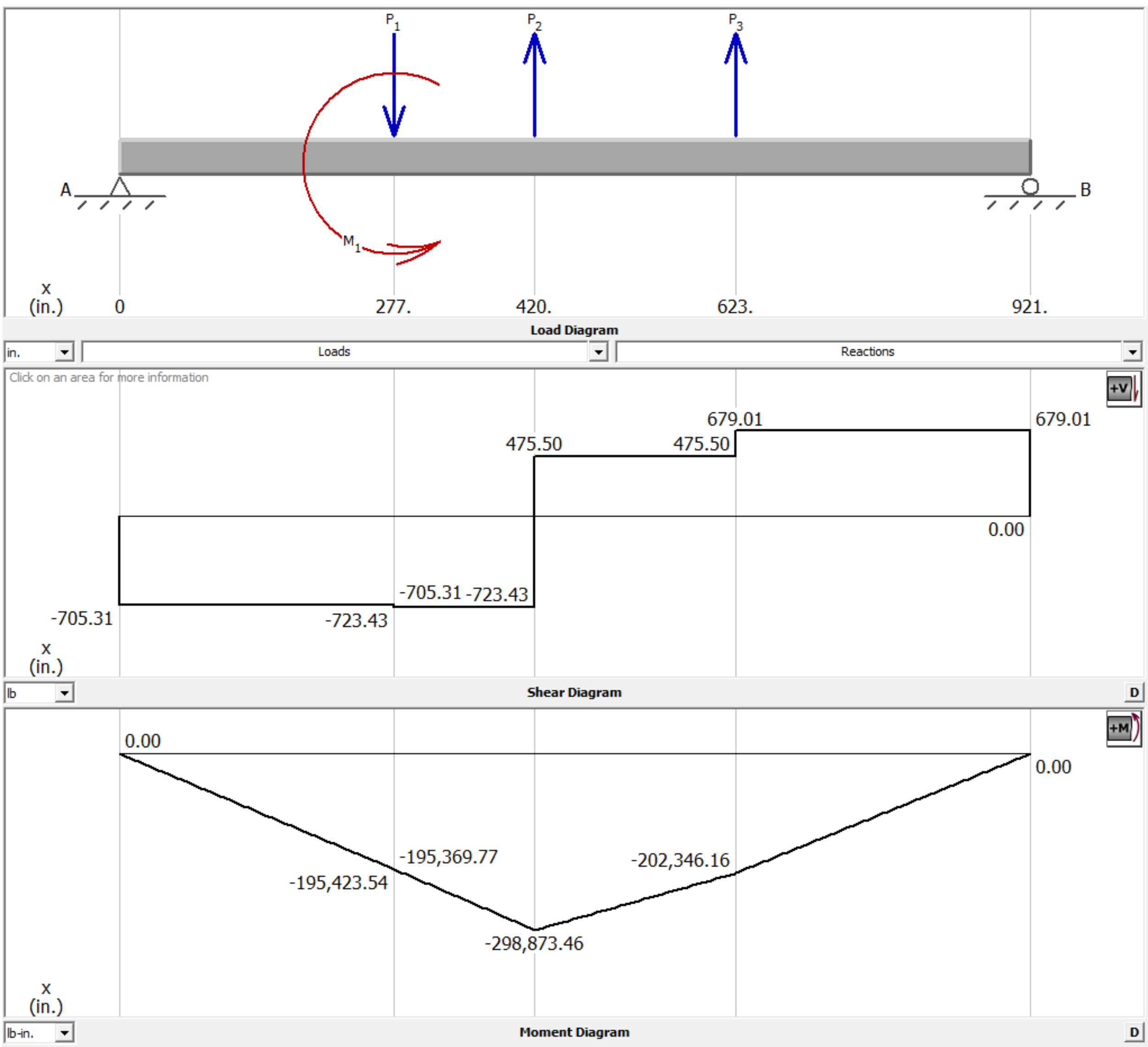


Figure 64. Shear Force and Bending Moment on Horizontal Pivot Arm

Due to the redundant equations in force analysis, there are minor errors and it causes the part isn’t in an equilibrium state. MD Solid adjusts this error by changing reaction forces on the selected support locations. Distances on the graph are adjusted as well, which are a hundred times longer than it is because MD Solid can’t read below two decimal places. It doesn’t affect shear forces, but it does on bending moment. Bending moment is a hundred less than the data on the graph.

2.2.3.4 Section Separation

The following figure shows the sections to be analyzed, which places are likely to have the highest stress.

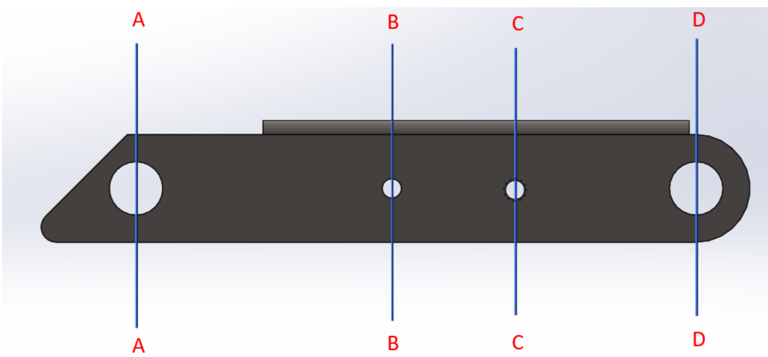


Figure 65. Sections to be Analyzed

2.2.3.5 Section A-A Properties

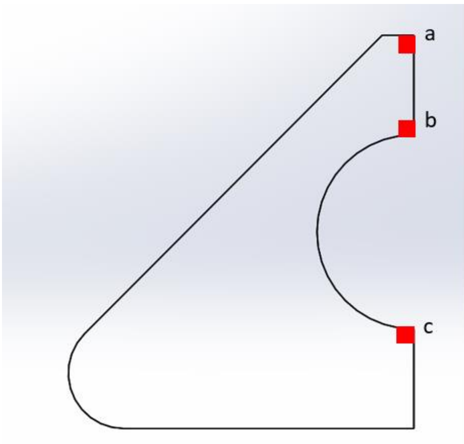


Figure 66. Locations analyzed

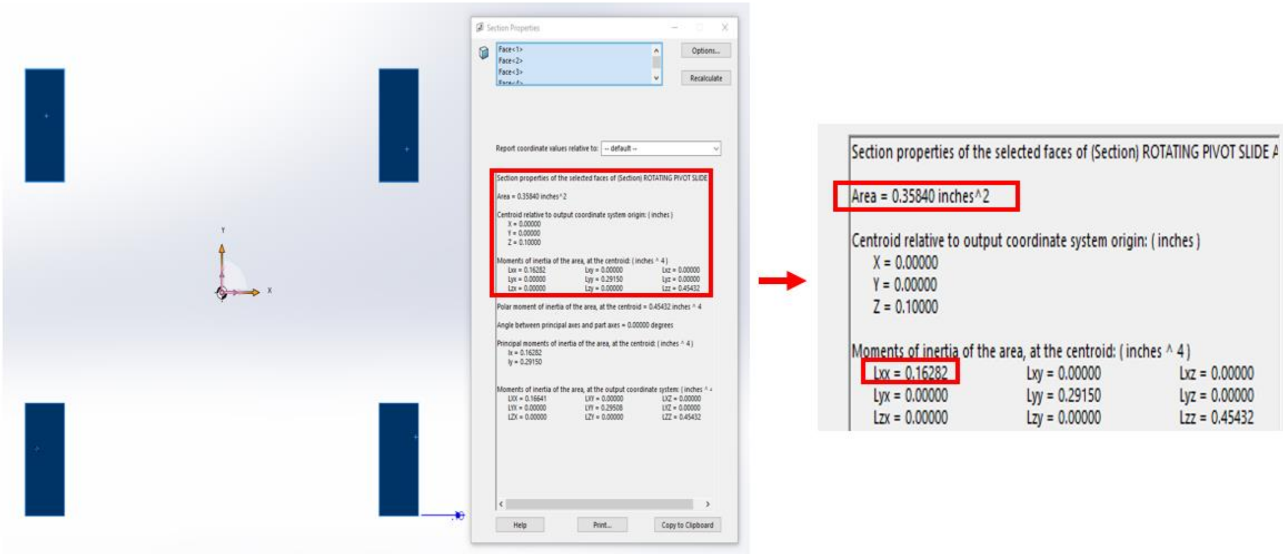


Figure 67. Section A-A Properties

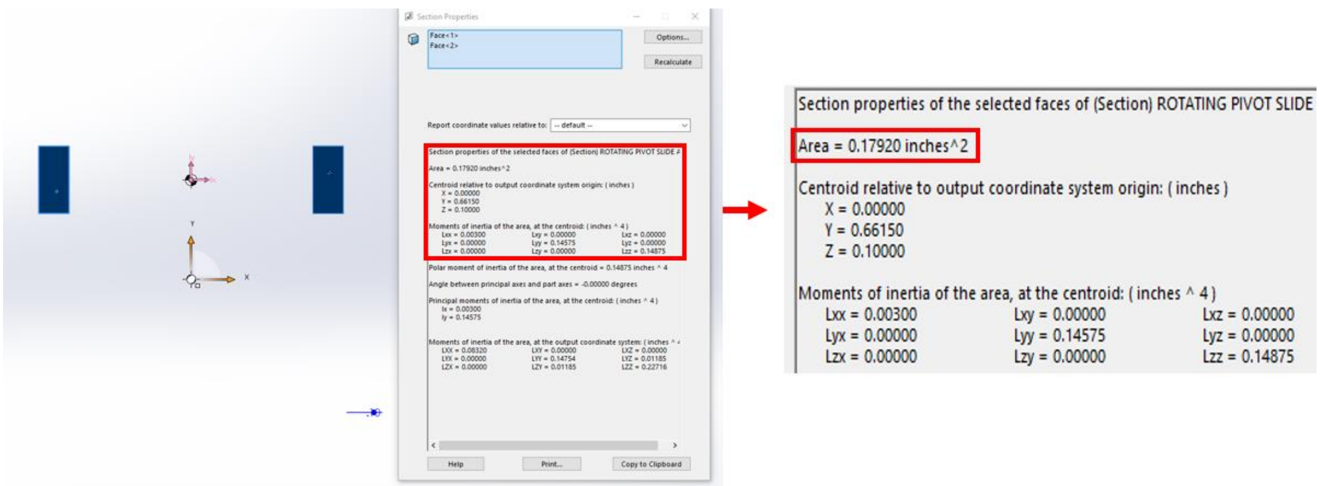


Figure 68. A_P at b on Section A-A

Figure 69. $\overline{Y}$ at b on Section A-A

2.2.3.6 Section A-A Transverse Shear Stress

Transverse shear stress applies to at b and c

$Q = A_P \cdot \overline{Y}$

$= 0.1792\ in^2 \times 0.6615\ in$

$= 0.1185 in^3$

Where, (1 Mott, p. 462)
$Q = First\ moment\ of\ area, in^3$
$A_P = Area\ of\ a\ part\ of\ the\ cross$
$section\ that\ lies\ away\ from\ the\ axis, in^2$
$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$\tau = \frac{VQ}{It}$

$= \frac{705.31\ lb\ \times 0.1185\ in^3}{0.16282\ \text{in}^4\ \times 0.4\ in}$

$= 1283.3\ psi$

Where, (1 Mott, p. 462)
$\tau = Shear\ stress, psi$
$V = Vertical\ shearing\ force, lb$
$I = Moment\ of\ inertia, in^4$
$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.3.7 Section A-A Analysis

<u>Stress at a</u>

a at the section A-A has no stress.

<u>Stress at b</u>

In summary, b at section A-A has 1283.3 psi shear stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$N = \frac{S_u}{\tau} = \frac{57000}{1280} = 44.5$

<u>Stress at c</u>

c at the section A-A has the same stress as b at the section A-A.

2.2.3.8 Section B-B Properties

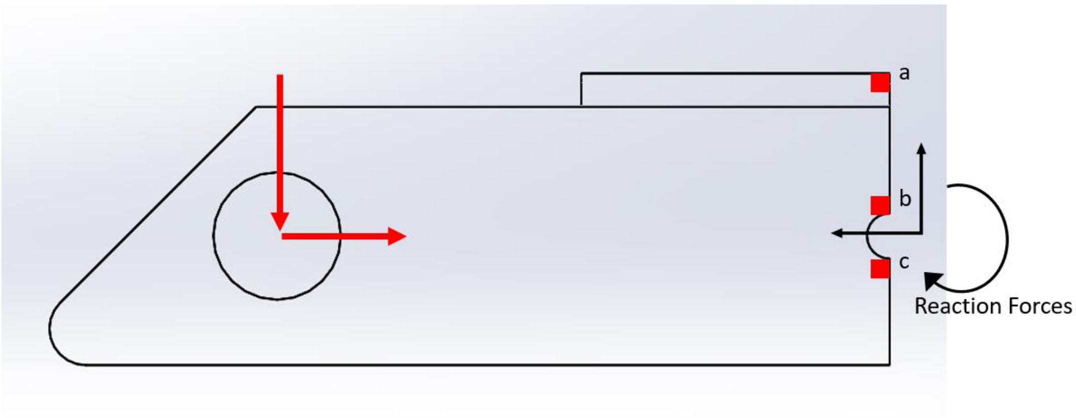


Figure 70. Locations analyzed

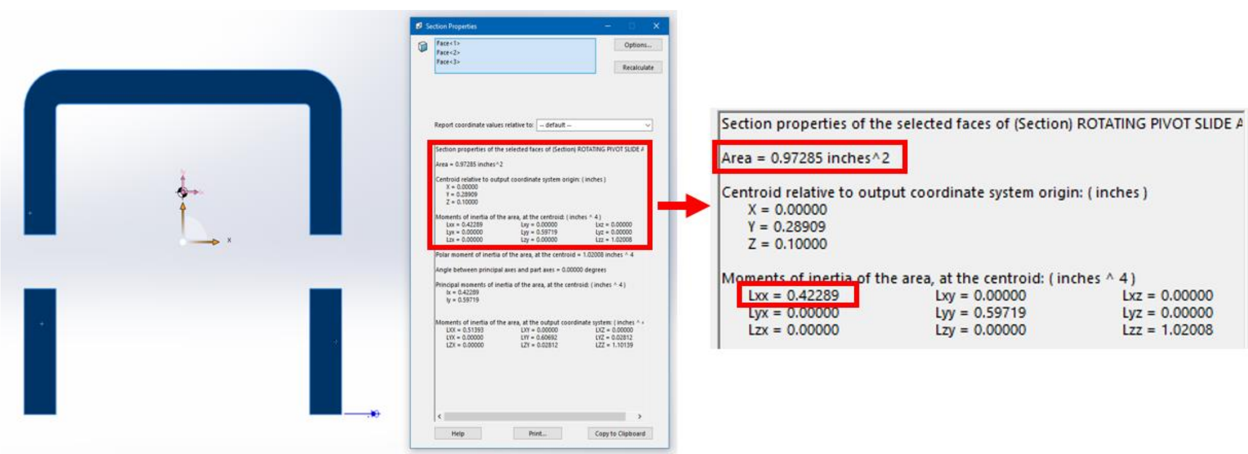


Figure 71. Section B-B Properties

Axial compressive and bending moment stress apply to at a on section B-B.

Axial compressive, bending moment and transverse shear stress apply to at b on section B-B.

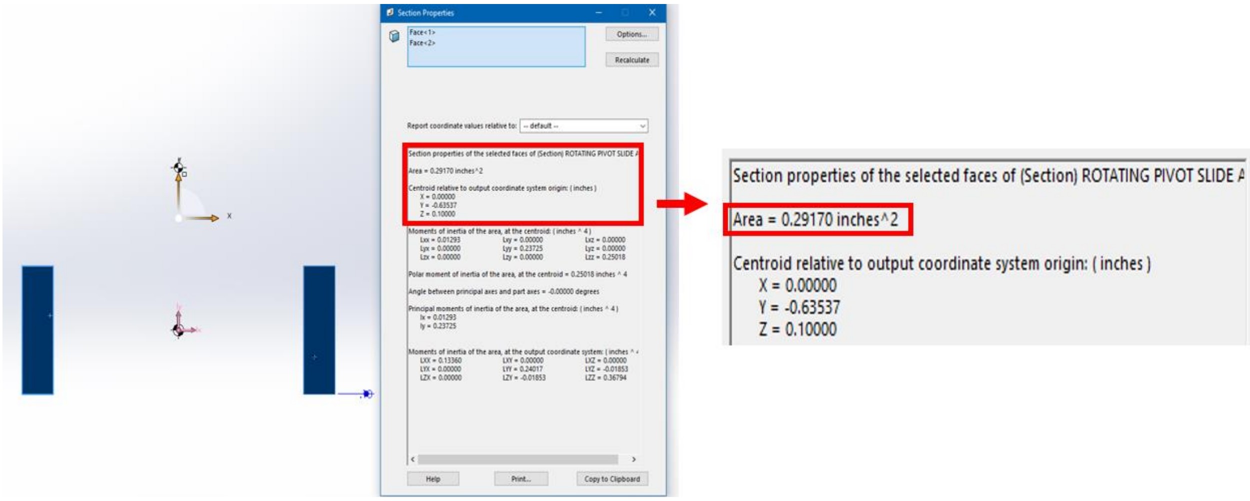


Figure 72. A_P at b on Section B-B

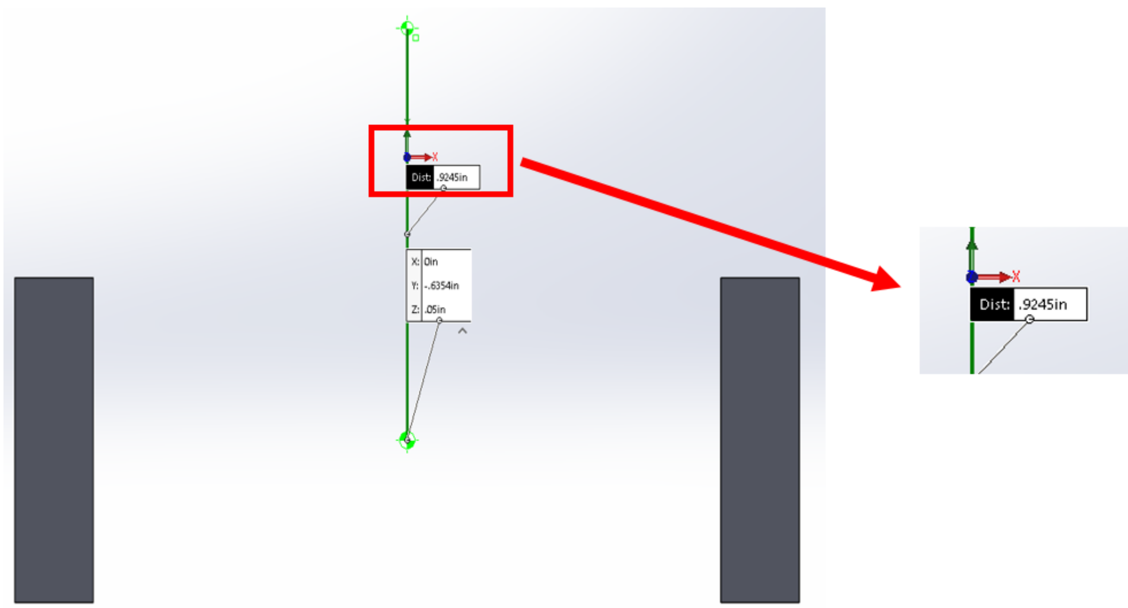


Figure 73. $\overline{Y}$ at b on Section B-B

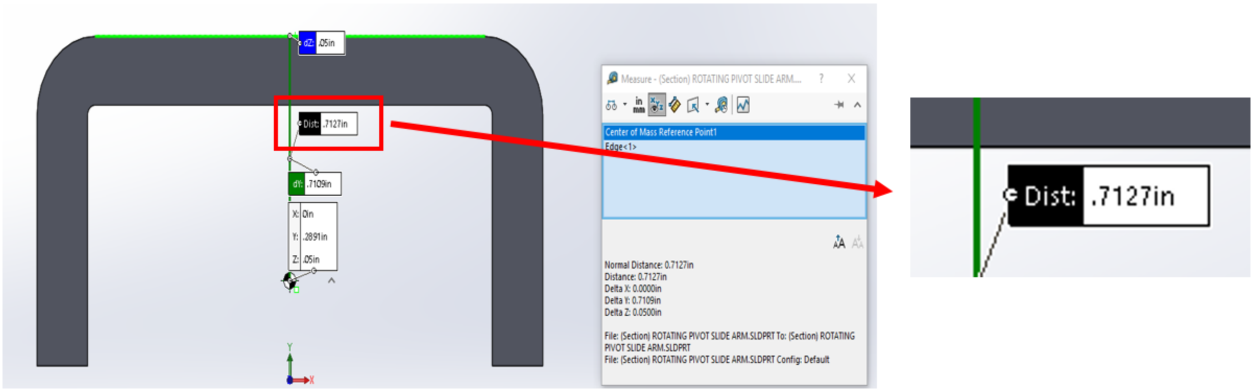


Figure 74. c at a on Section B-B

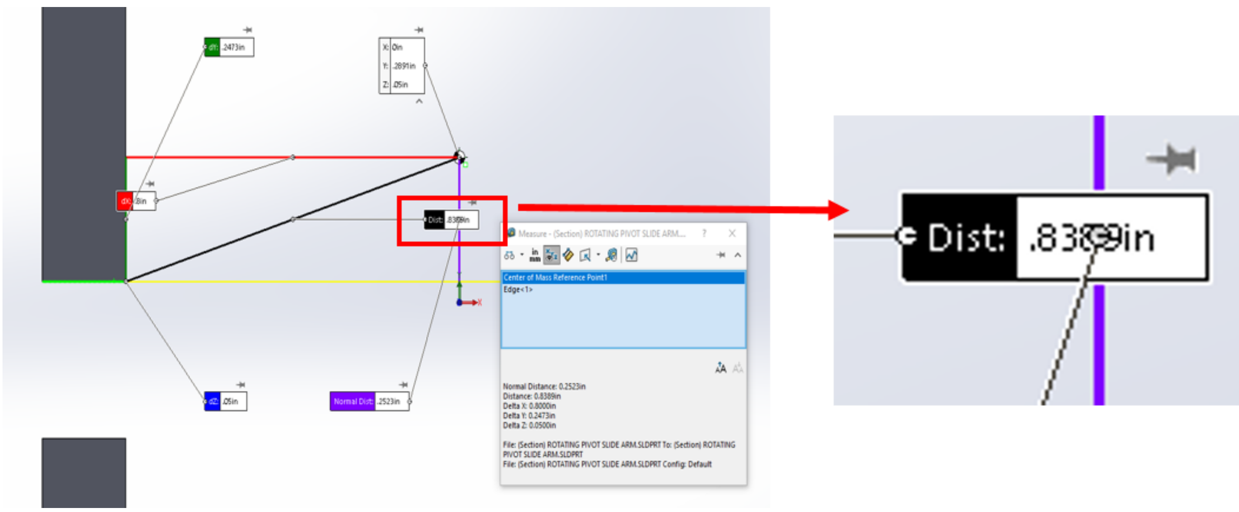


Figure 75. c at b on Section B-B

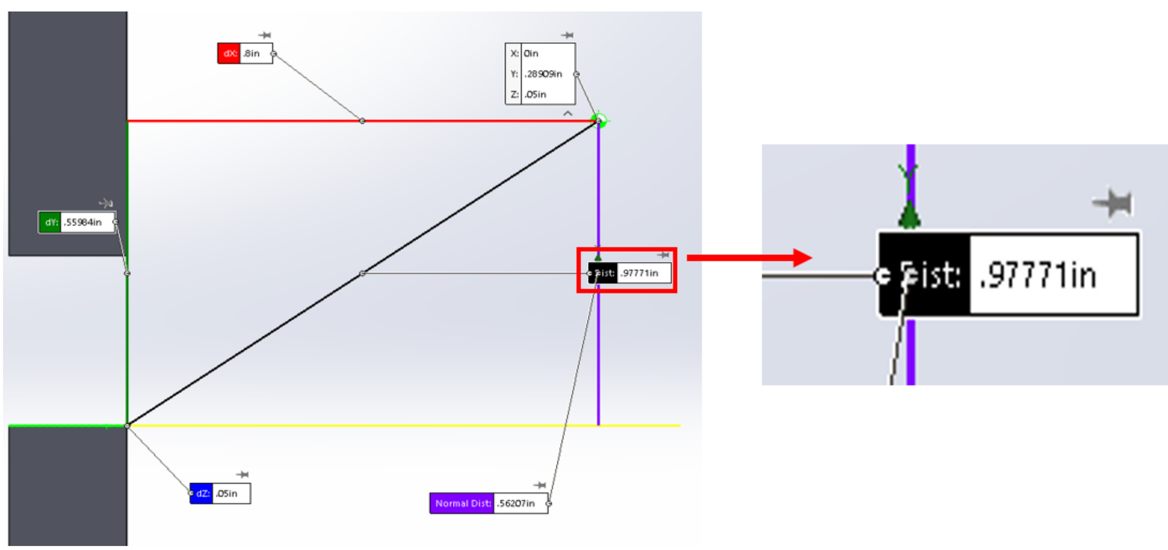


Figure 76. c at c on Section B-B

2.2.3.9 Section B-B Axial Compressive Stress

$$\sigma = \frac{F}{A} = \frac{69.33\ lb}{0.97285\ \text{in}^2} = 71.26\ psi$$

Where, (1 Mott, p. 23)
$\sigma = Axial\ stress, psi$
$F = Force, lbs$
$A = Area, in^2$

2.2.3.10 Section B-B Bending Stress

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

$$= \frac{2989\ lb - in\ \times 0.7127\ in}{0.42289\ \text{in}^4}$$

$$= 5037.39\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)
$\sigma = Axial\ stress, ksi$
$M = Bending\ moment, lb - in$
$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$
$I = Moment\ of\ inertia, in^4$

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

$$= \frac{2989\ lb - in\ \times 0.2473\ in}{0.42289\ \text{in}^4}$$

$$= 1747.92\ psi\ (Compression\ at\ b)$$

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

$$= \frac{2989\ lb - in\ \times 0.5598\ in}{0.42289\ \text{in}^4}$$

$$= 3956.68\ psi\ (Compression\ at\ c)$$

2.2.3.11 Section B-B Transverse Shear Stress

Transverse shear stress applies to at b and c.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.2917\ in^2 \times 0.9245\ in$$

$$= 0.2697 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{723.43\ lb\ \times 0.2697\ in^3}{0.42289\ \text{in}^4\ \times 0.4\ in}$$

$$= 1153.43\ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

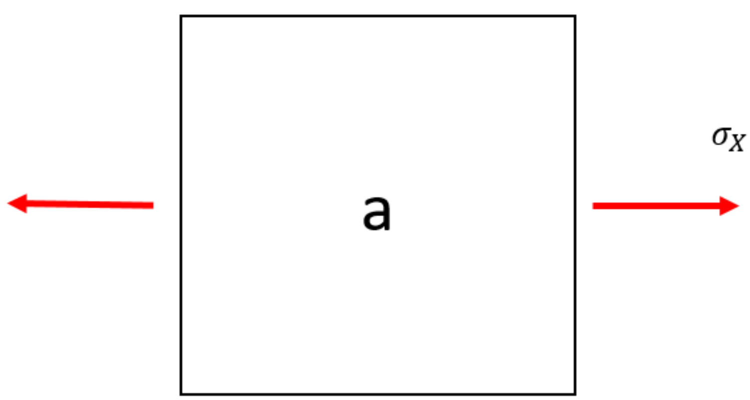
$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.3.12 Section B-B Analysis

<u>Stress at a</u>



$$\sigma_X = 71.26\ psi + 5037.39\ psi$$
$$= 5108.26\ psi$$

Figure 77. Applied Stress at a on Section B-B.

In summary, a at section B-B has 5108.26 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{5110} = 8.4$$

Stress at b

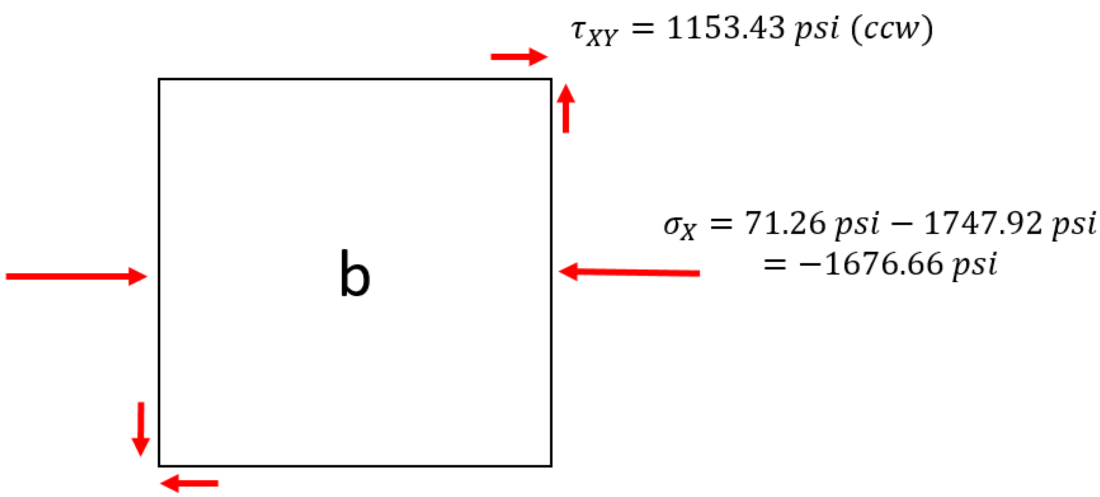


Figure 78. Applied Stress at b on Section B-B.

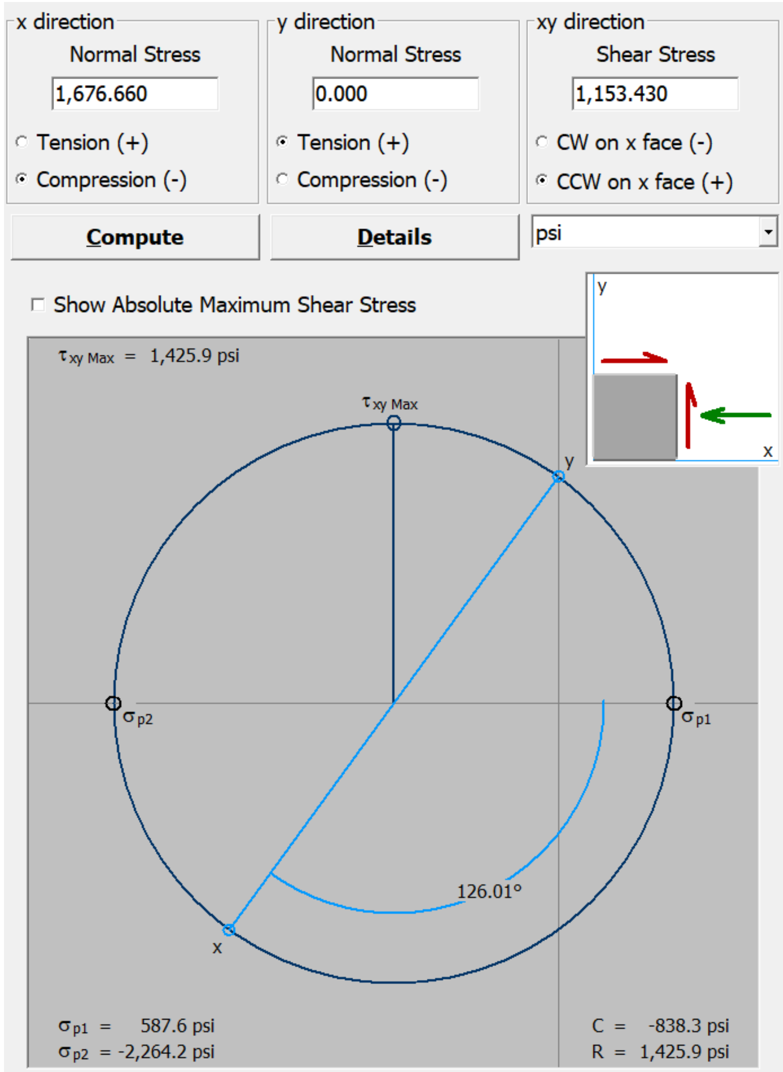


Figure 79. Principal Stress at b on Section B-B

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{587.6^2 + (-2264.2)^2 - 587.6(-2264.2)} = 2608.13\ psi$$

In summary, b at section B-B has $\sigma' = 2608.13\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{2610} = 16.4$$

Stress at c

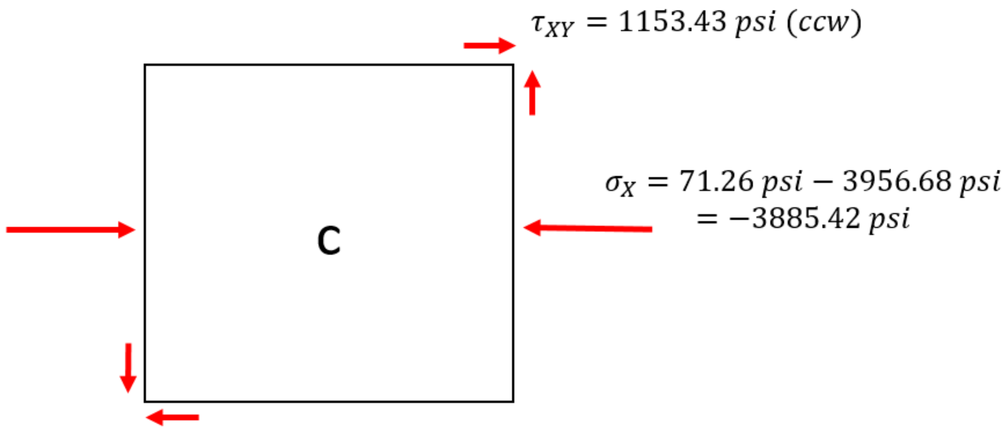


Figure 80. Applied Stress at c on Section B-B.

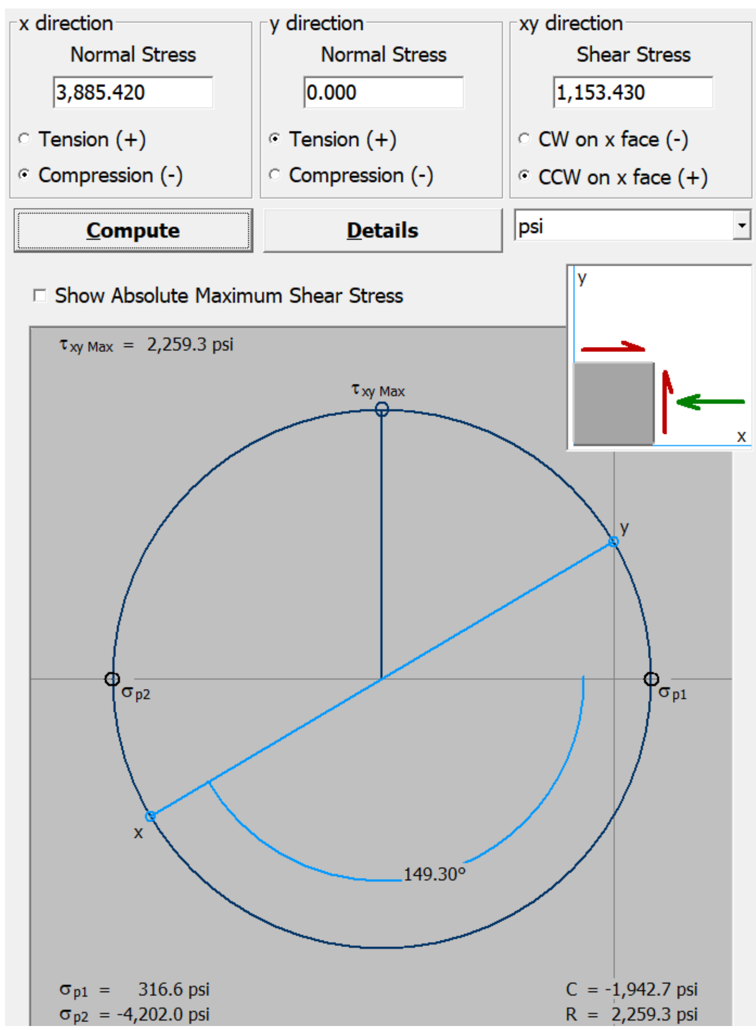


Figure 81. Principal Stress at c on Section B-B

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{316.6^2 + (-4202)^2 - 316.6(-4202)} = 4368.91\ psi$$

In summary, c at section B-B has $\sigma' = 4368.91\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{4370} = 9.8$$

2.2.3.13 Section C-C Properties

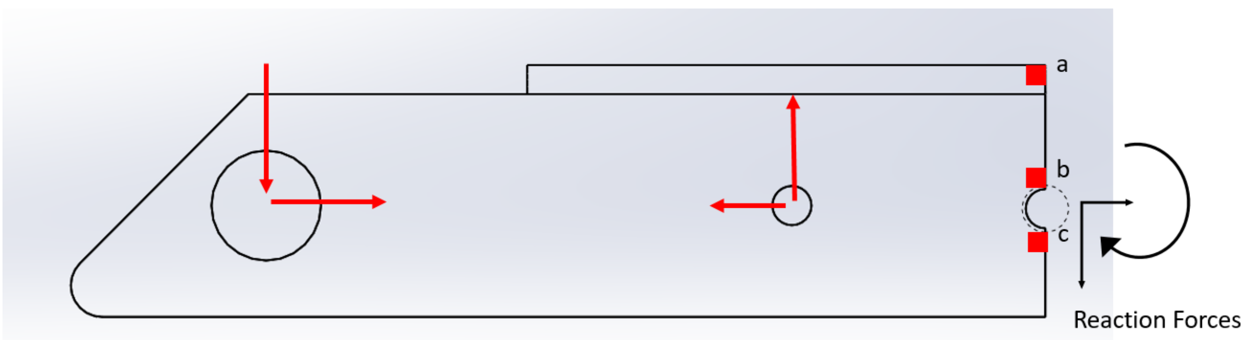


Figure 82. Locations analyzed

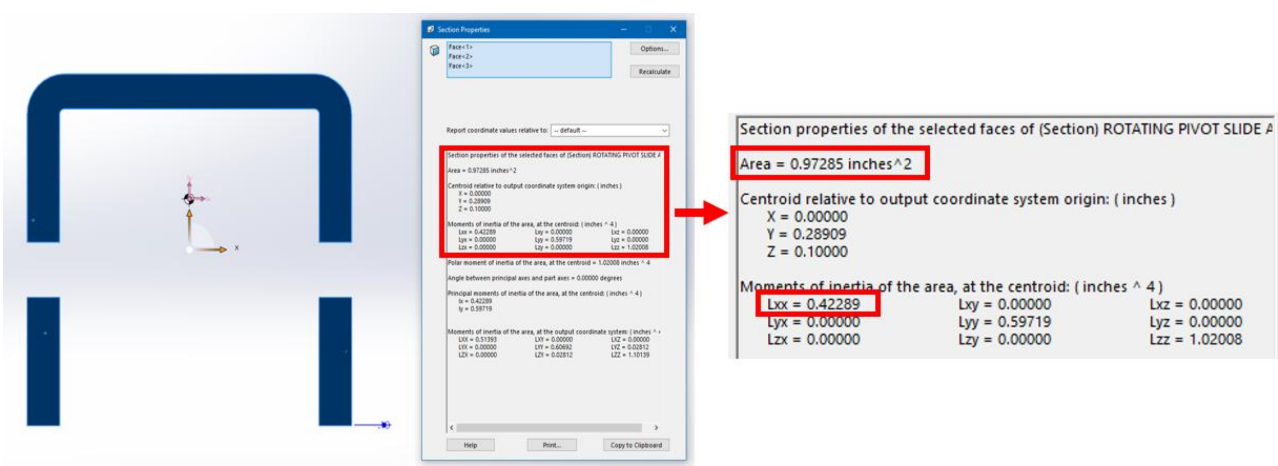


Figure 83. Section C-C Properties

Axial tensile and bending moment stress apply to at a on section C-C.

Axial tensile, bending moment and transverse shear stress apply to at b and c on section C-C.

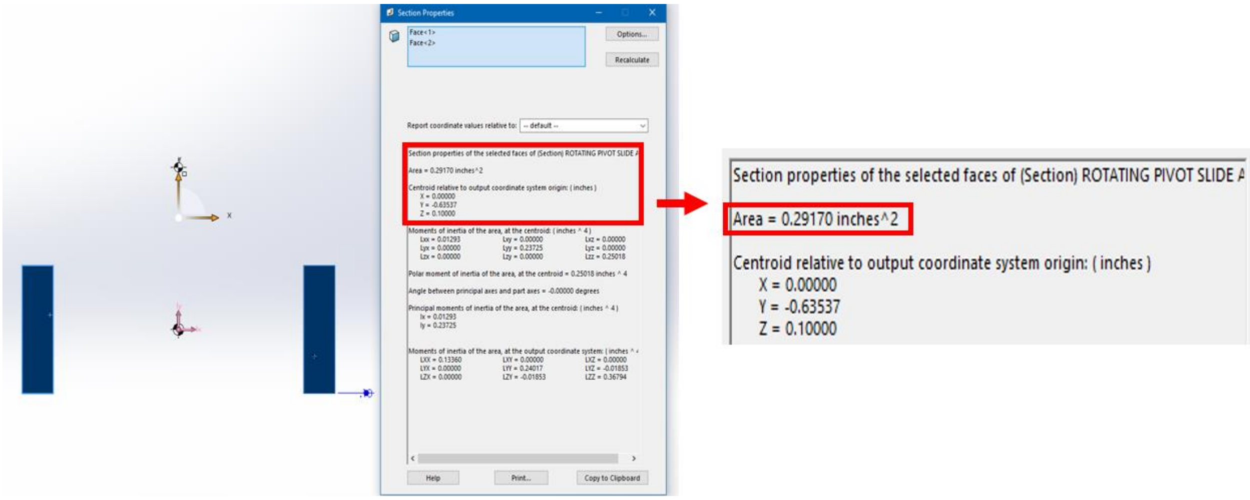


Figure 84. A_P at b on Section C-C

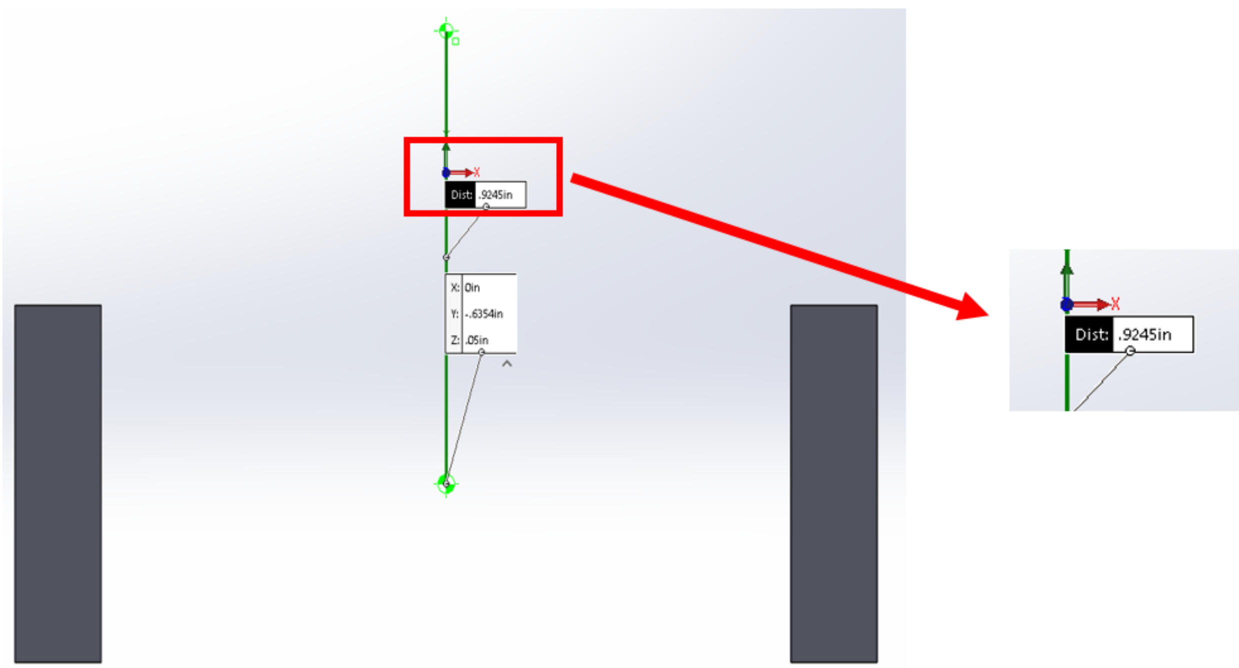


Figure 85. $\overline{Y}$ at b on Section C-C

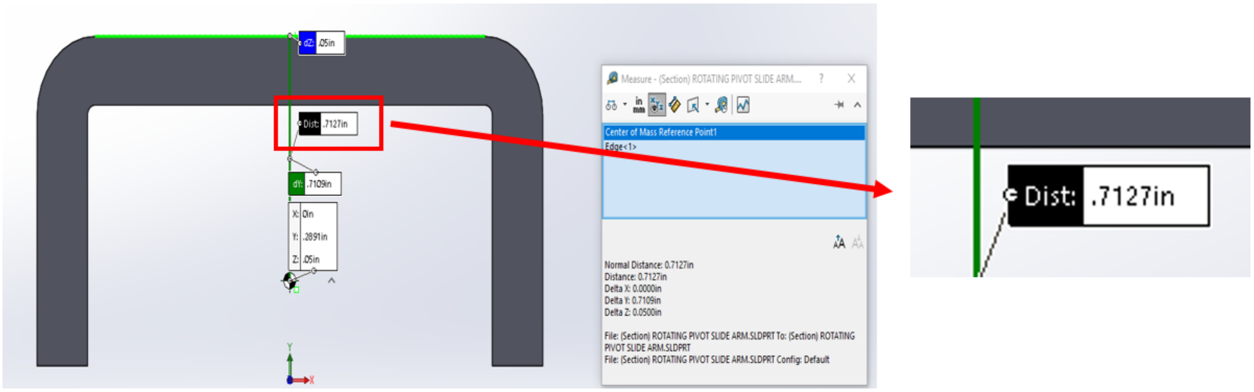


Figure 86. c at a on Section C-C

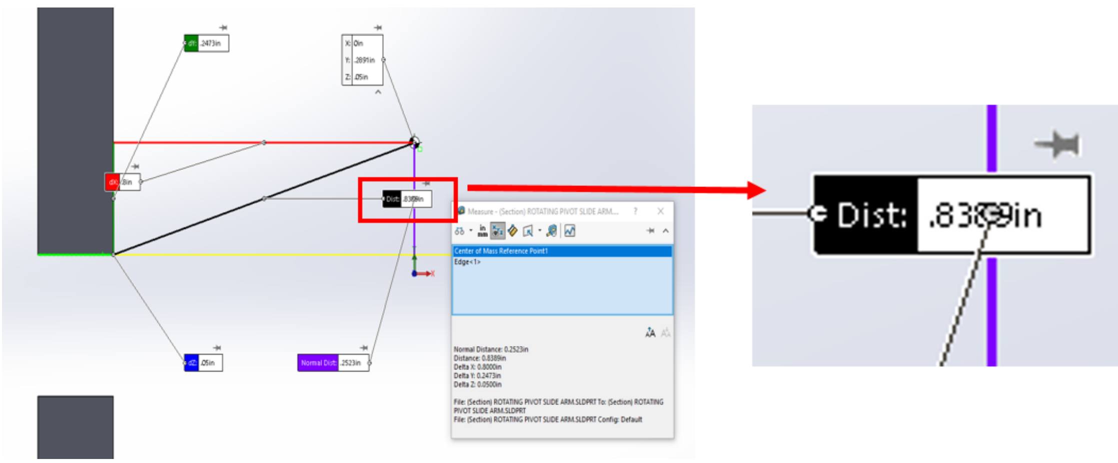


Figure 87. c at b on Section C-C

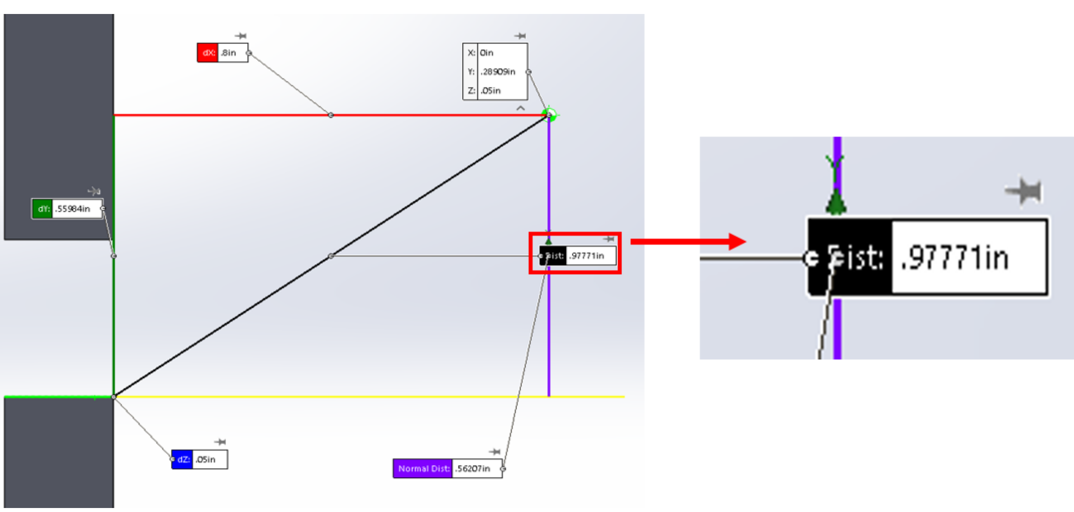


Figure 88. c at c on Section C-C

2.2.3.14 Section C-C Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{357.59\ lb}{0.97285\ \text{in}^2}$$

$$= 367.57\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.3.15 Section C-C Bending Stress

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

$$= \frac{2023\ lb - in\ \times 0.7127\ in}{0.42289\ \text{in}^4}$$

$$= 3409.38\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

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

$$= \frac{2023\ lb - in\ \times 0.2473\ in}{0.42289\ \text{in}^4}$$

$$= 1183.02\ psi\ (Compression\ at\ b)$$

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

$$= \frac{2023\ lb - in\ \times 0.5598\ in}{0.42289\ \text{in}^4}$$

$$= 2677.94\ psi\ (Compression\ at\ c)$$

2.2.3.16 Section C-C Transverse Shear Stress

Transverse shear stress applies to at b and c

$$Q = A_P \cdot \overline{Y}$$

$$= 0.2917\ in^2 \times 0.9245\ in$$

$$= 0.2697 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{679.01\ lb\ \times 0.2697\ in^3}{0.42289\ \text{in}^4\ \times 0.4\ in}$$

$$= 1082.6\ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

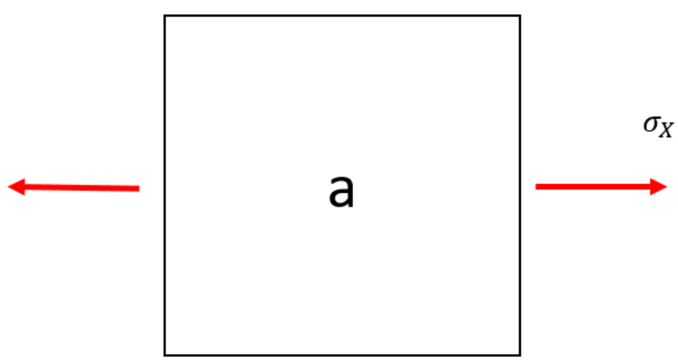
$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.3.17 Section C-C Analysis

<u>Stress at a</u>



$$\sigma_X = 367.57\ psi + 3409.38\ psi$$
$$= 3776.95\ psi$$

Figure 89. Applied Stress at a on Section C-C

In summary, a at section C-C has 3776.95 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{3780} = 11.3$$

<u>Stress at b</u>

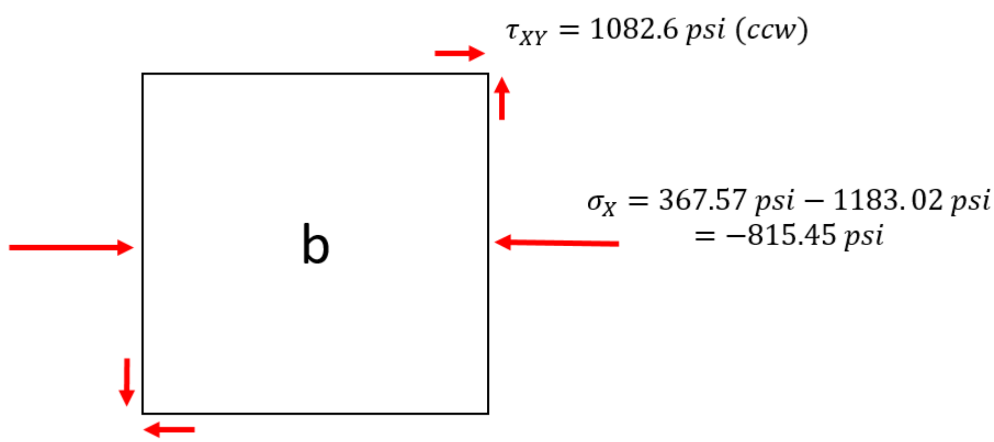


Figure 90. Applied Stress at b on Section C-C

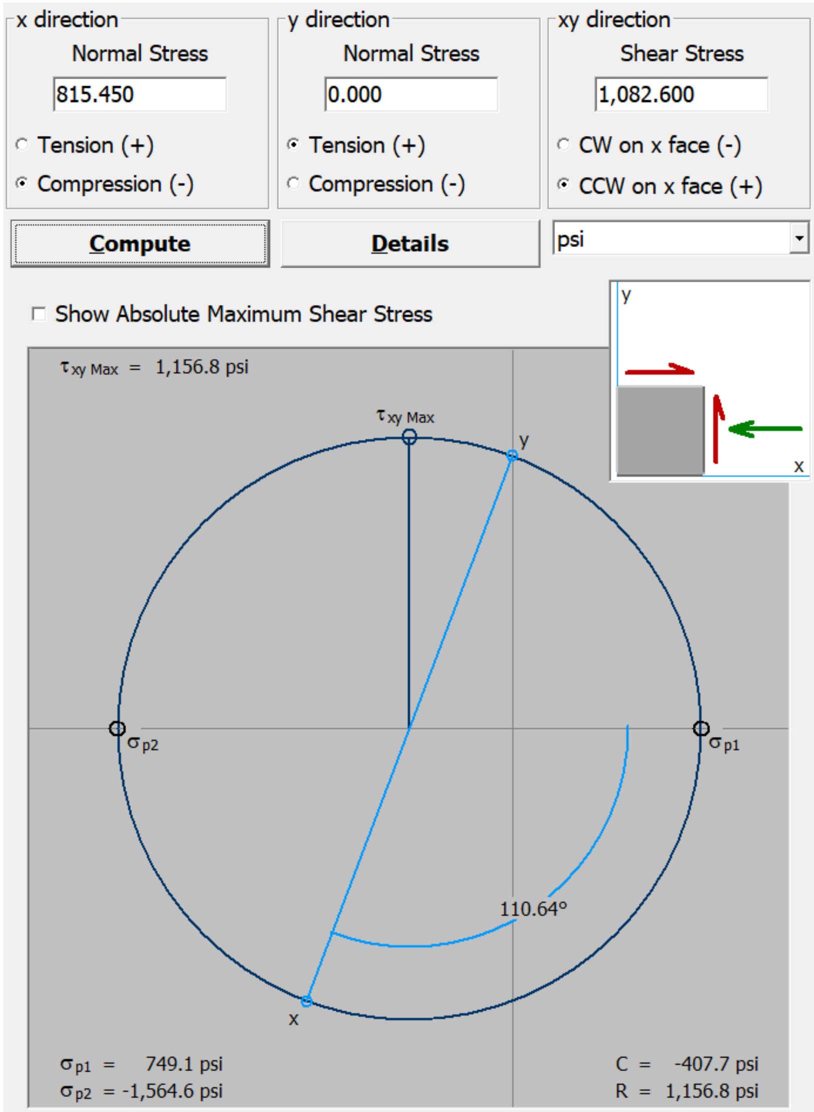


Figure 91. Principal Stress at b on Section C-C

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{749.1^2 + (-1564.6)^2 - 749.1(-1564.6)} = 2044.79\ psi$$

In summary, b at section B-B has $\sigma' = 2044.79\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_u}{\sigma'} = \frac{43000}{2040} = 21.0$$

Stress at c

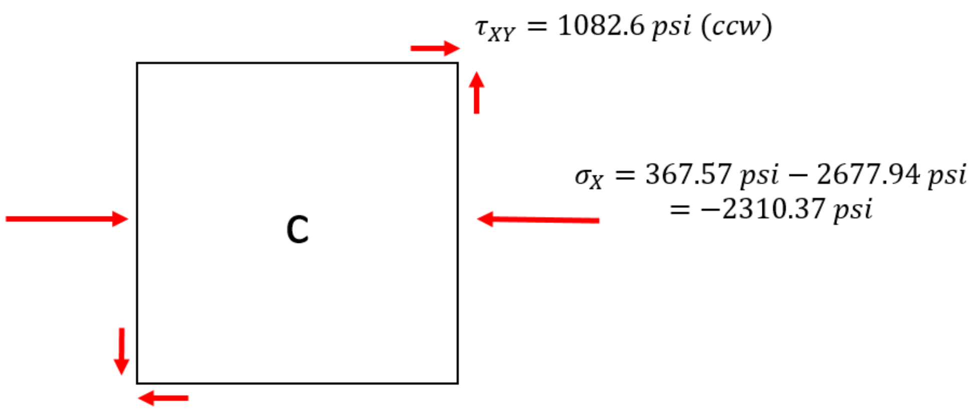


Figure 92. Applied Stress at c on Section C-C

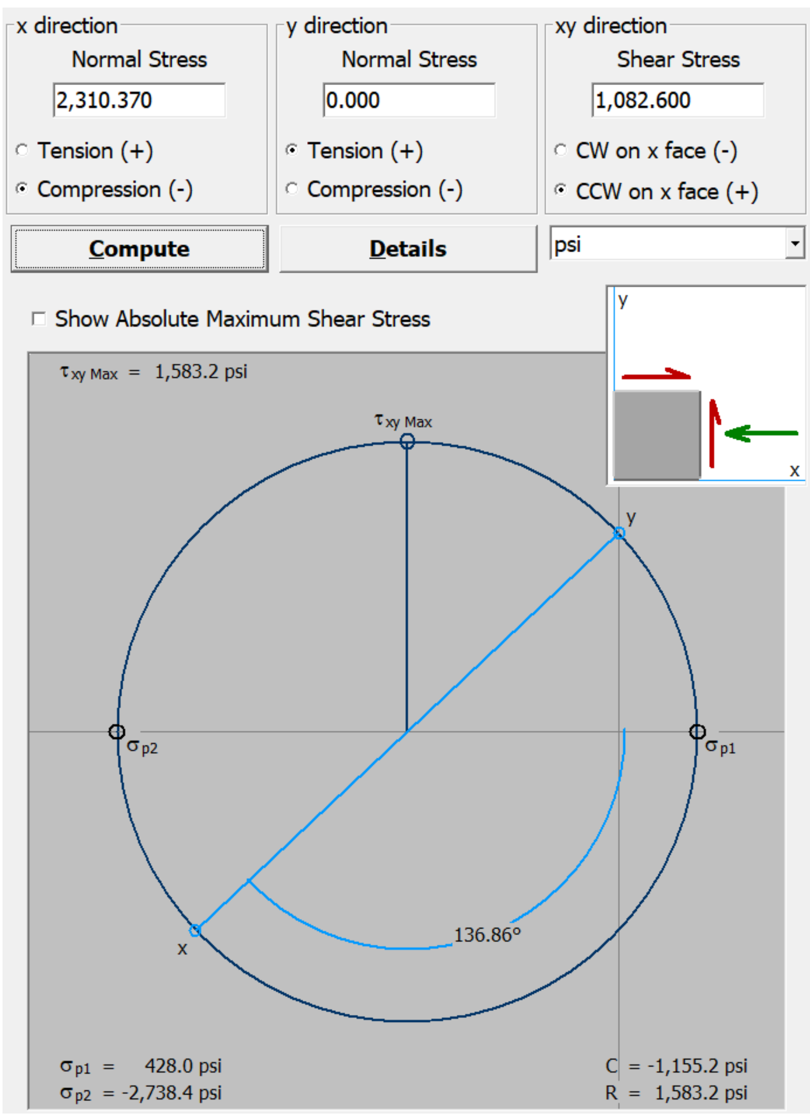


Figure 93. Principal Stress at c on Section C-C

MDET (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{428^2 + (-2738.4)^2 - 428(-2738.4)} = 2975.58\, psi$$

In summary, c at section B-B has $\sigma' = 2975.58\, psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{2980} = 14.4$$

2.2.3.18 Section D-D Properties

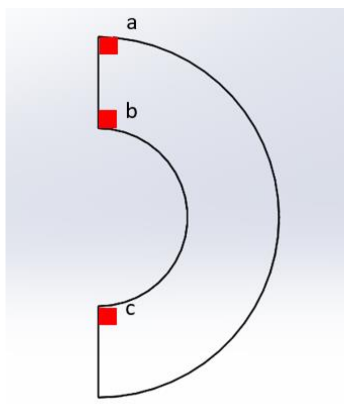


Figure 94. Locations analyzed

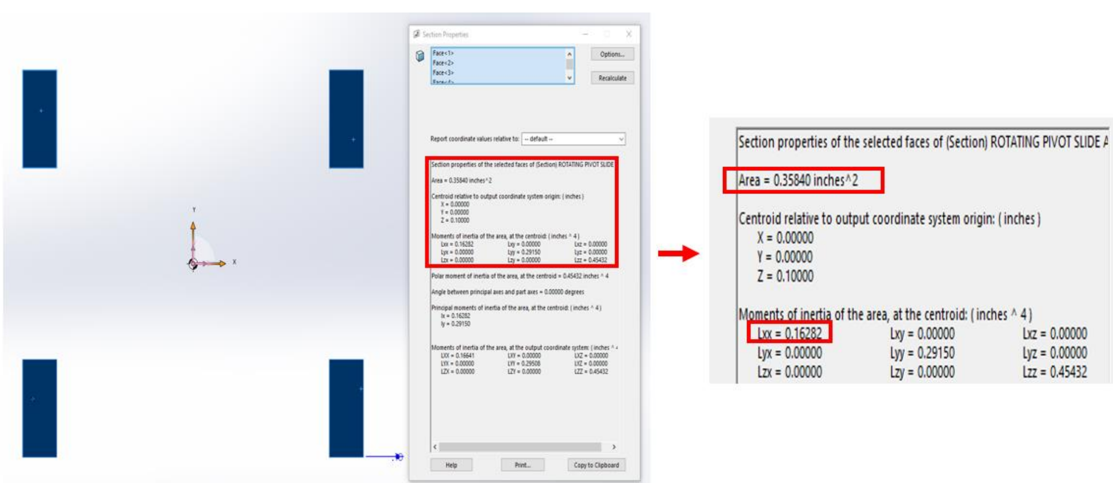


Figure 95. Section D-D Properties

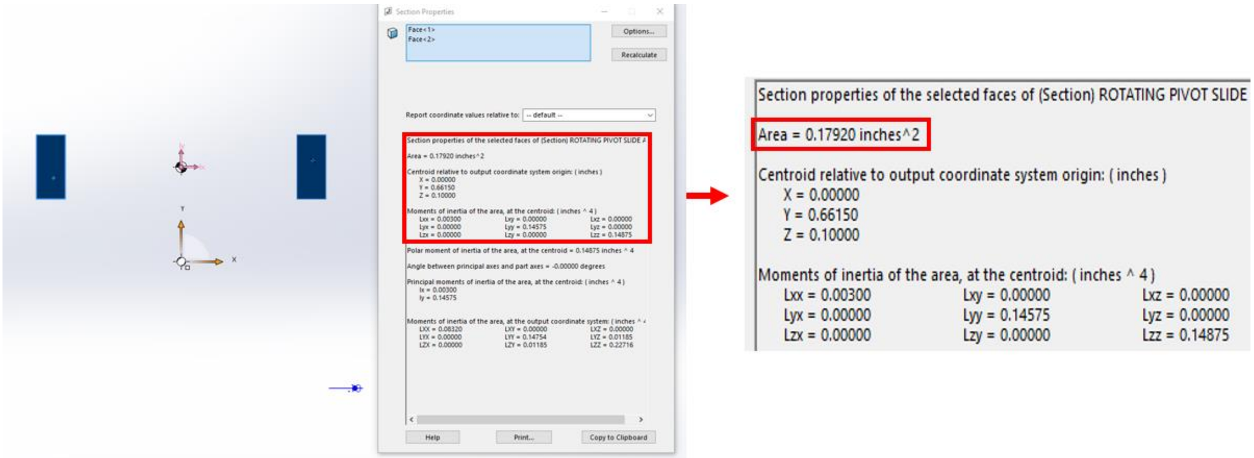


Figure 96. A_P at b on Section D-D

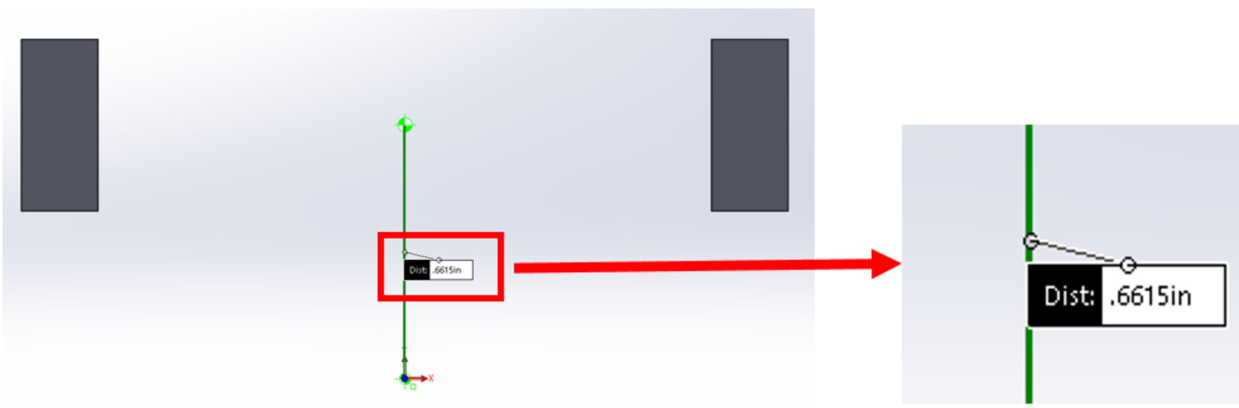


Figure 97. $\overline{Y}$ at b on Section D-D

2.2.3.19 Section D-D Transverse Shear Stress

Transverse shear stress applies to at b and c.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.1792\ in^2 \times 0.6615\ in$$

$$= 0.1185 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{679.01\ lb\ \times 0.1185\ in^3}{0.16282\ \text{in}^4\ \times 0.4\ in}$$

$$= 1235.45\ psi$$

Where, (1 Mott, p. 462)
$\tau = Shear\ stress, psi$
$V = Vertical\ shearing\ force, lb$
$I = Moment\ of\ inertia, in^4$
$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.3.20 Section D-D Analysis

Stress at a

a at the section D-D has no stress.

Stress at b

In summary, b at section D-D has 1235.45 psi shear stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_u}{\tau} = \frac{57000}{1240} = 45.9$$

Stress at c

c at the section D-D has the same stress as b at the section D-D.

2.2.3.21 Tear Out Stress on H

Hole E and G are excluded because both have relatively much wider areas.

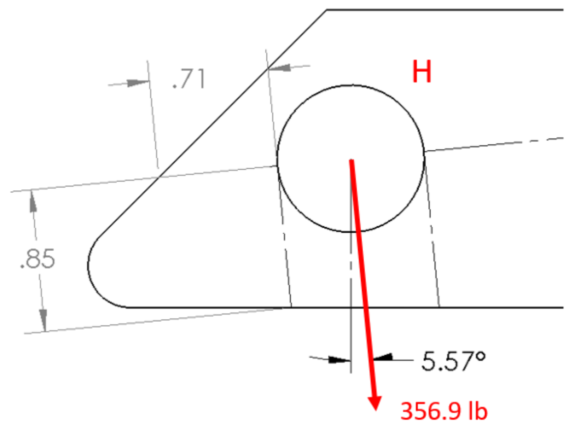


Figure 98. Vector Force on Hole H

<u>Hole H</u>

$$Vertor\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{710.44^2 + 69.33^2}$$

$$= 713.81\ lb$$

$$Angle = \tan^{-1}\left(\frac{X - directional\ force}{Y - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{69.33}{710.44}\right)$$

$$= 5.57°$$

Two plates share the force. Therefore, only half of the force, 356.9 lb is used to calculate tear out stress.

$$A_s = d \times t = 0.85 \times 0.2 = 0.17\ in^2$$

$$\tau = \frac{F}{2 \cdot A_S} = \frac{356.9}{2 \times 0.17} = 1049.7\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{1050} = 23.6$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

$$A_t = d \times t = 0.71 \times 0.2 = 0.142\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_T} = \frac{356.9}{2 \times 0.142} = 1256.69\ psi$$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{1260} = 34.1$$

2.2.3.22 Tear Out Stress on E

Hole E

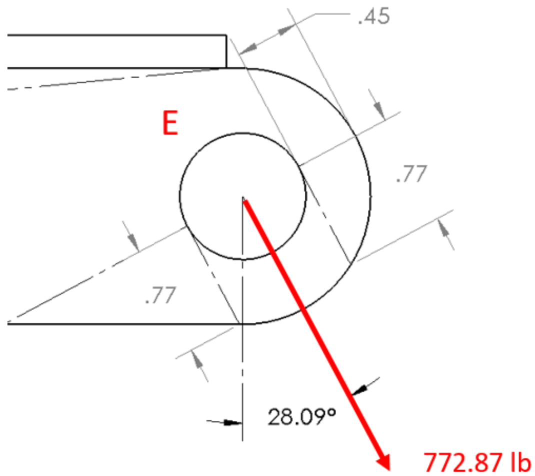


Figure 99. Vector Force on Hole E

$$Vector\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{363.94^2 + 681.82^2}$$

$$= 772.87\ lb$$

$$Angle = \tan^{-1}\left(\frac{X - directional\ force}{Y - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{363.94}{681.82}\right)$$

$$= 28.09°$$

Two plates share the force. Therefore, only half of the force, 386.44 lb is used to calculate tear out stress.

$A_s = d \times t = 0.77 \times 0.2 = 0.154\ in^2$

$$\tau = \frac{F}{2 \cdot A_s} = \frac{386.44}{2 \times 0.154} = 1254.68\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{1250} = 19.8$$

$A_t = d \times t = 0.45 \times 0.2 = 0.09\ in^2$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{386.44}{2 \times 0.09} = 2146.89\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{2150} = 20.0$$

2.2.4 Handrail

2.2.4.1 General Information

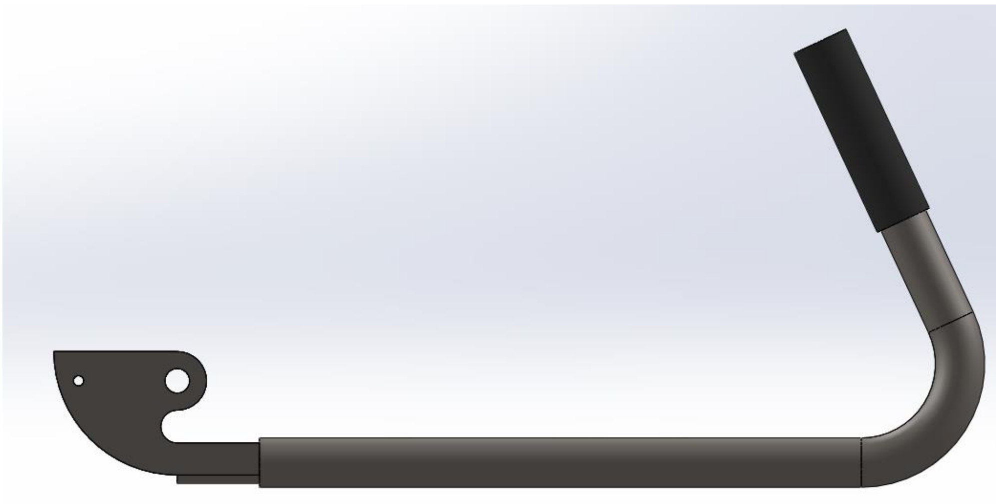


Figure 100. Handrail

The handrail is a component for passengers to hold on for support. It is assumed that a person pulls the handrail with 100 lb. In the force analysis section, this part can be solvable with only a single FBD. Therefore, forces calculated from the single FBD are used to remove small errors caused by the matrix calculation. In addition to that, the forces are shared with two handrails. Only half of the forces are applied to the handrail. The following table shows the recalculated forces.

Table 4. Recalculated Forces

Location	Force (lb)	Half Force (lb)
E_{X1}	170.66	85.33
E_{Y2}	416.82	208.41
F_F	407.01	203.51

2.2.4.2 Force Revision

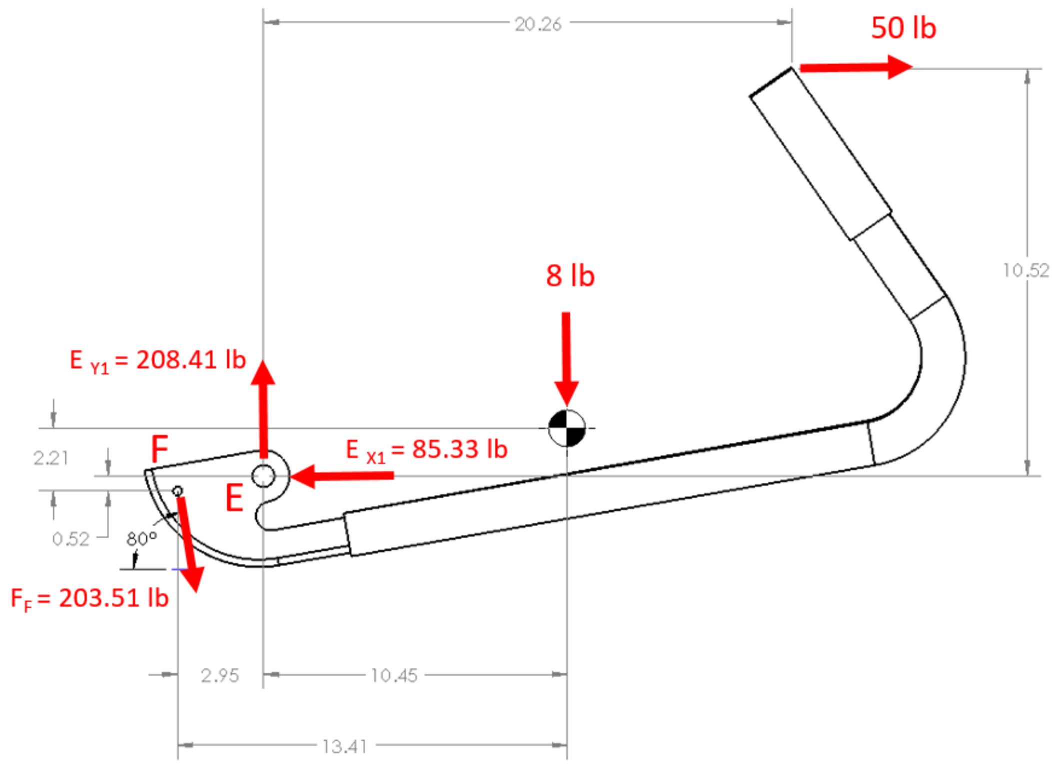


Figure 101. Applied Forces on The Tilted Part

$$Weight_X = 8 \times \sin 10 = 1.39\ lb$$

$$Weight_Y = 8 \times \cos 10 = 7.88\ lb$$

$$External\ Force_X = External\ Force \times \cos 10 = 50 \times \cos 10 = 49.24\ lb$$

$$External\ Force_Y = External\ Force \times \sin 10 = 50 \times \sin 10 = 8.68\ lb$$

$$E'_{X1} = E_{X1} \times \cos 10 - E_{Y1} \times \sin 10$$

$$= 85.33 \times \cos 10 - 208.41 \times \sin 10$$

$$= 47.84\ lb$$

$E'_{Y1} = E_{X1} \times \sin 10 + E_{Y1} \times \cos 10$

$= 85.33 \times \sin 10 + 208.41 \times \cos 10$

$= 220.06\ lb$

$F'_Y = F_F \times \sin(80 + 10) = 203.51 \times \sin 90$

$= 203.51\ lb$

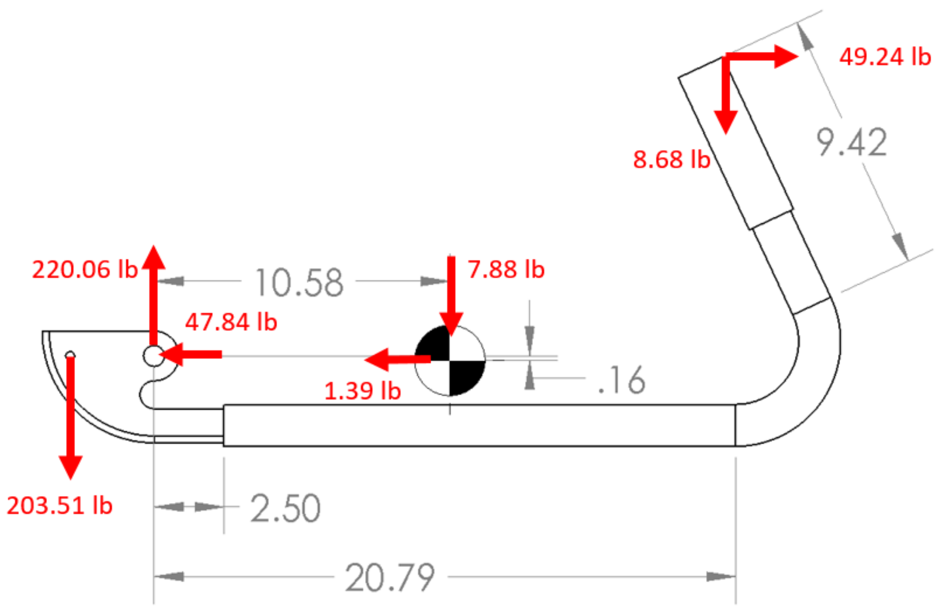


Figure 102. Revised Forces

2.2.4.3 Section Separation

The following figure shows the sections to be analyzed, which places are likely to have the highest stress.

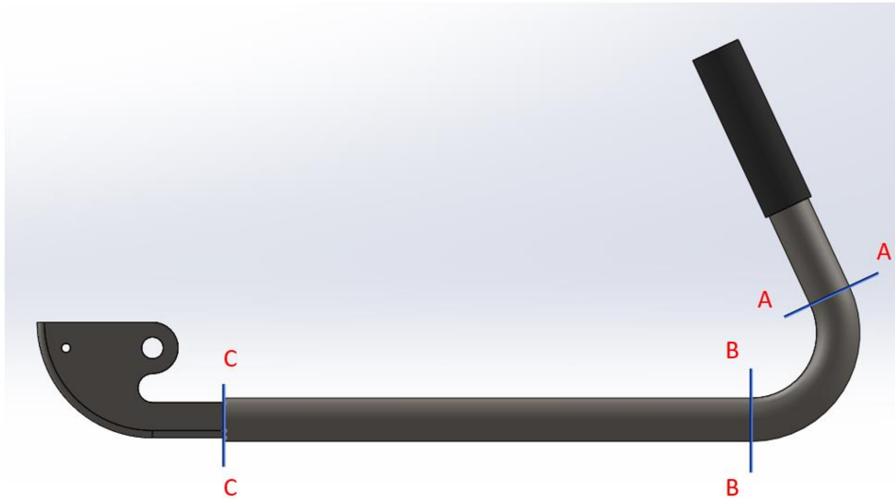


Figure 103. Sections To Be Analyzed

2.2.4.4 Section A-A Force Revision

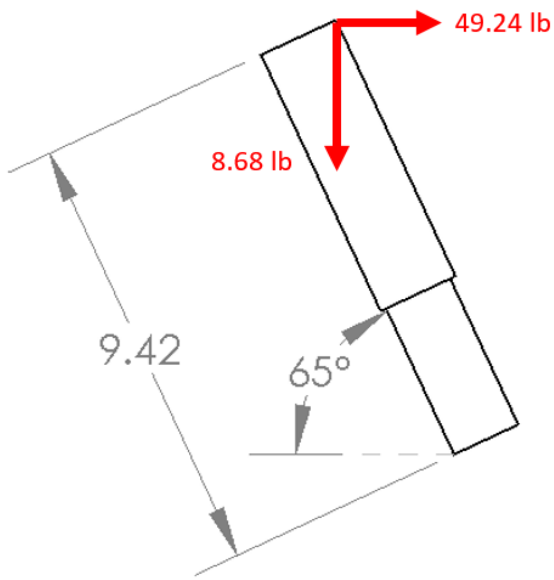


Figure 104. Section A-A Position 1

To calculate stress on section A-A, forces are required to be re-organized horizontally and vertically along the cross-section. Besides, it is rotated 90 degrees to make a beam support position.

$$Horizontal\ Force = 49.24 \times \sin 65 - 8.68 \times \cos 65 = 40.96\ lb$$

$$Vertical\ Force = 49.24 \times \cos 65 + 8.68 \times \sin 65 = 28.68\ lb$$

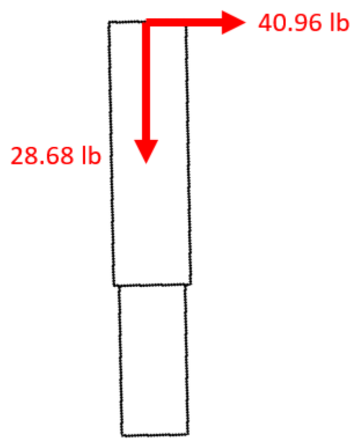


Figure 105. Section A-A Position 2

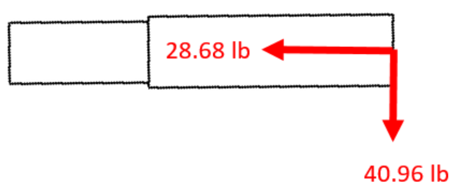


Figure 106. Section A-A Position 3

2.2.4.5 Section A-A Properties

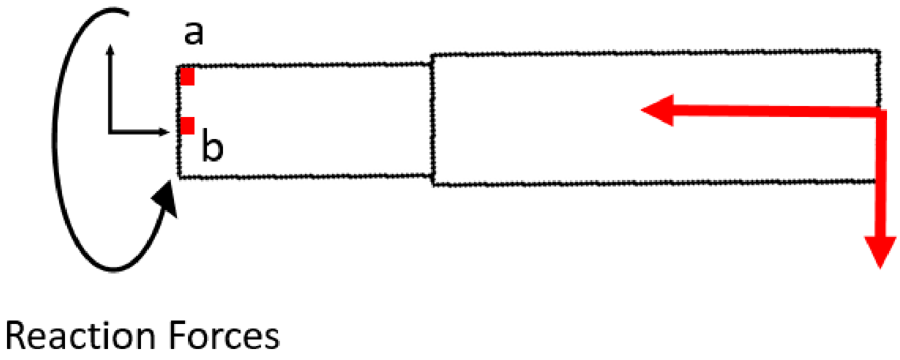


Figure 107. Locations Analyzed

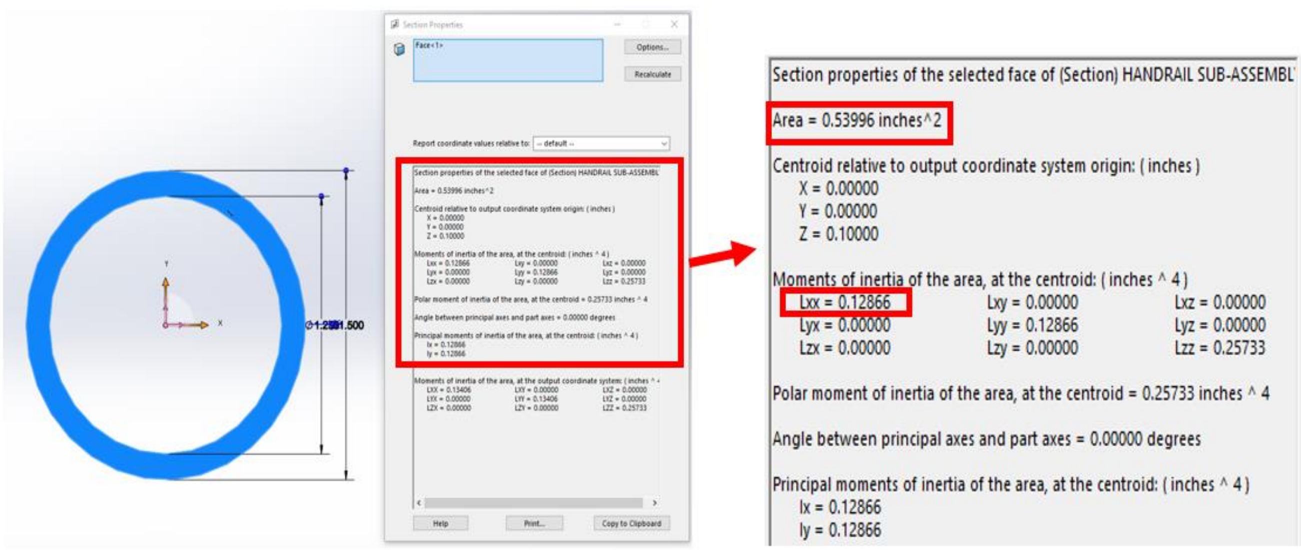


Figure 108. Section A-A Properties

2.2.4.6 Section A-A Axial Stress

$$\sigma = \frac{F}{A} = \frac{28.68\ lb}{0.54\ \text{in}^2} = 53.11\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.4.7 Section A-A Bending Stress

Bending stress only applied to a.

$$M = Force \times Distance$$

$$= 40.96 \times 9.42$$

$$= 385.84\ lb - in$$

Where, (1 Mott, p. 403)
$\sigma = Axial\ stress, ksi$
$M = Bending\ moment, lb - in$
$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$
$I = Moment\ of\ inertia, in^4$

$$c = Outer\ Radius\ of\ Pipe = 0.75\ in$$

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

$$= \frac{385.84\ lb - in\ \times 0.75\ in}{0.12866\ \text{in}^4}$$

$$= 2249.18\ psi$$

2.2.4.8 Section A-A Transverse Shear Stress

Transverse shear stress only applies to at b.

$$\tau = \left(\frac{16V}{3\pi}\right)\frac{\left(D_o^3 - D_i^3\right)}{\left(D_o^4 - D_i^4\right)(D_o - D_i)}$$

$$= \left(\frac{16 \times 40.96}{3\pi}\right)\frac{(1.5^3 - 1.25^3)}{(1.5^4 - 1.25^4)(1.5 - 1.25)} = 150.89\ psi$$

Where,
$\tau = Shear\ stress, psi$
$V = Vertical\ shearing\ force, lb$
$D_o = Outer\ diameter, in$
$D_i = Inner\ diameter, in$

2.2.4.9 Section A-A Analysis

<u>Stress at a</u>

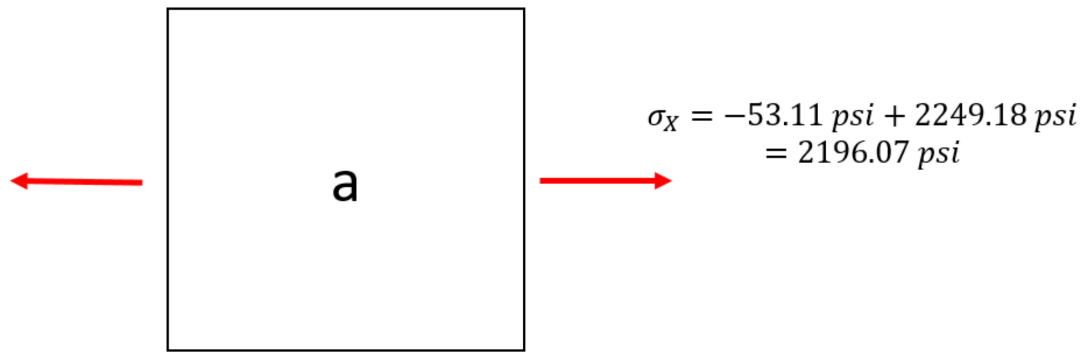


Figure 109. Applied Stress at a on Section A-A

In summary, a at section A-A has 2196.07 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{2200} = 19.5$$

<u>Stress at b</u>

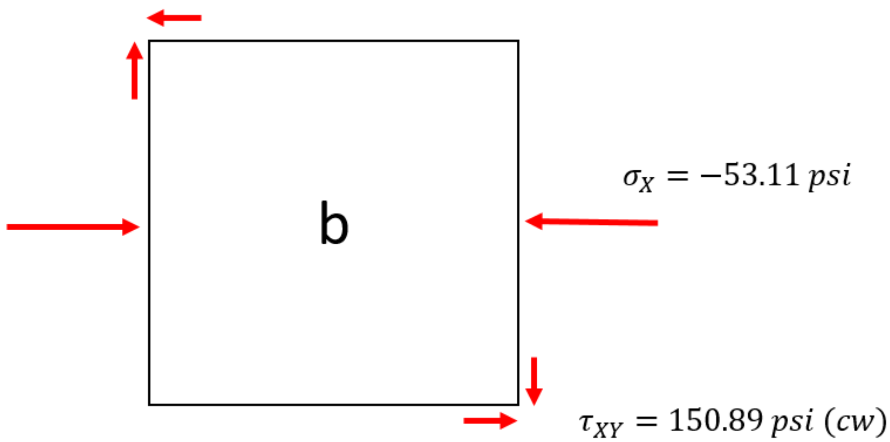


Figure 110. Applied Stress at b on Section A-A.

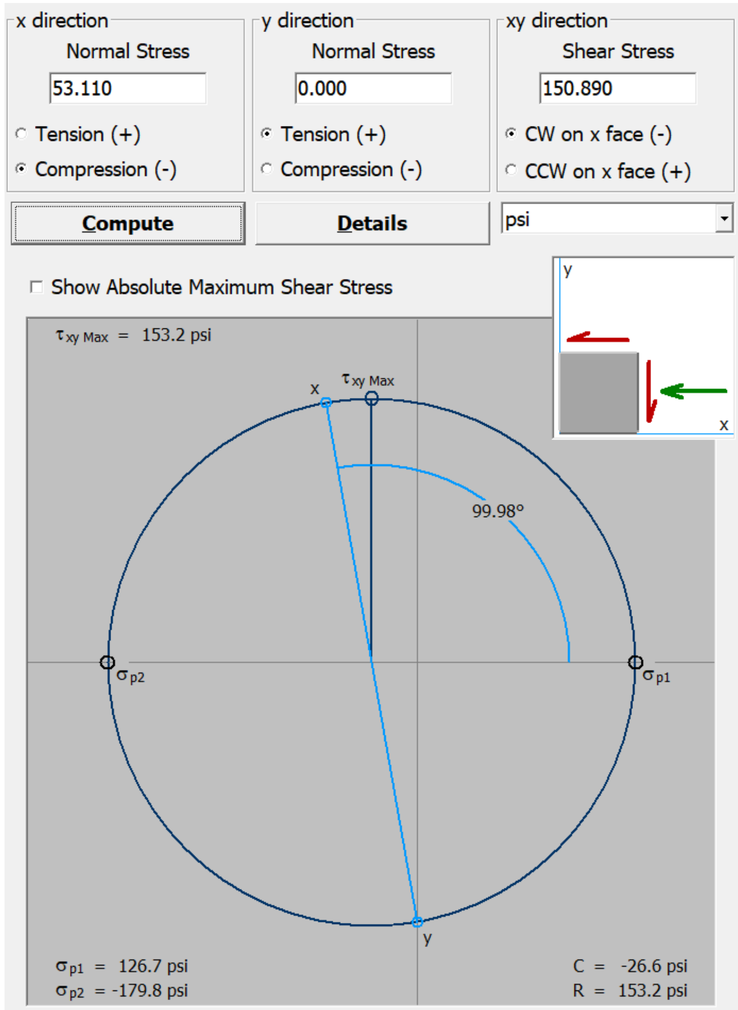


Figure 111. Principal Stress at b on Section A-A

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{126.7^2 + (-179.8)^2 - 126.7(-179.8)} = 266.76\,psi$$

In summary, b at section A-A has $\sigma' = 266.76\,psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{267} = 161.0$$

2.2.4.10 Section B-B Properties

A cross-section is a vertical plane. The area of a horizon plane is infinite. Therefore, any calculation which requires horizontal cross-section area is neglected.

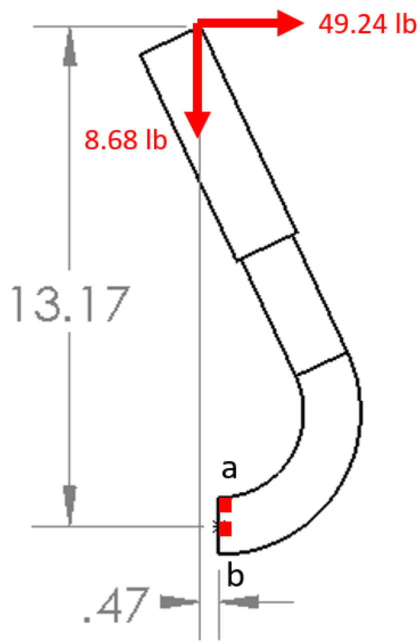


Figure 112. Locations Analyzed

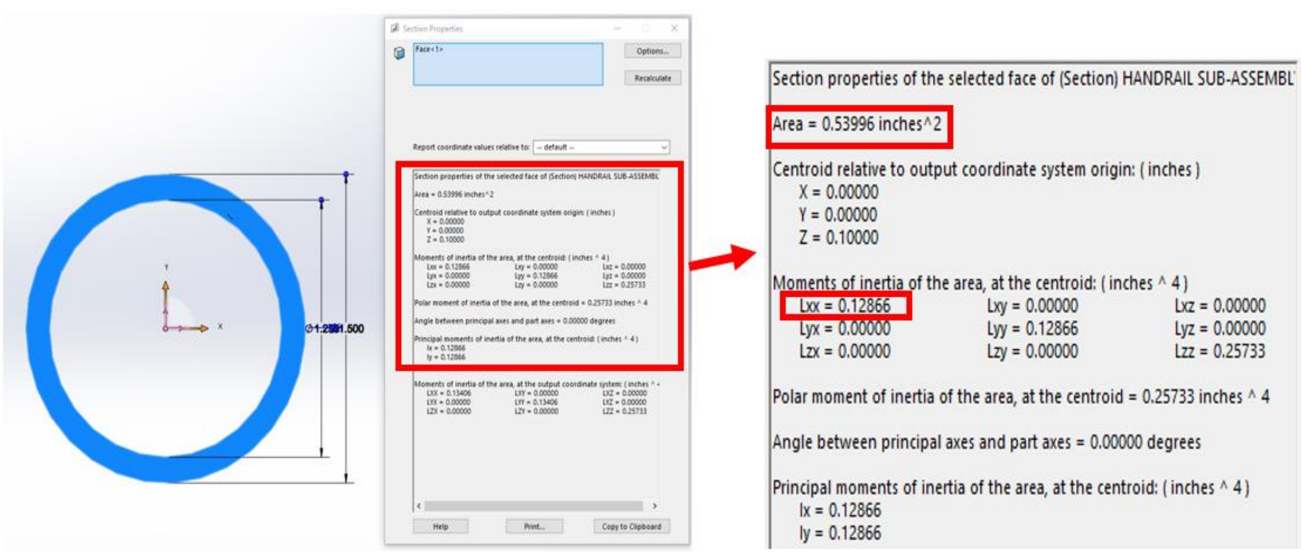


Figure 113. Section B-B Properties

2.2.4.11 Section B-B Bending Stress

$M = Force \times Distance$

Where, (1 Mott, p. 403)

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

$= 8.68 \times 0.47$

$= 4.08\ lb - in$

$c = Outer\ Radius\ of\ Pipe = 0.75\ in$

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

$$= \frac{4.08\ lb - in\ \times 0.75\ in}{0.12866\ \text{in}^4}$$

$= 23.78\ psi\ (Tension\ at\ a)$

2.2.4.12 Section B-B Transverse Shear Stress

$$\boldsymbol{\tau} = \left(\frac{\mathbf{16V}}{\mathbf{3\pi}}\right)\frac{\left(\mathbf{D_o^3 - D_i^3}\right)}{\left(\mathbf{D_o^4 - D_i^4}\right)\left(\mathbf{D_o - D_i}\right)}$$

$$= \left(\frac{16 \times 8.68}{3\pi}\right)\frac{(1.5^3 - 1.25^3)}{(1.5^4 - 1.25^4)(1.5 - 1.25)} = 31.97\ psi$$

Where,

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$D_o = Outer\ diameter, in$

$D_i = Inner\ diameter, in$

2.2.4.13 Section B-B Analysis

Stress at a

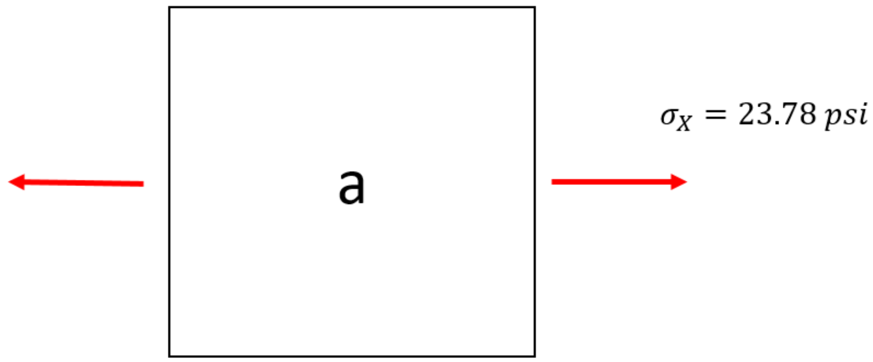


Figure 114. Applied Stress at a on Section B-B

In summary, a at section B-B has 23.78 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{23.8} = 1806.7$$

Stress at b

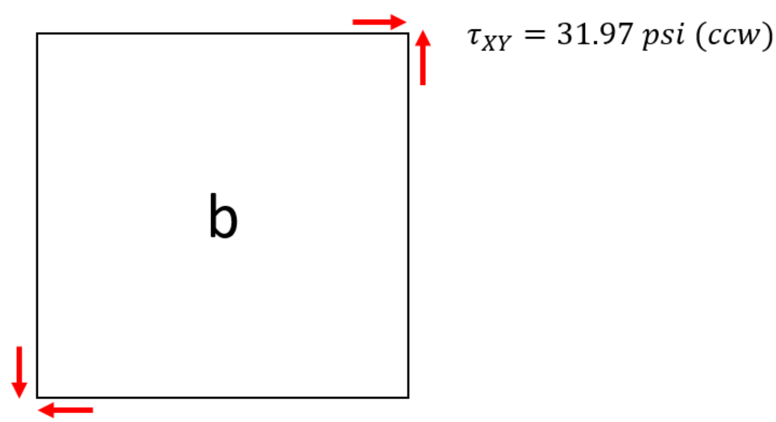


Figure 115. Applied Stress at b on Section B-B.

In summary, b at section B-B has $\tau = 31.97\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{0.577 \cdot S_y}{\tau} = \frac{0.577 \times 43000}{32.0} = 775$$

2.2.4.14 Section C-C Shear Force and Bending Moment

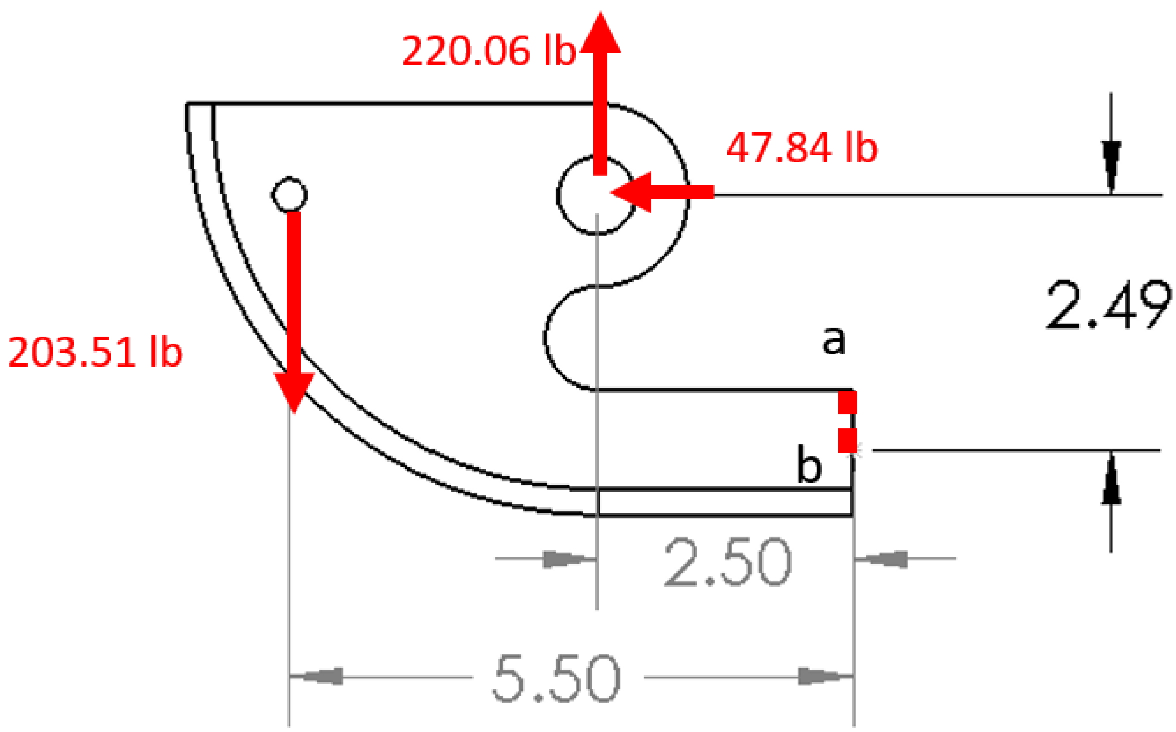


Figure 116. Locations Analyzed

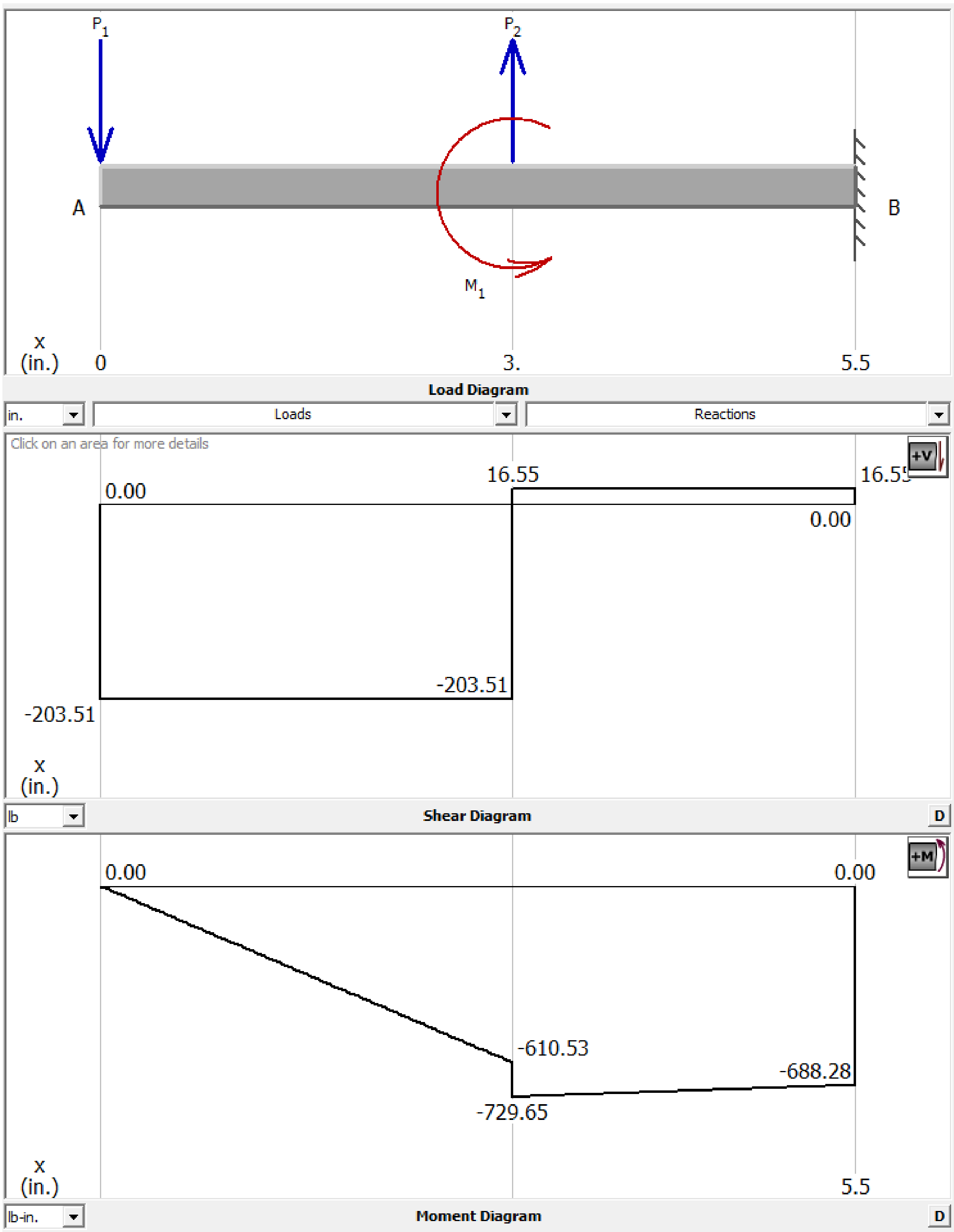


Figure 117. Shear Force and Bending Moment on Section C-C

2.2.4.15 Section C-C Properties

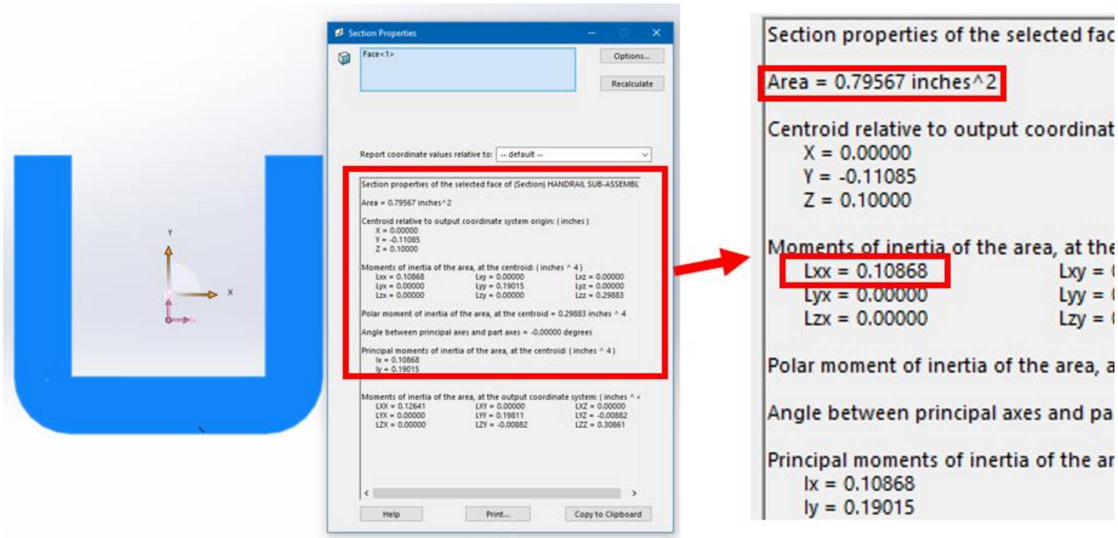


Figure 118. Section C-C Properties

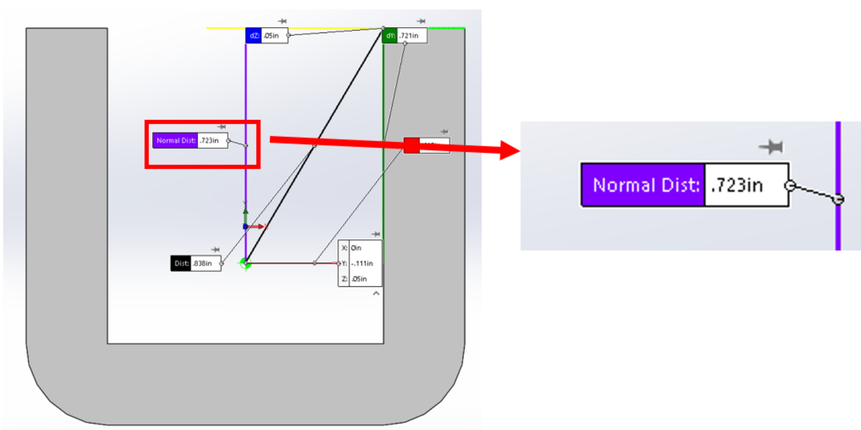


Figure 119. c at a on Section C-C

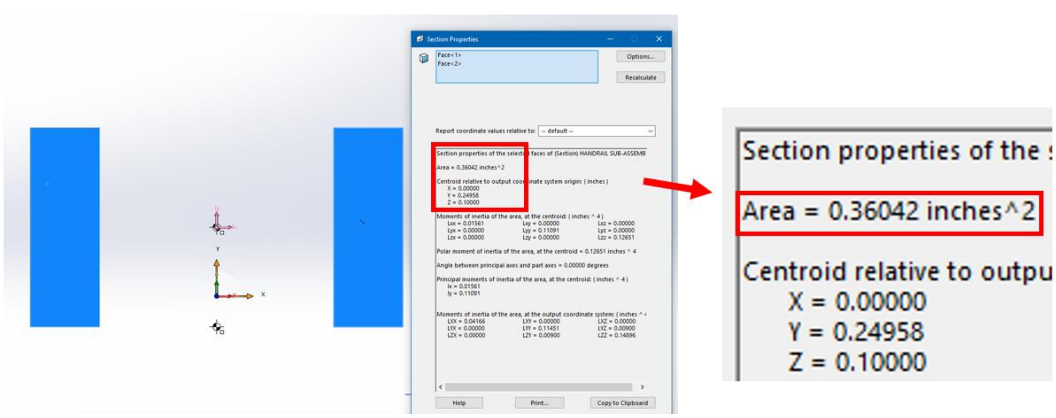


Figure 120. A_P at b on Section C-C

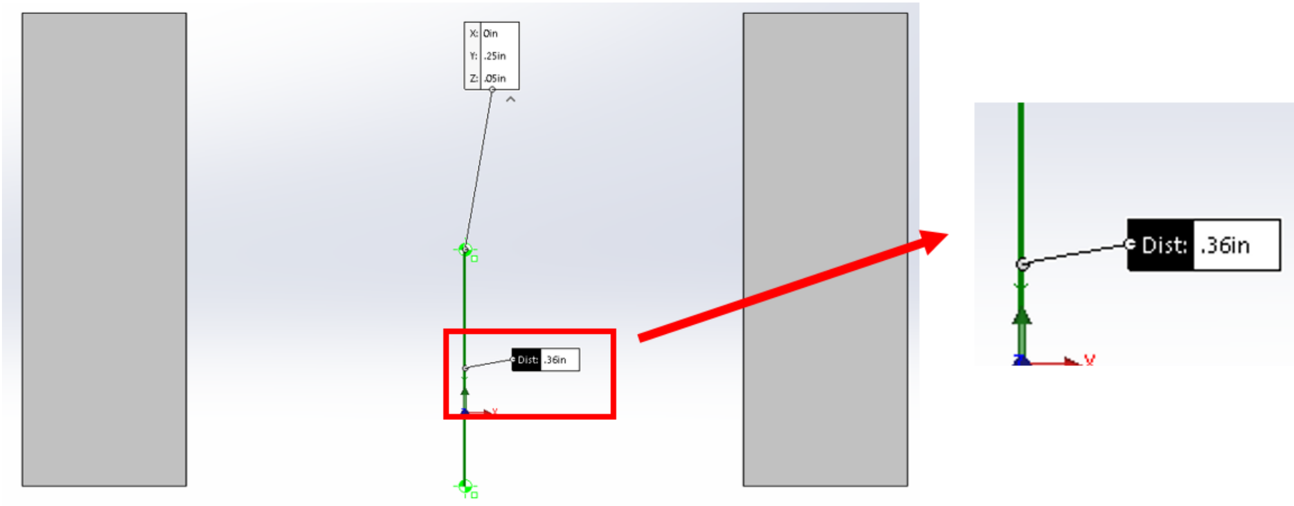


Figure 121. $\bar{Y}$ at b on Section B-B

2.2.4.16 Section C-C Axial Stress

$$\sigma = \frac{F}{A} = \frac{47.84\ lb}{0.796\ \text{in}^2} = 60.1\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.4.17 Section C-C Bending Stress

Bending stress only applied to a

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

$$= \frac{688.28\ lb - in\ \times 0.723\ in}{0.10868\ \text{in}^4}$$

$$= 4578.82\ psi$$

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

2.2.4.18 Section C-C Transverse Shear Stress

Transverse shear stress only applied to b

$$Q = A_P \cdot \overline{Y}$$

$$= 0.36042\ in^2 \times 0.36\ in$$

$$= 0.1298 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross\ section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{16.55\ lb\ \times 0.1298\ in^3}{0.10868\ \text{in}^4\ \times 0.5\ in}$$

$$= 39.53\ psi$$

Where, (1 Mott, p. 462)

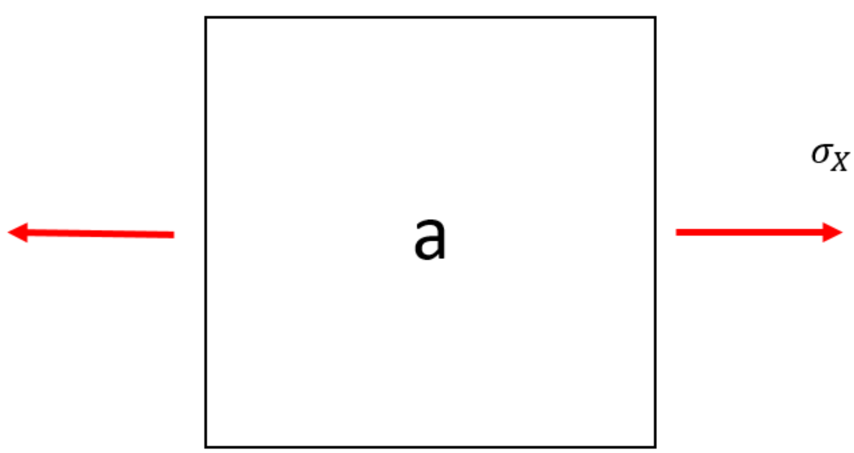
$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

Stress at a



$$\sigma_X = 60.1\ psi + 4578.82\ psi$$
$$= 4638.92\ psi$$

Figure 122. Applied Stress at a on Section C-C

In summary, a at section C-C has 4638.92 psi stress

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{4640} = 9.2$$

Stress at b

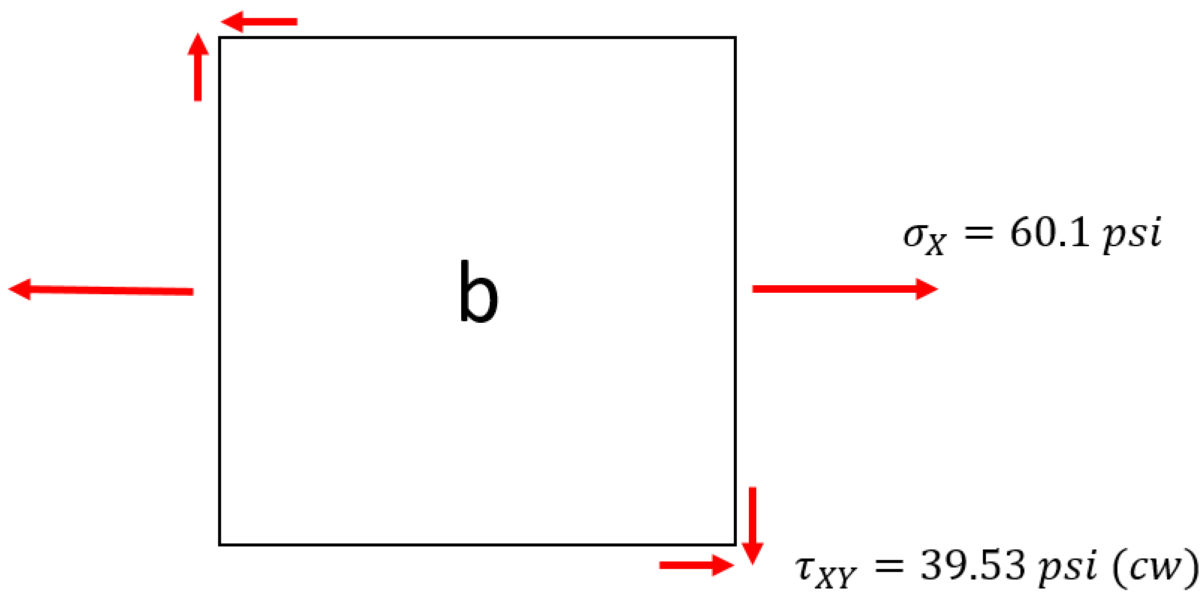


Figure 123. Applied Stress at b on Section C-C.

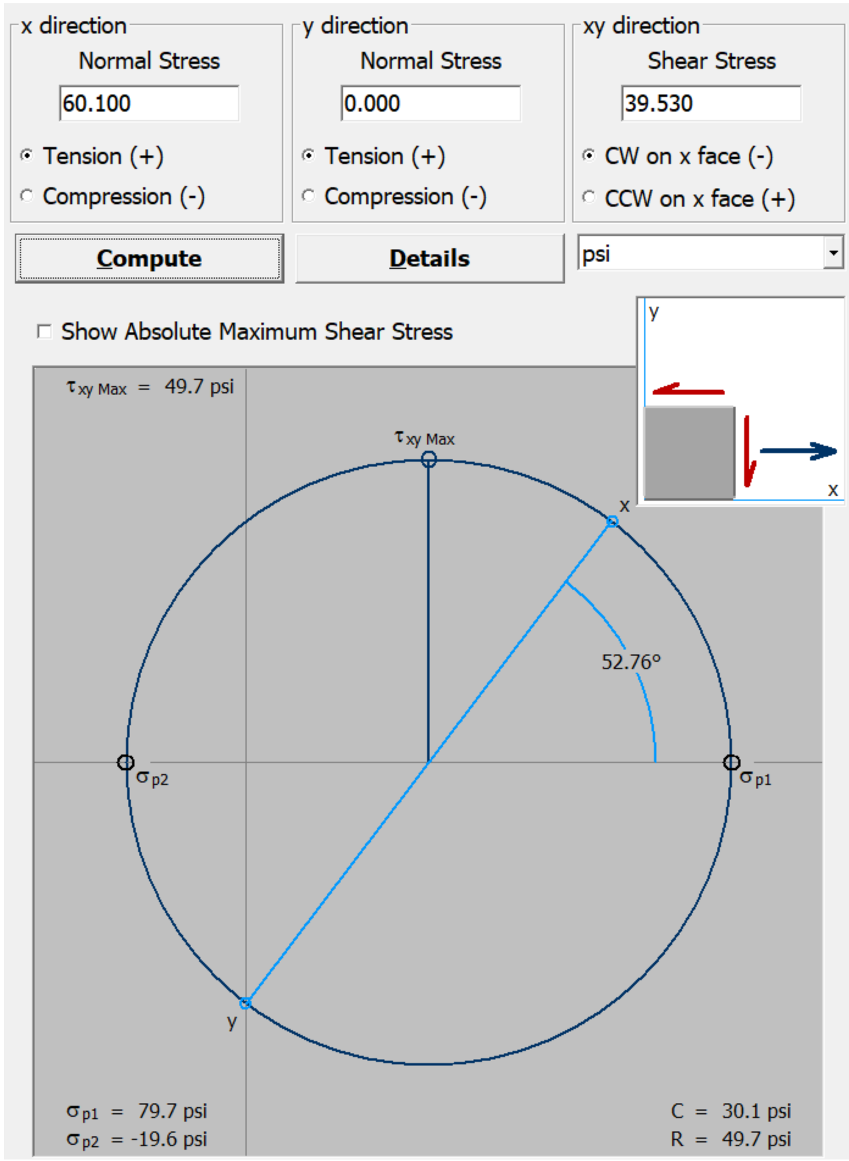


Figure 124. Principal Stress at b on Section C-C

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{79.7^2 + (-19.6)^2 - 79.7(-19.6)} = 91.1\, psi$$

In summary, b at section C-C has $\sigma' = 91.1\, psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{91.1} = 472.0$$

2.2.4.19 Tear Out Stress on E

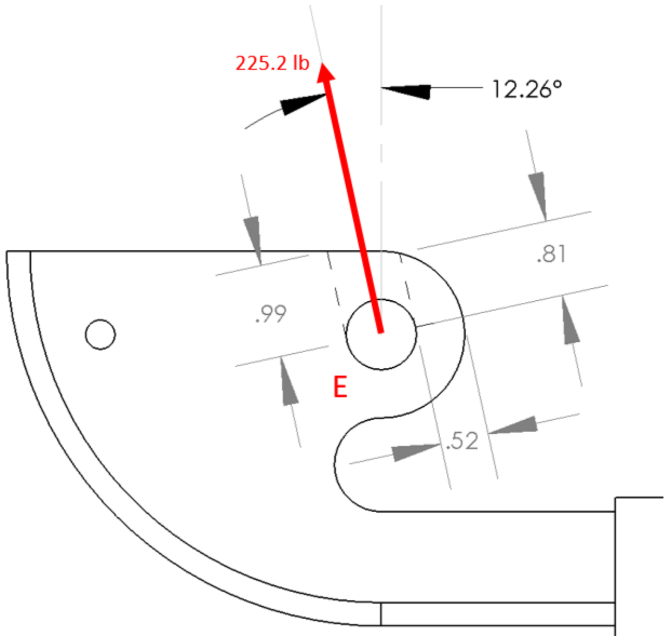


Figure 125. Teat Out on Hole E

$$Vertor\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{47.84^2 + 220.06^2}$$

$$= 225.2\ lb$$

$$Angle = \tan^{-1}\left(\frac{X - directional\ force}{Y - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{47.84}{220.06}\right)$$

$$= 12.26°$$

Two plates share the force. Therefore, only half of the force, 112.6 lb is used to calculate tear out stress.

$$A_s = d \times t = 0.81 \times 0.25 = 0.203\ in^2$$

$$\tau = \frac{F}{2 \cdot A_S} = \frac{112.6}{2 \times 0.203} = 277.34\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{277} = 89.5$$

$$A_t = d \times t = 0.52 \times 0.25 = 0.13\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{112.6}{2 \times 0.13} = 433.08\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{433} = 99.3$$

2.2.4.20 Tear Out Stress on F

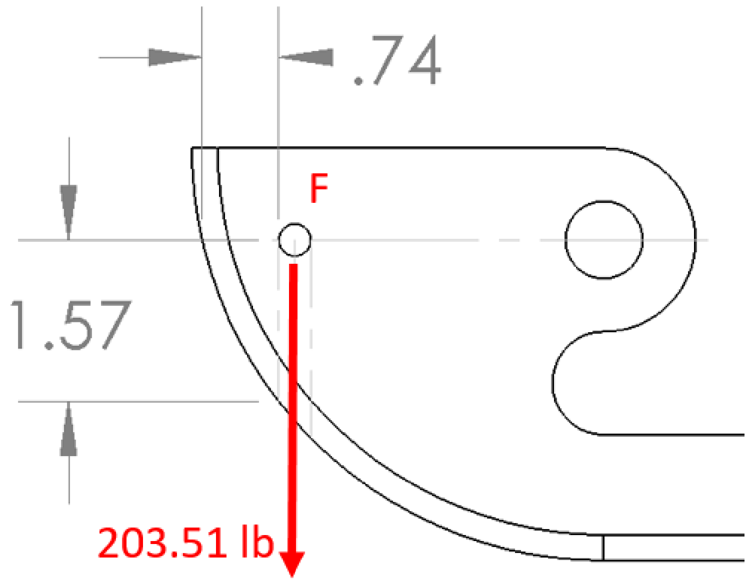


Figure 126.Teat Out on Hole F

It is assumed that two plates share the force. Therefore, only half of the force, 101.76 lb is used to calculate tear out stress.

$A_s = d \times t = 1.57 \times 0.25 = 0.3925\ in^2$

$\tau = \frac{F}{2 \cdot A_s} = \frac{101.76}{2 \times 0.3925} = 129.63\ psi$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{130} = 190$

$A_t = d \times t = 0.74 \times 0.25 = 0.185\ in^2$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{101.76}{2 \times 0.185} = 275.03\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{275} = 156.3$$

2.2.5 Vertical Arm

2.2.5.1 General Information

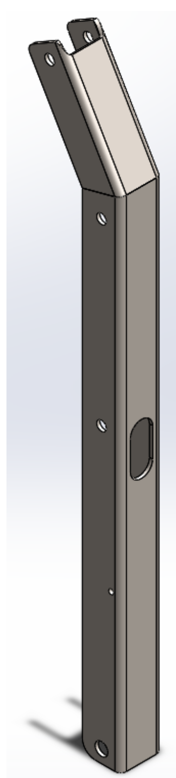


Figure 127. Vertical Arm

The vertical arm is a component connecting the top parallel arm, bottom parallel arm, handrail, pivot arm and platform. The part is welded with two separate sheet metal. In force analysis, when the lift is on up-position, forces concentrate on C and D. On the contrary, when the lift is on down-position, forces are gradually distributed on the other point. Therefore, the forces on up-position were used to analyze stress. In addition to that, the forces are shared with two vertical arms. Only half of the forces are applied to the vertical arm. The following table shows the recalculated forces.

Table 5. Recalculated Forces

Location	Force (lb)	Half Force (lb)
CX	1815.81	907.91
CY	2193.40	1096.70
DX	1787.88	893.94
DY	3588.79	1794.40
EX3	75.90	37.95
EY3	127.60	63.80
GI	76.07	38.04
JX	14063.17	7031.58
JY	1050.88	525.44
FN	14129.43	7064.71

2.2.5.2 Force Revision

The vertical arm has an identical cross-section area along the Y-axis. Therefore, it was rotated 90 degrees to analyze stress.

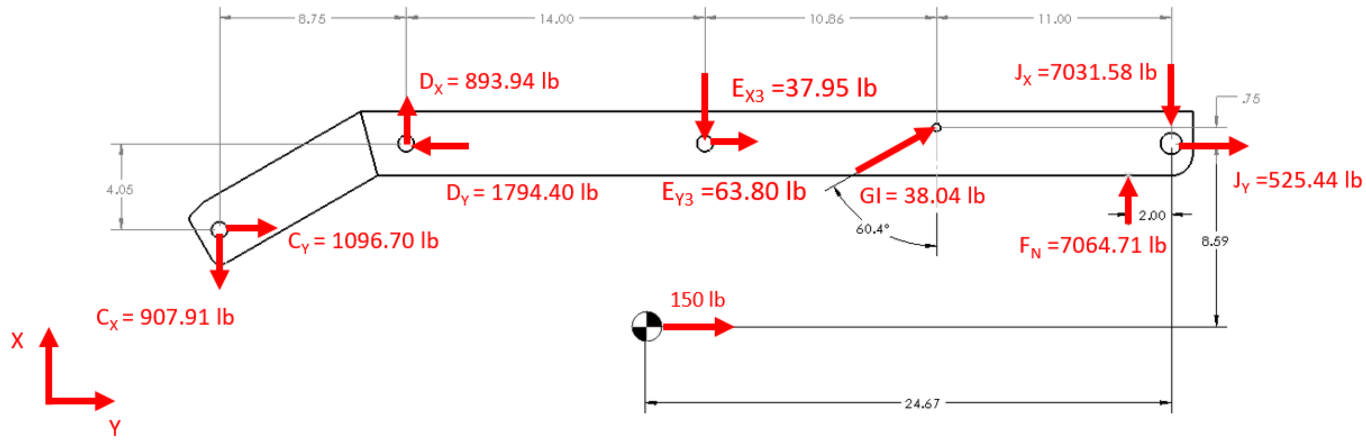


Figure 128. Applied Forces on the part

$$GI_X = GI \times \sin 60.4 = 38.04 \times \sin 60.4 = 33.08\ lb$$

$$GI_Y = GI \times \cos 60.4 = 38.04 \times \cos 60.4 = 18.79\ lb$$

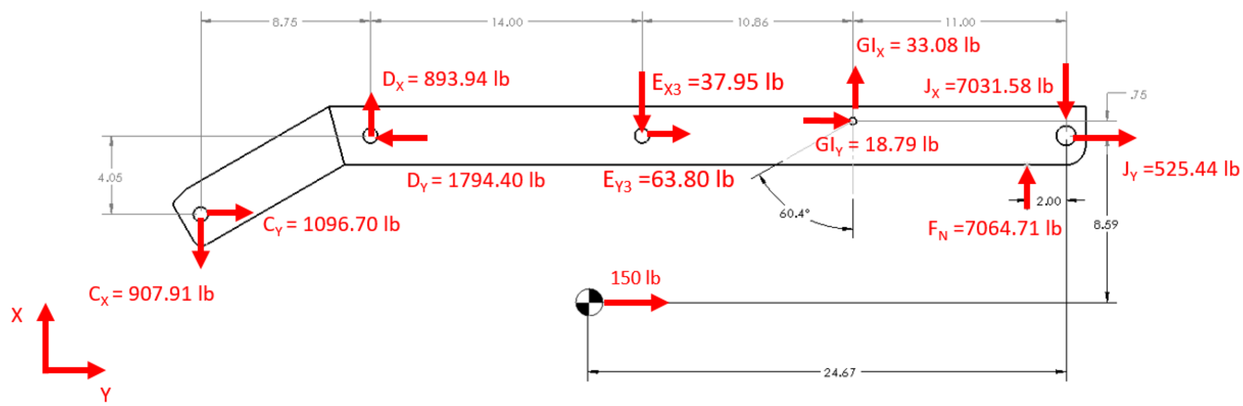


Figure 129. Revised Forces

2.2.5.3 Shear Force and Bending Moment

Distance and forces are multiplied by ten because MD solid can't read two decimal places. Therefore, vertical forces have to be divided by ten. In addition to that, bending moments have to be divided by one hundred.

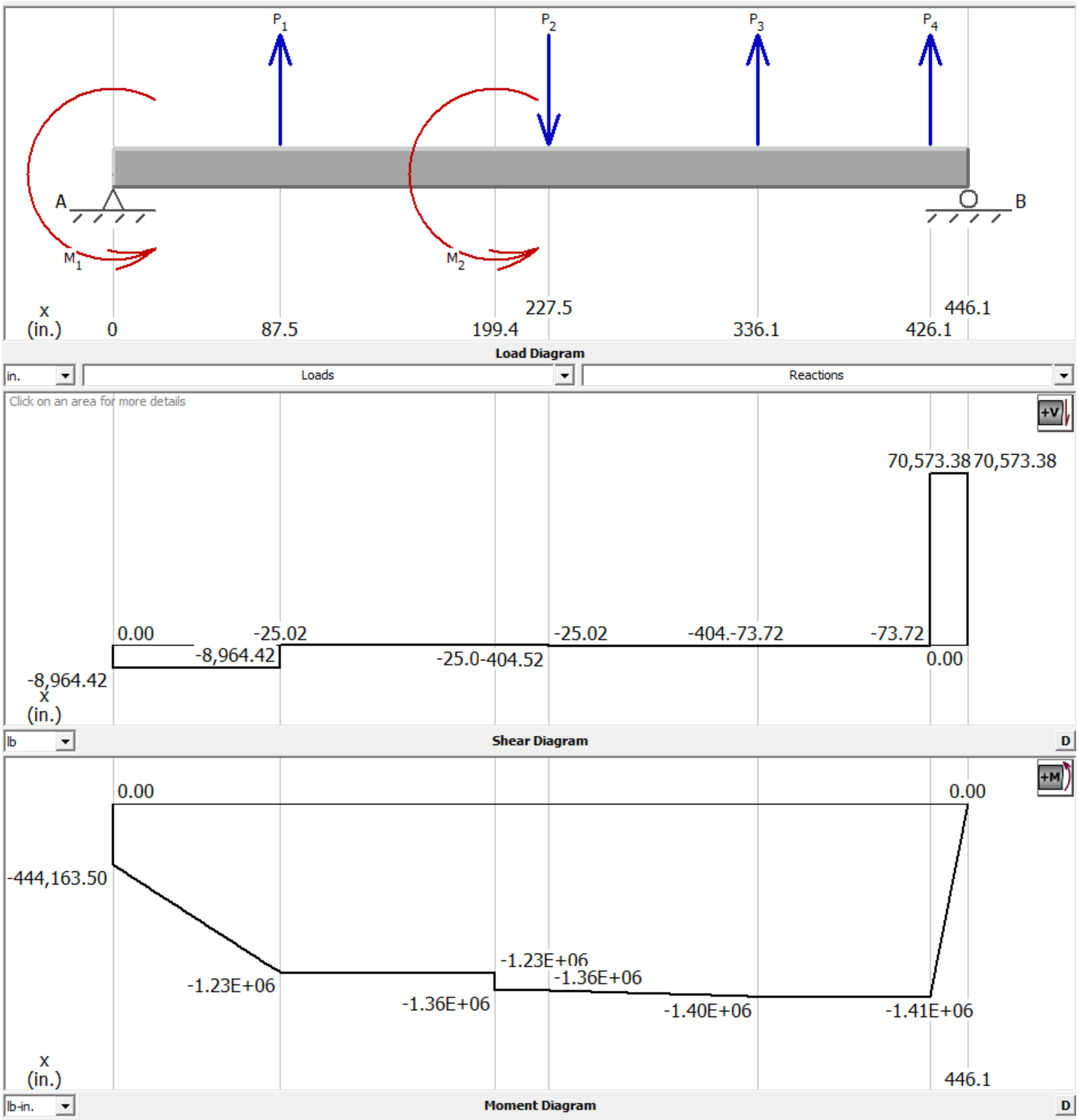


Figure 130. Shear Force and Bending Moment on Vertical Arm

2.2.5.4 Section Separation

The following figure shows the sections to be analyzed, which places are likely to have the highest stress.

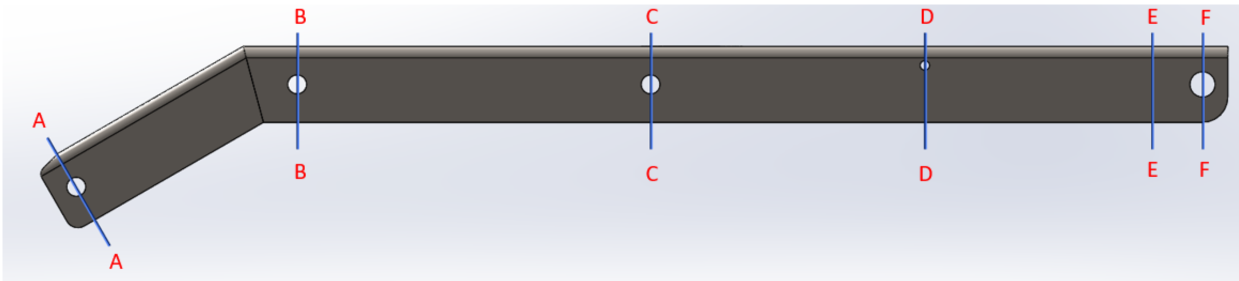


Figure 131. Sections To Be Analyzed

2.2.5.5 Section A-A Force Revision

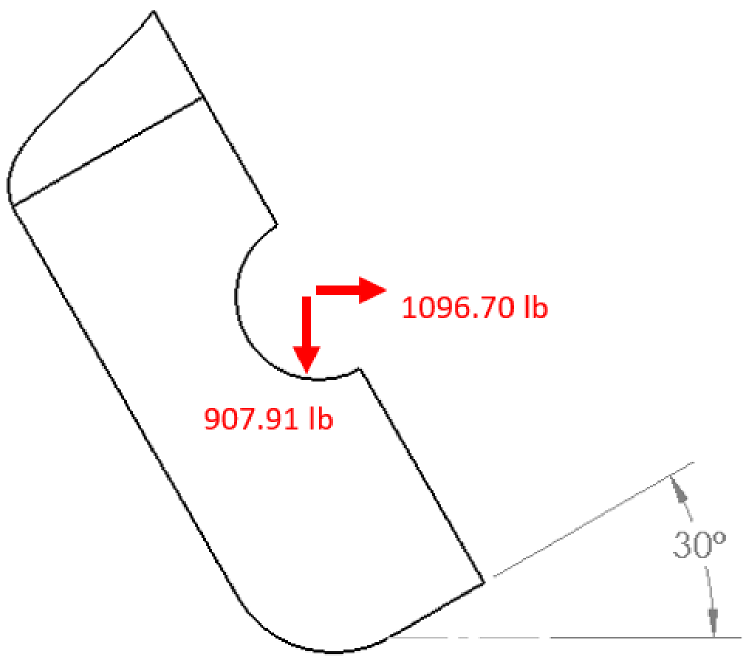


Figure 132. Section A-A Position 1

To calculate stress on section A-A, forces are required to be re-organized horizontally and vertically along the cross-section. Therefore, the shear force and bending moment above the graph doesn't concern section A-A, which means it has to be analyzed independently.

$$Horizontal\ Force = 1096.70 \times \cos 30 - 907.91 \times \sin 30 = 495.82\ lb$$

$$Vertical\ Force = 1096.70 \times \sin 30 + 907.91 \times \cos 30 = 1334.62\ lb$$

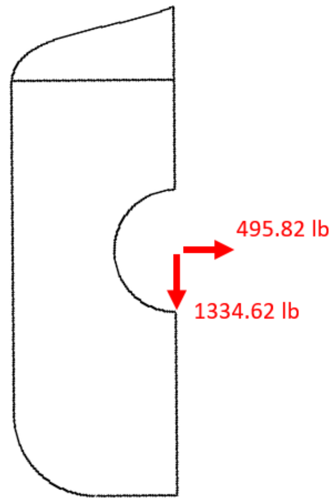


Figure 133. Section A-A Position 2

2.2.5.5 Section A-A Properties

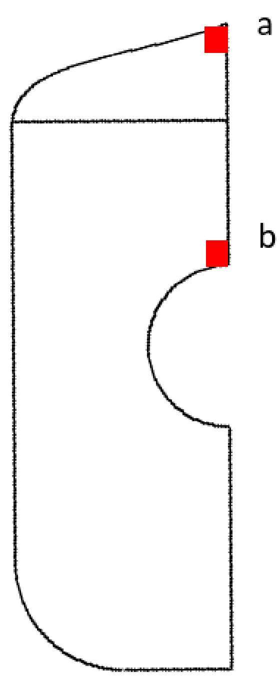


Figure 134. Locations Analyzed

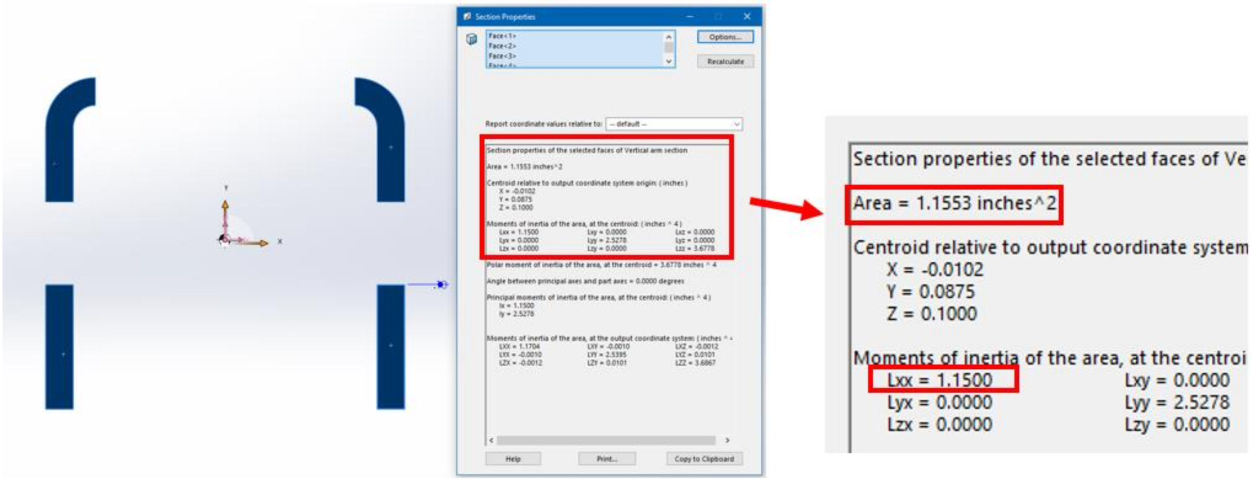


Figure 135. Section A-A Properties

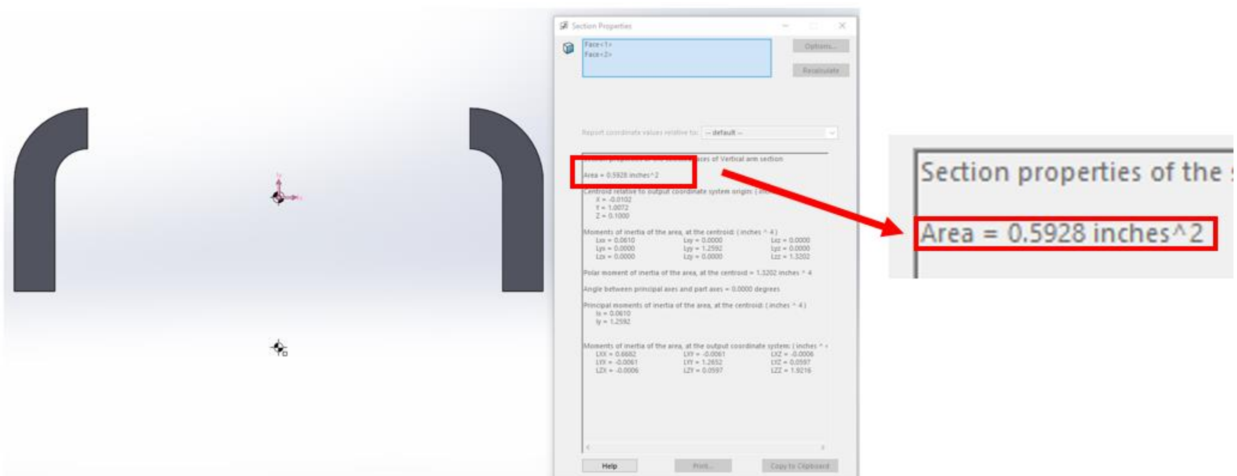


Figure 136. A_P at b on Section A-A

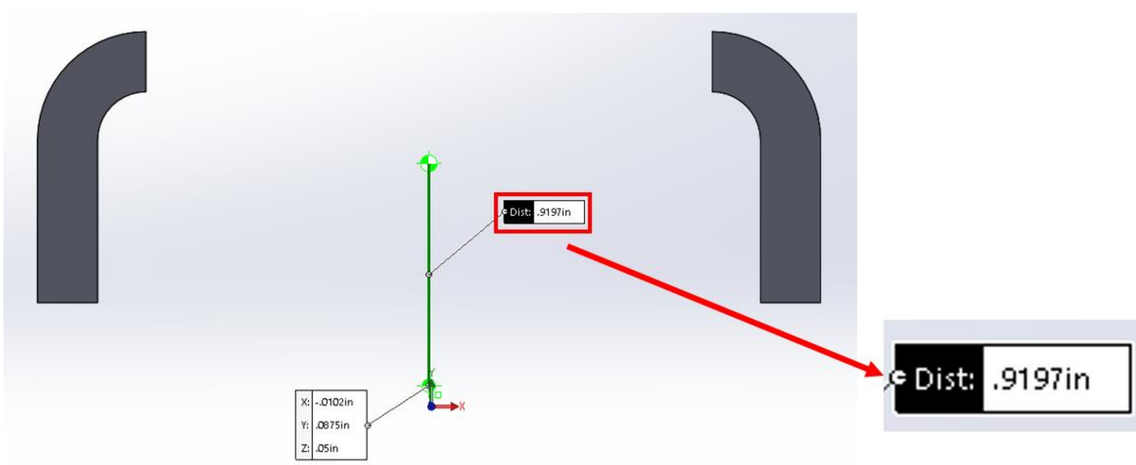


Figure 137. $\overline{Y}$ at b on Section A-A

2.2.5.6 Section A-A Transverse Shear Stress

Transverse shear stress applies to at b.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.5928\ in^2 \times 0.9197\ in$$

$$= 0.5452\ in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{1334.62\ lb\ \times 0.5452\ in^3}{1.15\ \mathrm{in}^4\ \times 0.5\ in}$$

$$= 1265.5\ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.5.7 Section A-A Analysis

<u>Stress at a</u>

a at the section A-A has no stress.

<u>Stress at b</u>

In summary, b at section A-A has 1265.5 psi shear stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\tau} = \frac{43000}{1270} = 33.8$$

2.2.5.8 Section B-B Properties

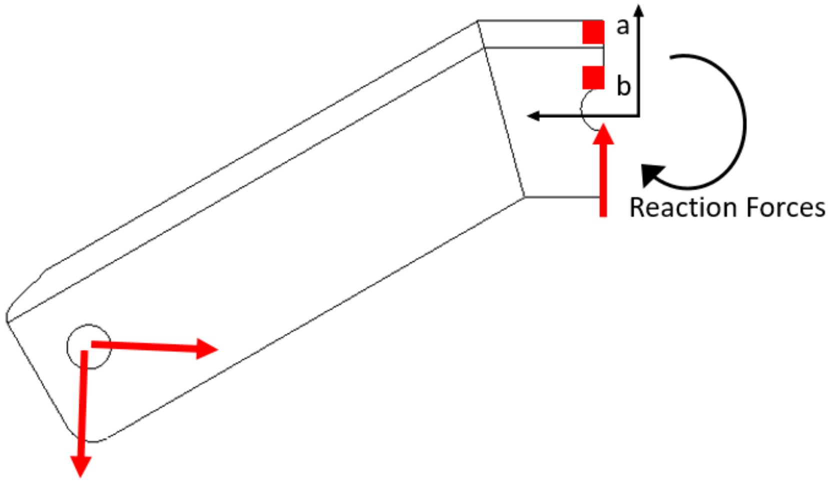


Figure 138. Locations analyzed

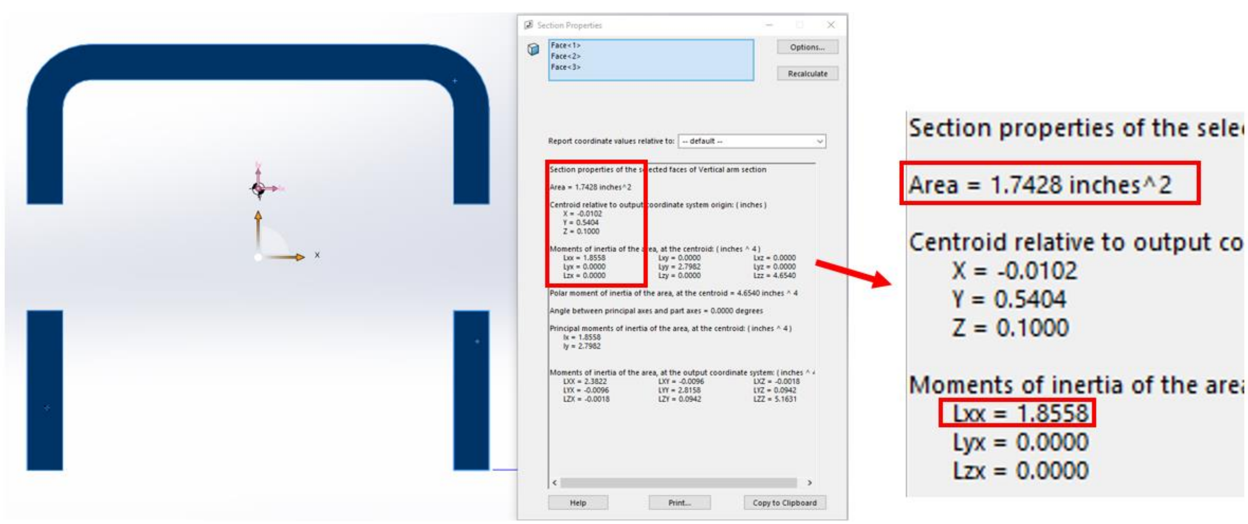


Figure 139. Section B-B Properties

Axial compressive and bending moment stress apply to at a on section B-B.

Axial compressive, bending moment and transverse shear stress apply to at b on section B-B.

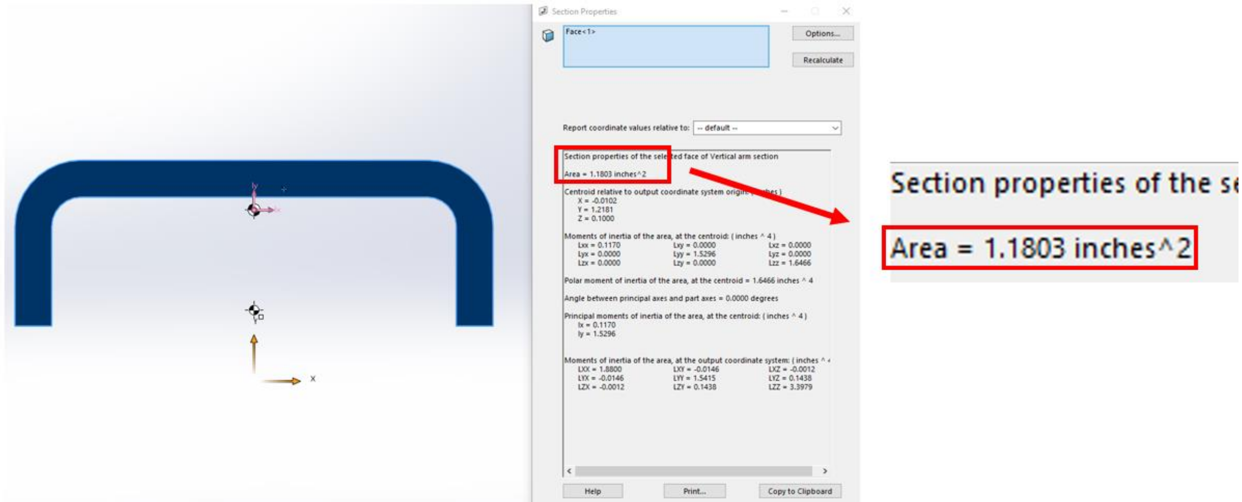


Figure 140. A_P at b on Section B-B

Figure 141. $\overline{Y}$ at b on Section B-B

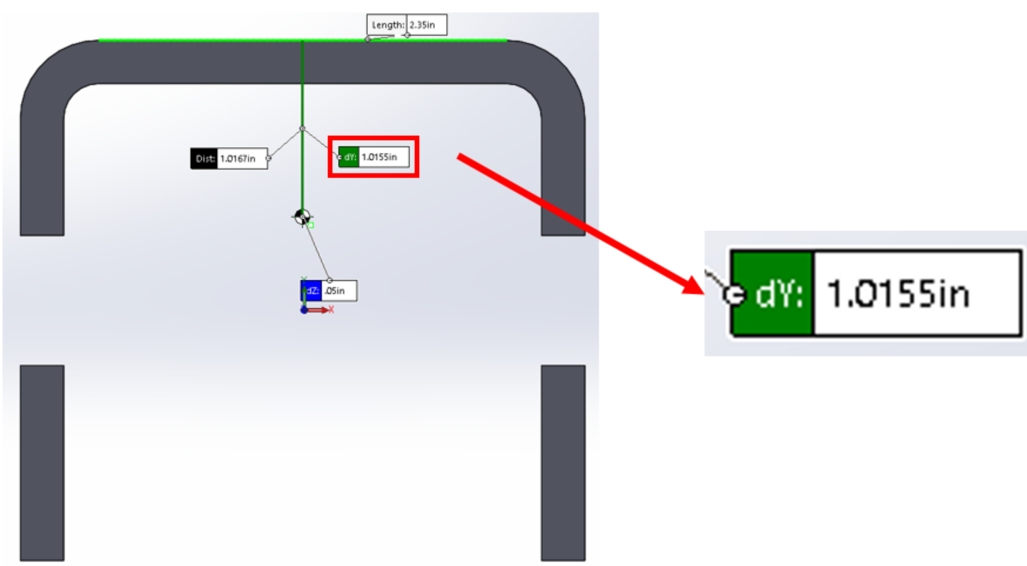


Figure 142. c at a on Section B-B

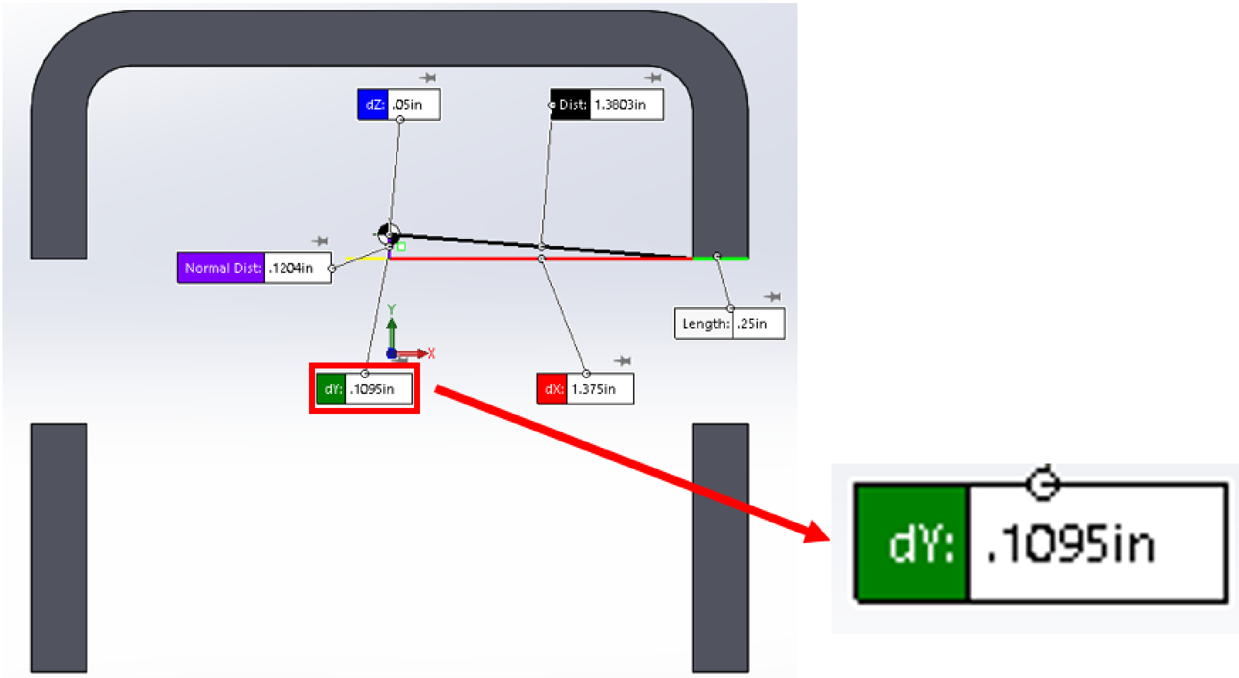


Figure 143. c at b on Section B-B

2.2.5.9 Section B-B Axial Compressive Stress

$$\sigma = \frac{F}{A} = \frac{1096.70\ lb}{1.7428\ \text{in}^2} = 629.27\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.5.10 Section B-B Bending Stress

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

$$= \frac{12300\ lb - in\ \times 1.0155\ in}{1.8558\ \text{in}^4}$$

$$= 6730.6\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

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

$$= \frac{12300\ lb - in\ \times 0.1095\ in}{1.8558\ \text{in}^4}$$

$$= 725.8\ psi\ (Compression\ at\ b)$$

2.2.5.11 Section B-B Transverse Shear Stress

Transverse shear stress applies to at b.

$$Q = A_P \cdot \overline{Y}$$

$$= 1.1803\ in^2 \times 0.6777\ in$$

$$= 0.7999 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{2.502\ lb\ \times 0.7999\ in^3}{1.8558\ \text{in}^4\ \times 0.5\ in}$$

$$= 2.16\ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

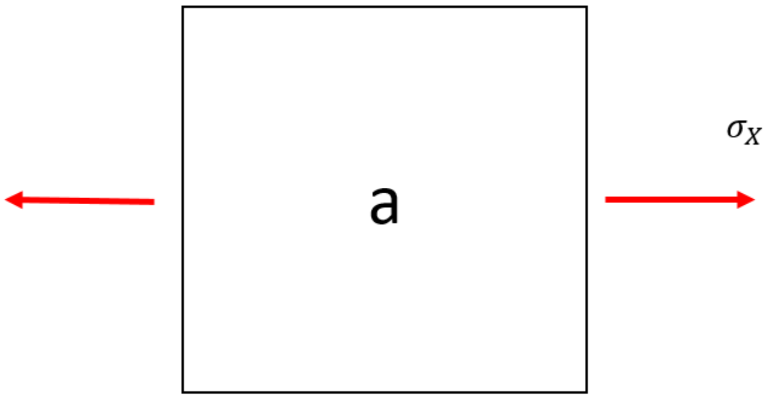
$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.5.12 Section B-B Analysis

<u>Stress at a</u>



$$\sigma_X = -629.27\,psi + 6730.6\,psi$$
$$= 6101.33\,psi$$

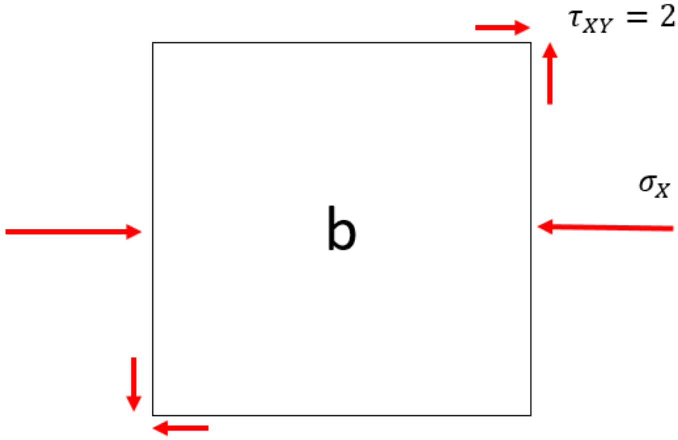
Figure 144. Applied Stress at a on Section B-B.

In summary, a at section B-B has 6101.33 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{6100} = 7.0$$

<u>Stress at b</u>



$$\tau_{XY} = 2.16\,psi\ (ccw)$$

$$\sigma_X = -629.27\,psi - 725.8\,psi$$
$$= -1355.07\,psi$$

Figure 145. Applied Stress at b on Section B-B.

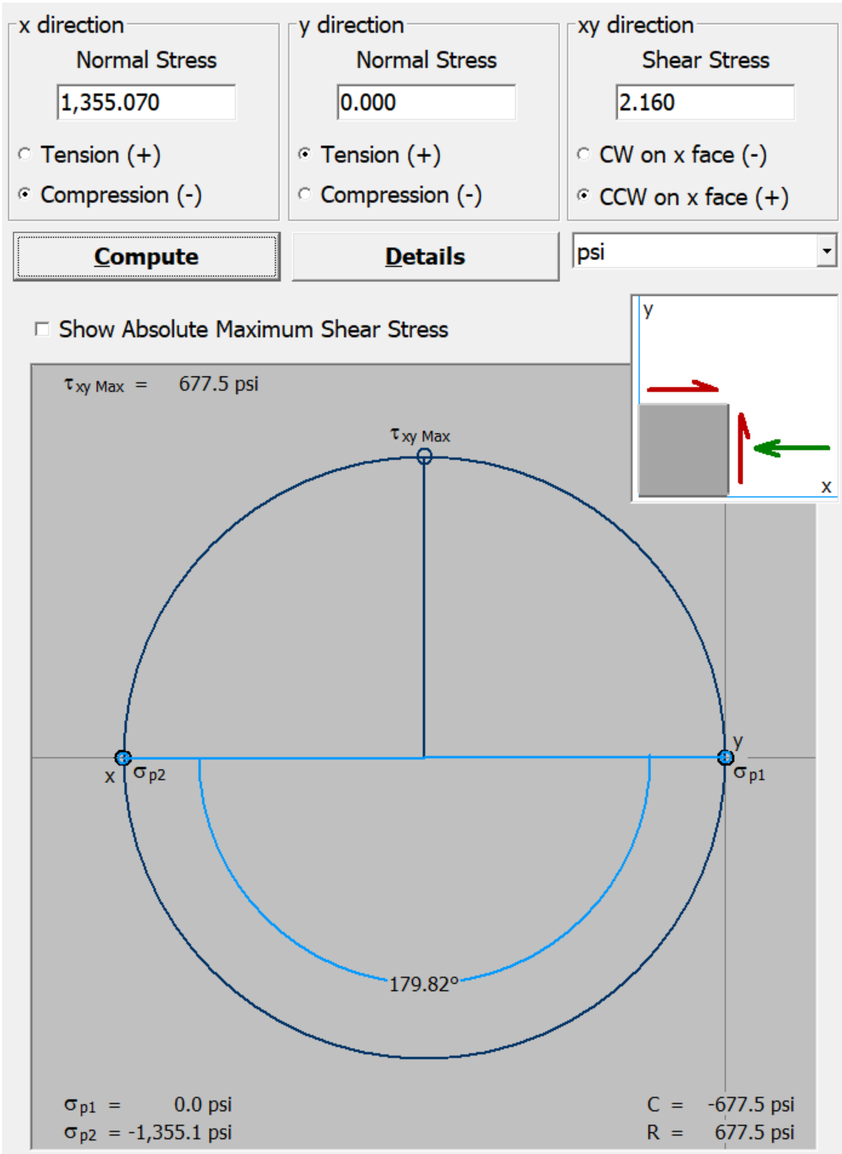


Figure 146. Principal Stress at b on Section B-B

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{0^2 + (-1355.1)^2 - 0(-1355.1)} = 1355.1\ psi$$

In summary, b at section B-B has $\sigma' = 1355.1\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{1360} = 31.6$$

2.2.5.13 Section C-C Properties

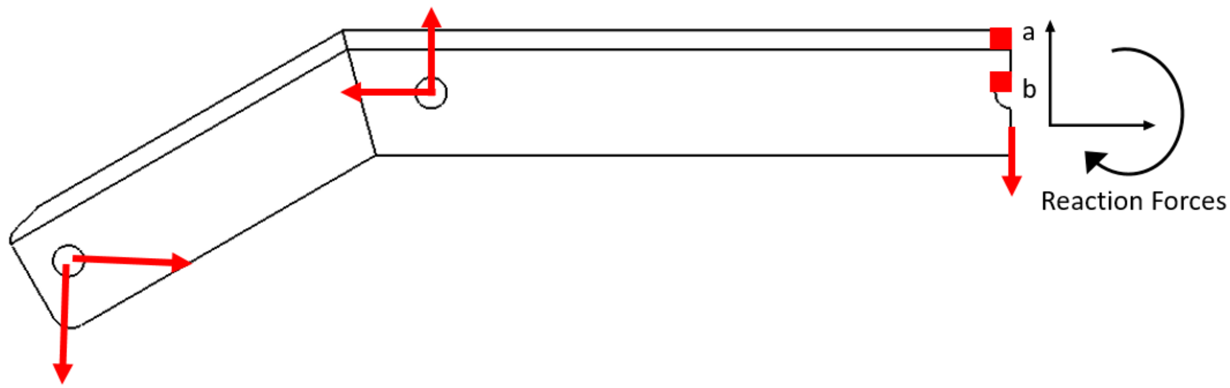


Figure 147. Locations analyzed

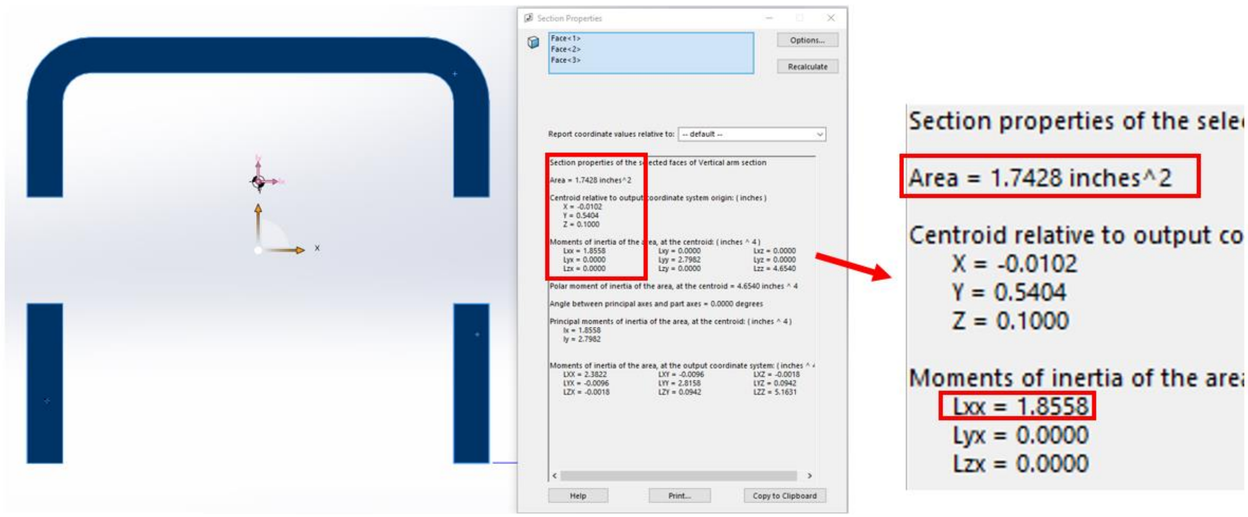


Figure 148. Section C-C Properties

Axial tensile and bending moment stress apply to at a on section C-C.

Axial tensile, bending moment and transverse shear stress apply to at b on section C-C.

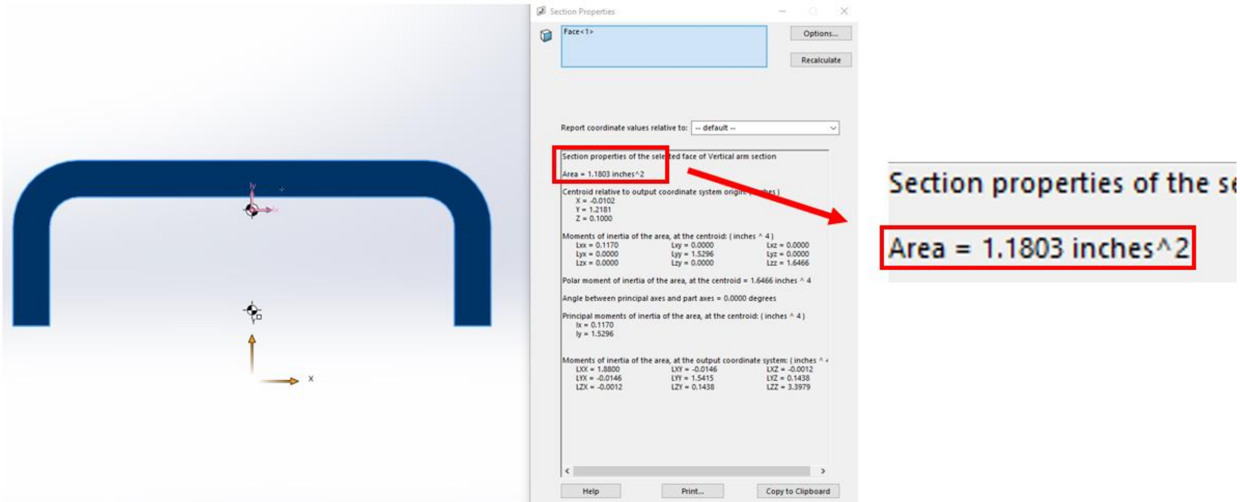


Figure 149. A_P *at b on Section C-C*

Figure 150. $\overline{Y}$ *at b on Section C-C*

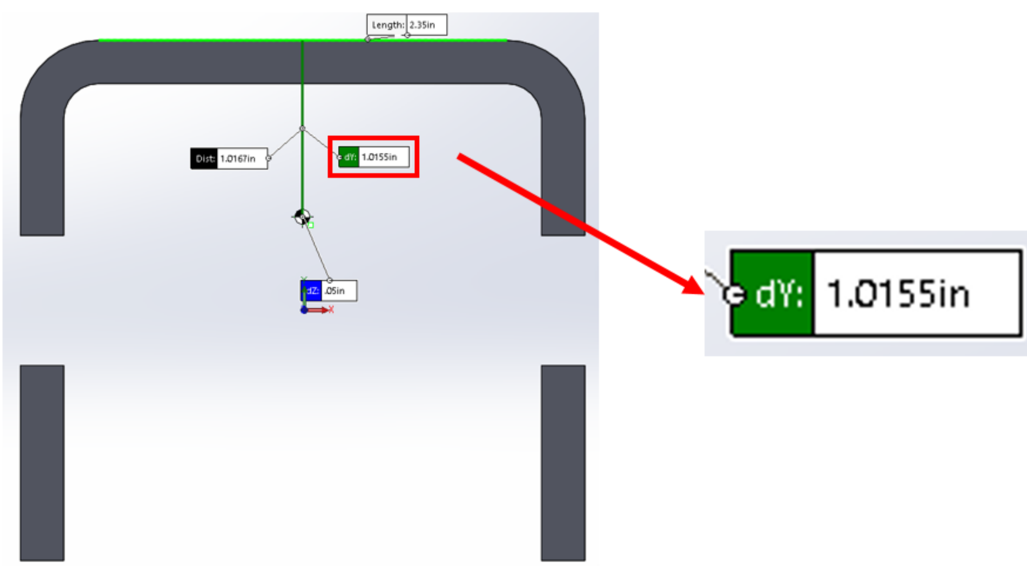


Figure 151. c at a on Section C-C

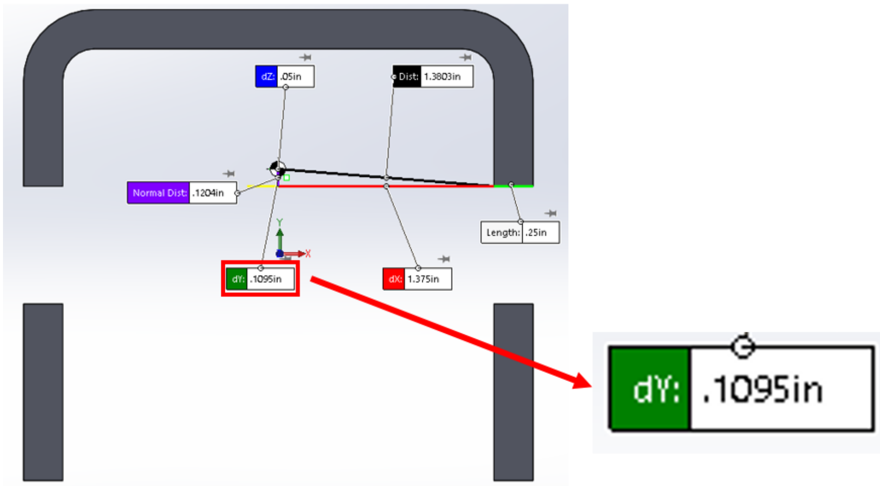


Figure 152. c at b on Section C-C

2.2.5.14 Section C-C Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{697.7\ lb}{1.7428\ \mathrm{in}^2}$$

$$= 400.33\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.5.15 Section C-C Bending Stress

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

$$= \frac{13600\ lb - in\ \times 1.0155\ in}{1.8558\ \ \mathrm{in}^4}$$

$$= 7442.0\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

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

$$= \frac{13600\ lb - in\ \times 0.1095\ in}{1.8558\ \ \mathrm{in}^4}$$

$$= 802.5\ psi\ (Compression\ at\ b)$$

2.2.5.16 Section C-C Transverse Shear Stress

Transverse shear stress applies to at b.

$$Q = A_P \cdot \overline{Y}$$

$$= 1.1803\ in^2 \times 0.6777\ in$$

$$= 0.7999 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{40.45\ lb\ \times 0.7999\ in^3}{1.8558\ \text{in}^4\ \times 0.5\ in}$$

$$= 34.87\ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

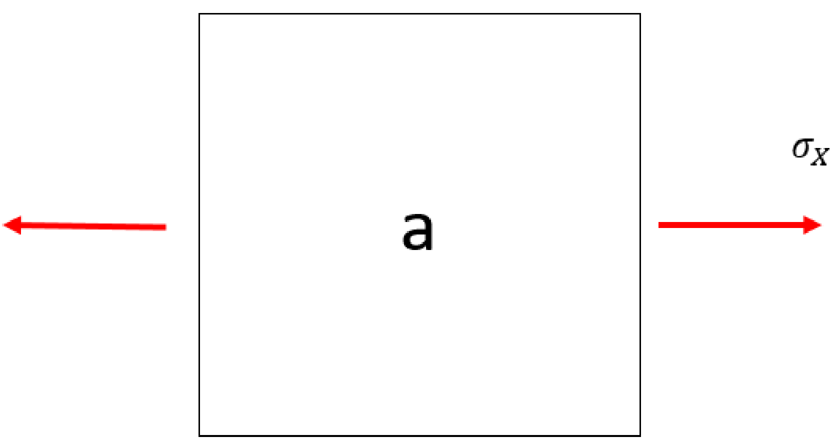
$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.5.17 Section C-C Analysis

Stress at a



$$\sigma_X = 400.33\ psi + 7442.0\ psi$$
$$= 7842.33\ psi$$

Figure 153. Applied Stress at a on Section C-C

In summary, a at section C-C has 7842.33 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{7840} = 5.4$$

Stress at b

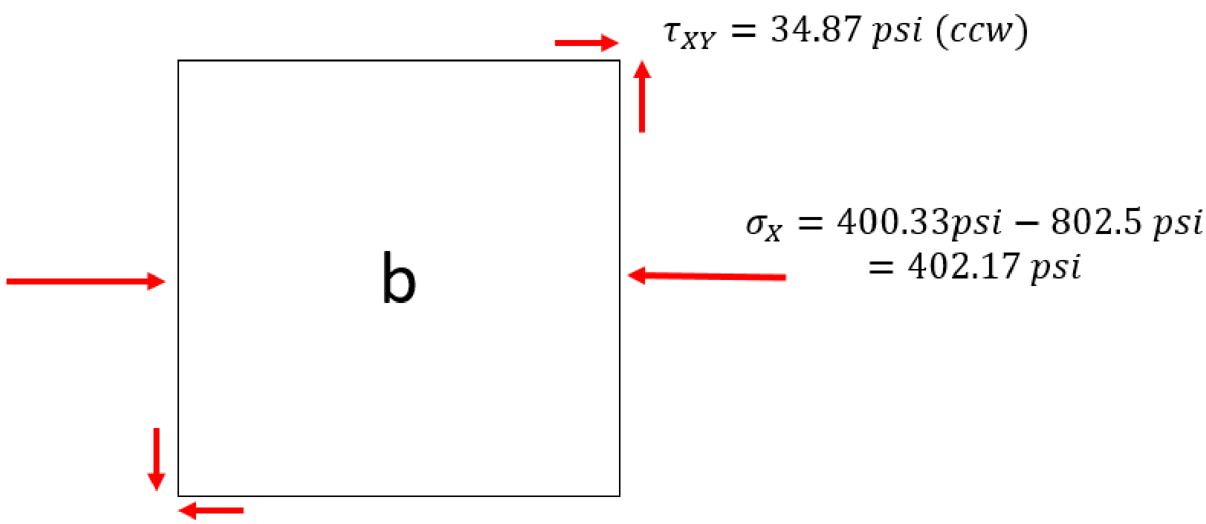


Figure 154. Applied Stress at b on Section C-C

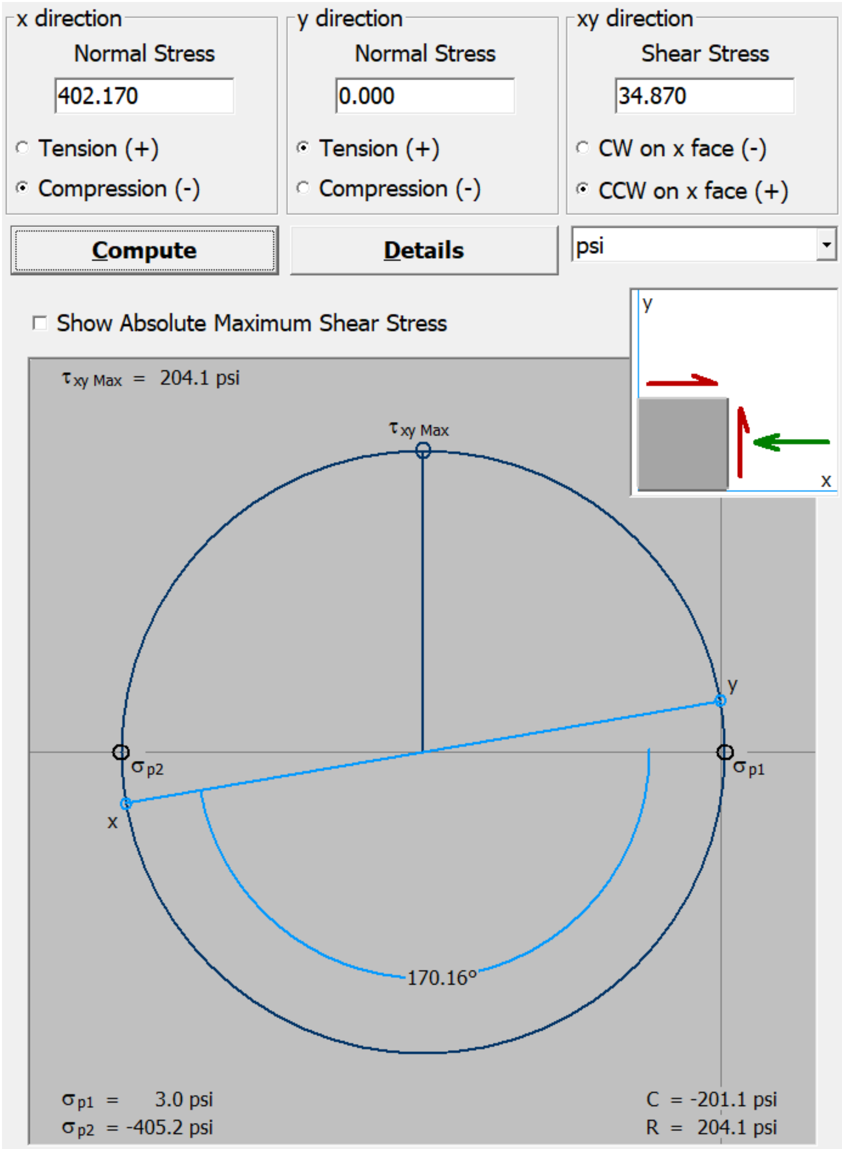


Figure 155. Principal Stress at b on Section C-C

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{3^2 + (-405.2)^2 - 3(-405.2)} = 406.7\ psi$$

In summary, b at section C-C has $\sigma' = 406.7\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{407} = 105.6$$

2.2.5.18 Section D-D Properties

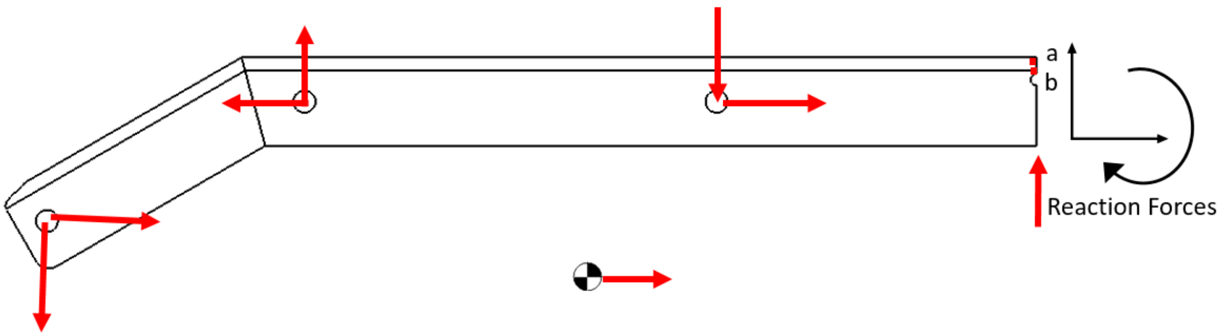


Figure 156. Locations analyzed

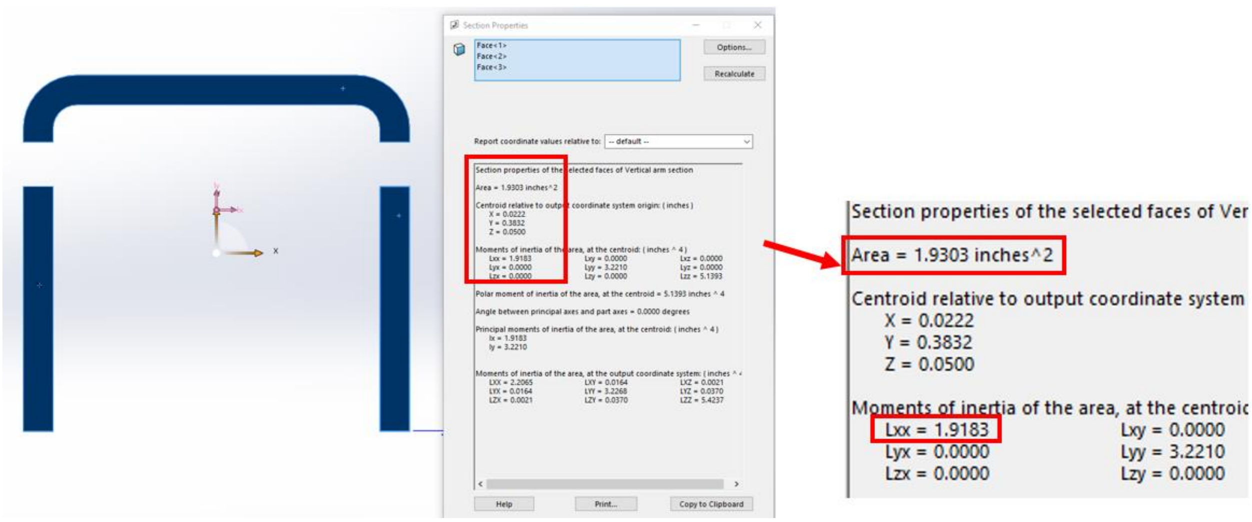


Figure 157. Section D-D Properties

Axial tensile and bending moment stress apply to at a on section D-D.

Axial tensile, bending moment and transverse shear stress apply to at b on section D-D.

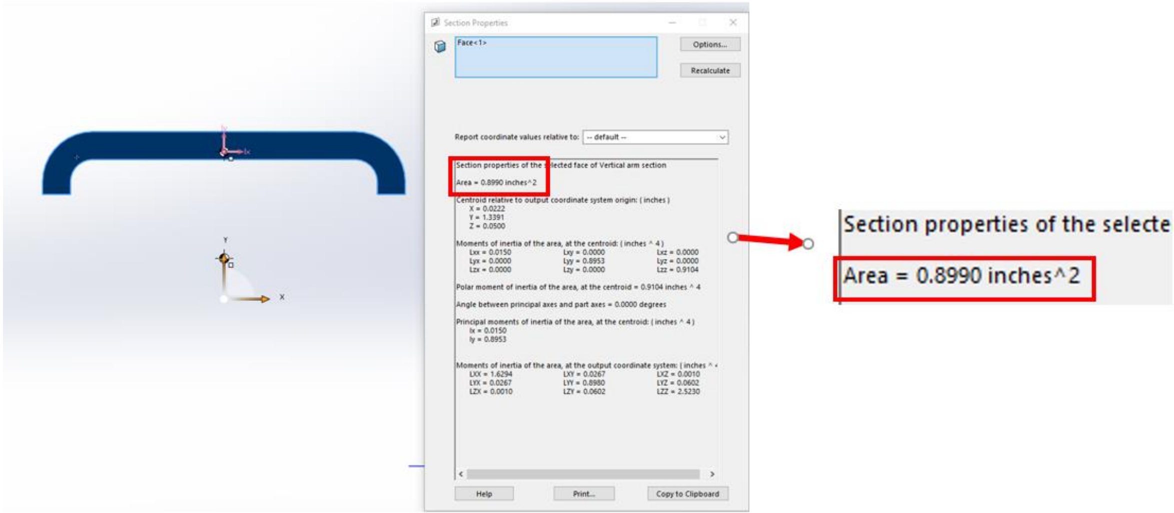


Figure 158. A_P at b on Section D-D

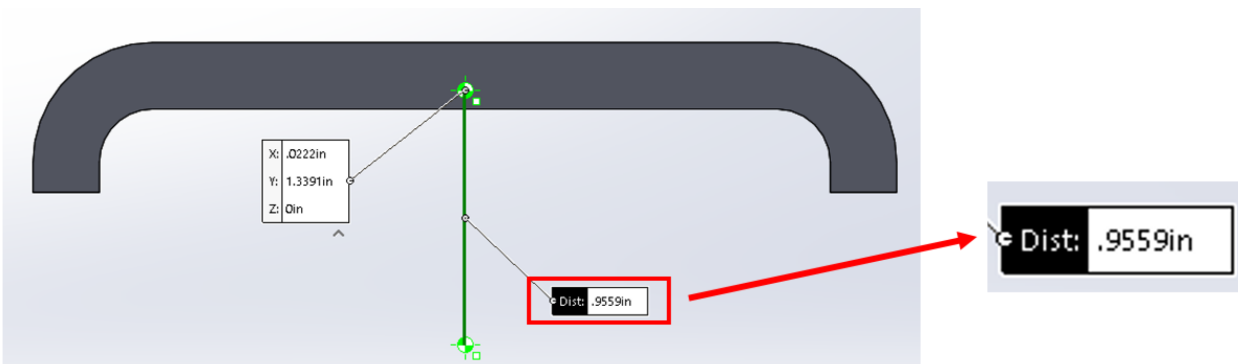


Figure 159. $\overline{Y}$ at b on Section D-D

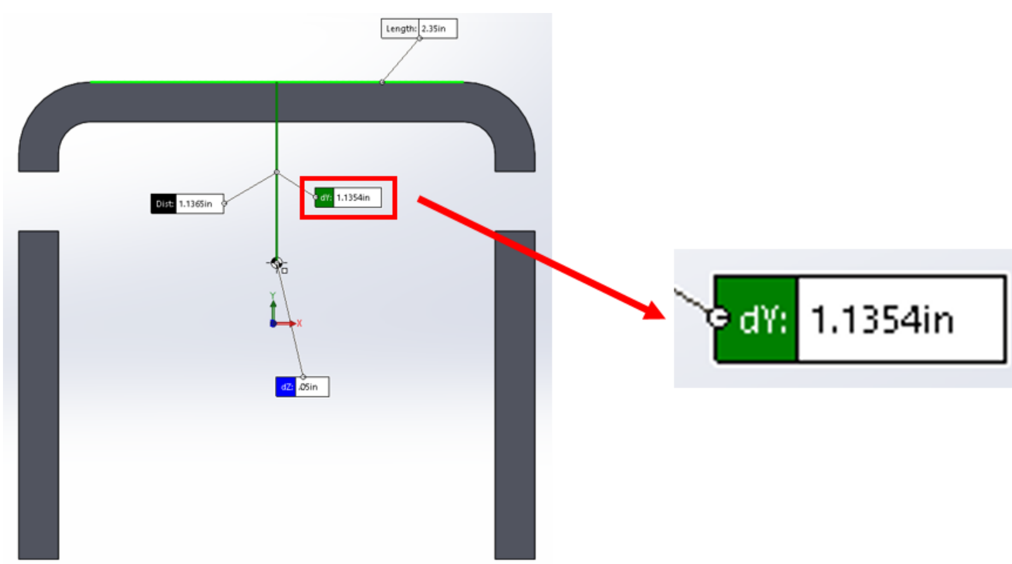


Figure 160. c at a on Section D-D

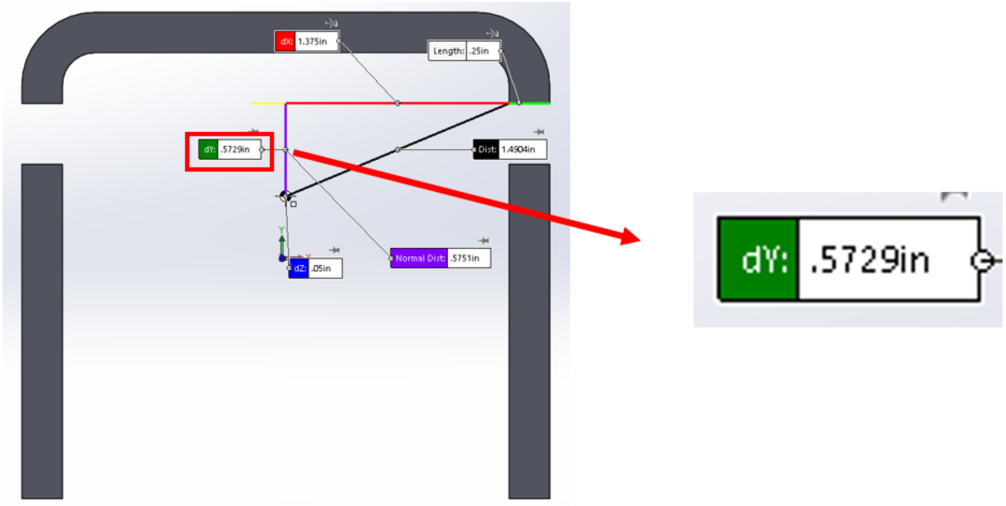


Figure 161. c at b on Section D-D

2.2.5.19 Section D-D Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{633.9\ lb}{1.9303\ \text{in}^2}$$

$$= 328.4\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.5.20 Section D-D Bending Stress

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

$$= \frac{14000\ lb - in\ \times 1.1354\ in}{1.9183\ \text{in}^4}$$

$$= 8286.3\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

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

$$= \frac{14000\ lb - in\ \times 0.5729\ in}{1.9183\ \ \text{in}^4}$$

$$= 4181.1\ psi\ (Tension\ at\ b)$$

2.2.5.21 Section D-D Transverse Shear Stress

Transverse shear stress applies to at b.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.8990\ in^2 \times 0.9559\ in$$

$$= 0.8594\ in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{7.37\ lb\ \times 0.8594\ in^3}{1.9183\ \text{in}^4\ \times 0.5\ in}$$

$$= 6.6\ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

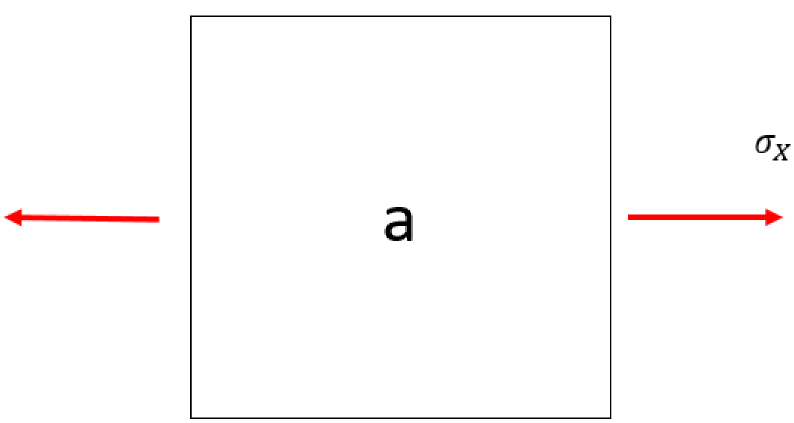
$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.5.22 Section D-D Analysis

<u>Stress at a</u>



$$\sigma_X = 328.4\ psi + 8286.3\ psi$$
$$= 8614.7\ psi$$

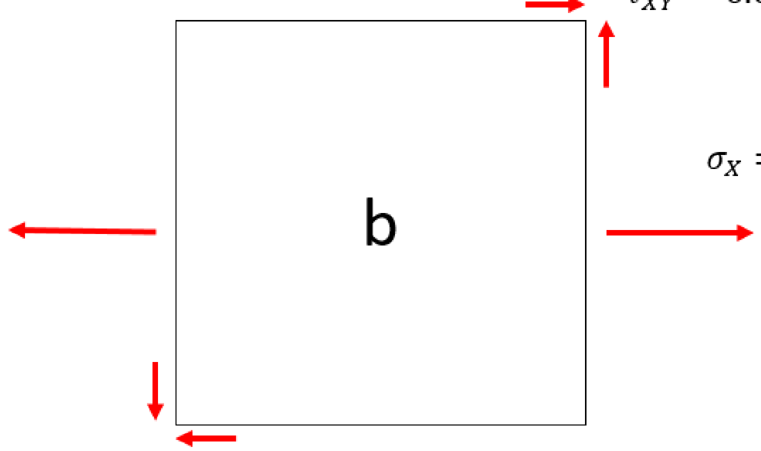
Figure 162. Applied Stress at a on Section D-D

In summary, a at section D-D has 8614.7 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{8610} = 4.9$$

<u>Stress at b</u>



$\tau_{XY} = 6.6\,psi\ (ccw)$

$\sigma_X = 328.4\,psi + 4181.1\,psi = 4509.5\,psi$

Figure 163. Applied Stress at b on Section D-D

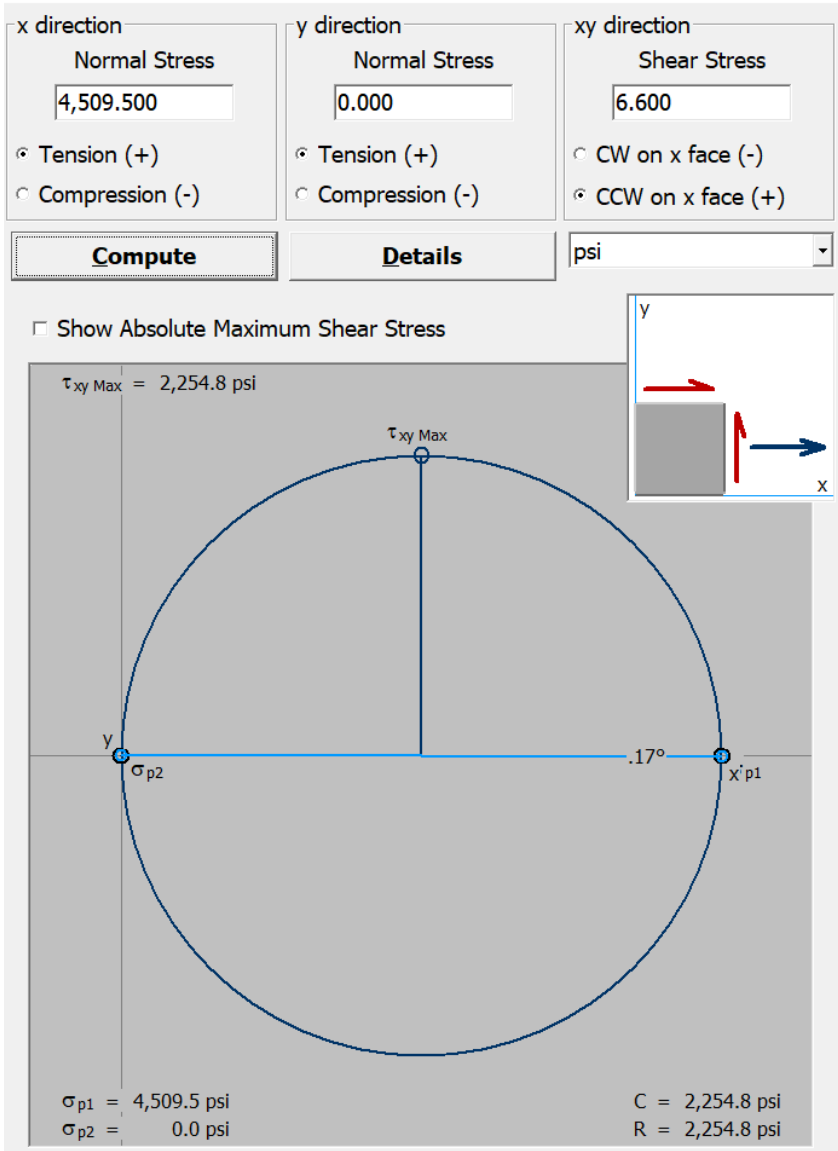


Figure 164. Principal Stress at b on Section D-D

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{4509.5^2 + (0)^2 - 4509.5(0)} = 4509.5\ psi$$

In summary, b at section D-D has $\sigma' = 4509.5\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{4510} = 9.5$$

2.2.5.23 Section E-E Properties

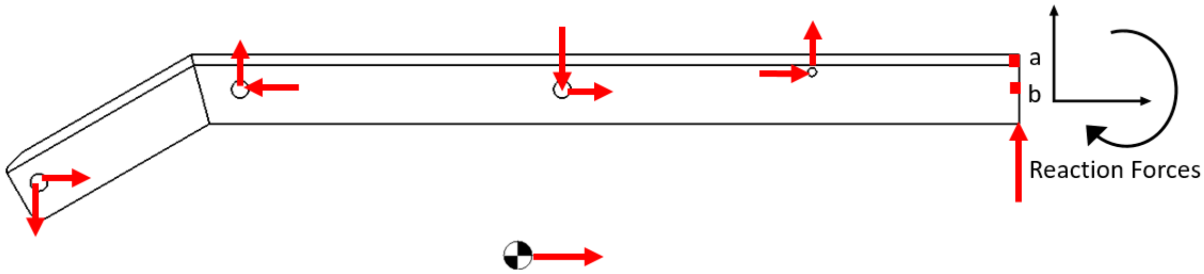


Figure 165. Locations analyzed

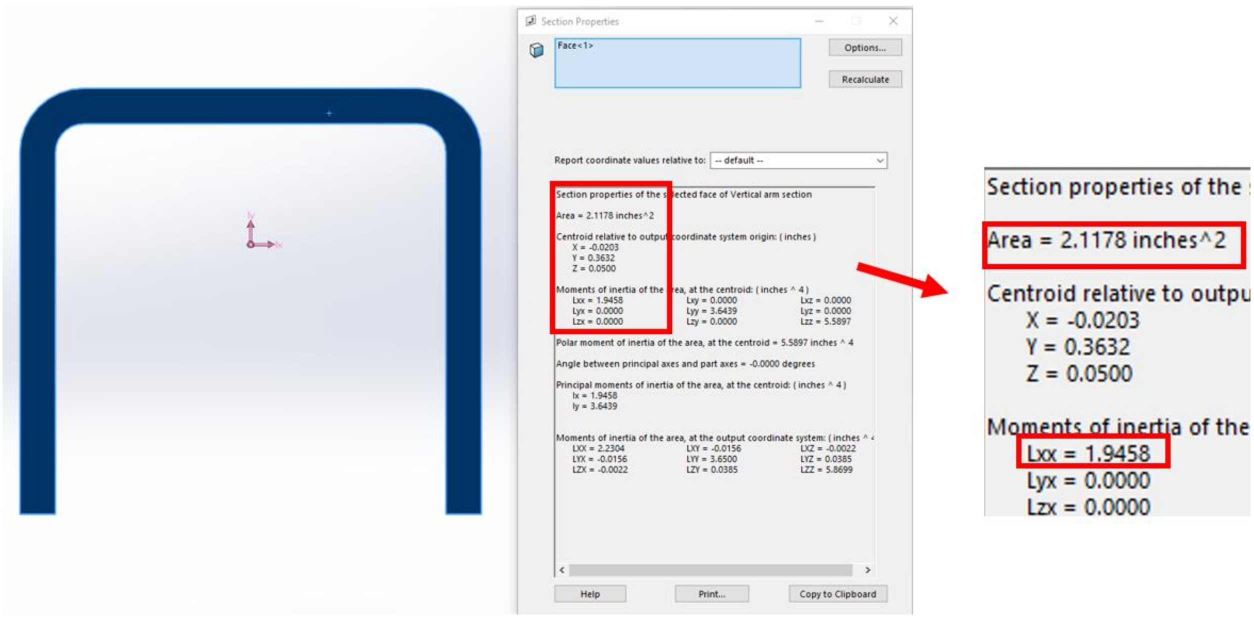


Figure 166. Section E-E Properties

Axial tensile and bending moment stress apply to at a on section E-E.

Axial tensile and transverse shear stress apply to at b on section E-E.

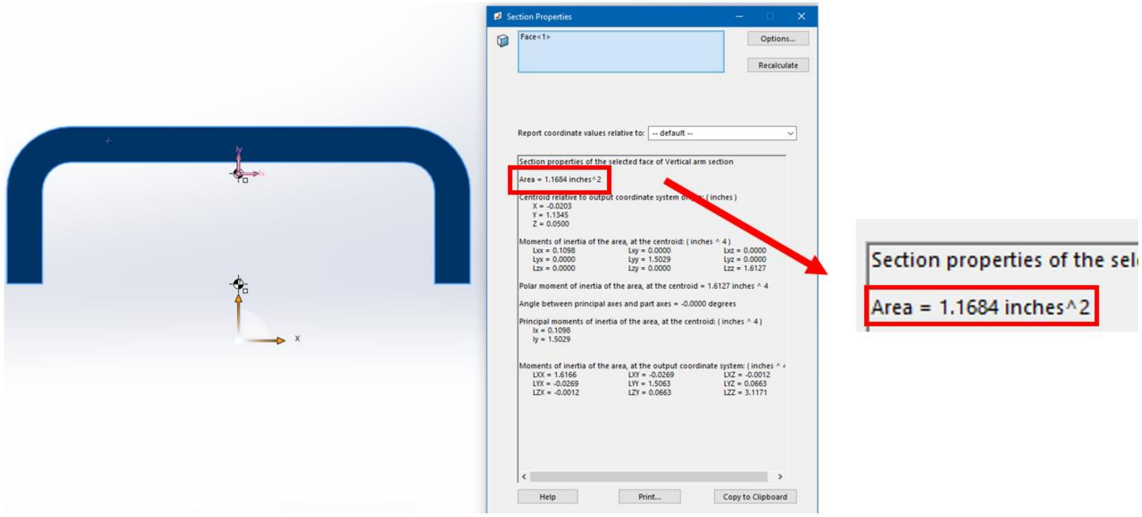


Figure 167. A_P at b on Section E-E

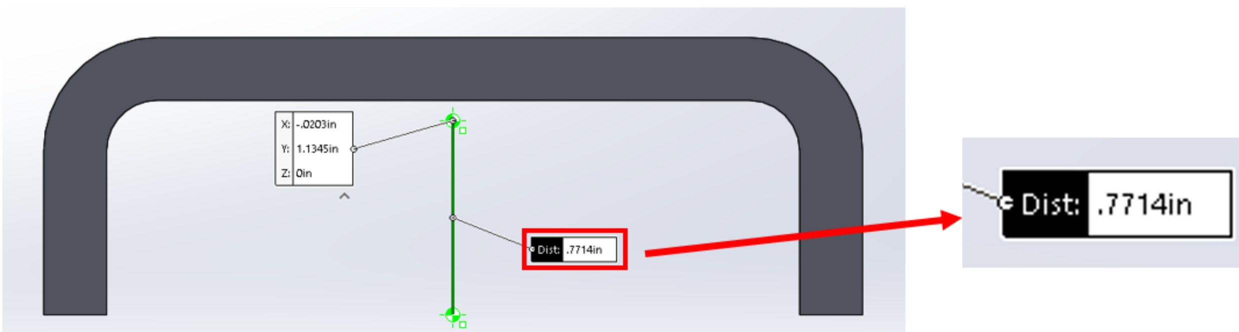


Figure 168. $\overline{Y}$ at b on Section E-E

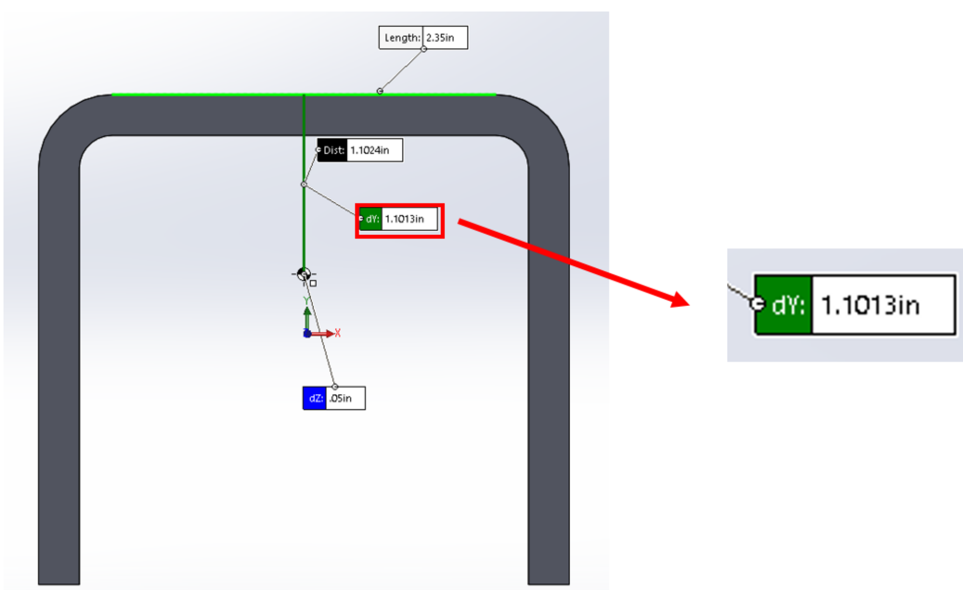


Figure 169. c at a on Section E-E

2.2.5.24 Section E-E Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{525.44\ lb}{2.1178\ \text{in}^2}$$

$$= 248.1\ psi$$

Where, (1 Mott, p. 23)
$\sigma = Axial\ stress, psi$
$F = Force, lbs$
$A = Area, in^2$

2.2.5.25 Section E-E Bending Stress

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

$$= \frac{14100\ lb - in\ \times 1.1013\ in}{1.9458\ \text{in}^4}$$

$$= 7980.4\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)
$\sigma = Axial\ stress, ksi$
$M = Bending\ moment, lb - in$
$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$
$I = Moment\ of\ inertia, in^4$

2.2.5.26 Section E-E Transverse Shear Stress

Transverse shear stress applies to at b.

$$Q = A_P \cdot \overline{Y}$$

$$= 1.1684\ in^2 \times 0.7714\ in$$

$$= 0.9013\ in^3$$

Where, (1 Mott, p. 462)
$Q = First\ moment\ of\ area, in^3$
$A_P = Area\ of\ a\ part\ of\ the\ cross$
$section\ that\ lies\ away\ from\ the\ axis, in^2$
$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{7057.3\ lb\ \times 0.9013\ in^3}{1.9458\ \text{in}^4\ \times 0.5\ in}$$

$$= 6537.9\ psi$$

Where, (1 Mott, p. 462)
$\tau = Shear\ stress, psi$
$V = Vertical\ shearing\ force, lb$
$I = Moment\ of\ inertia, in^4$
$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.5.27 Section E-E Analysis

<u>Stress at a</u>

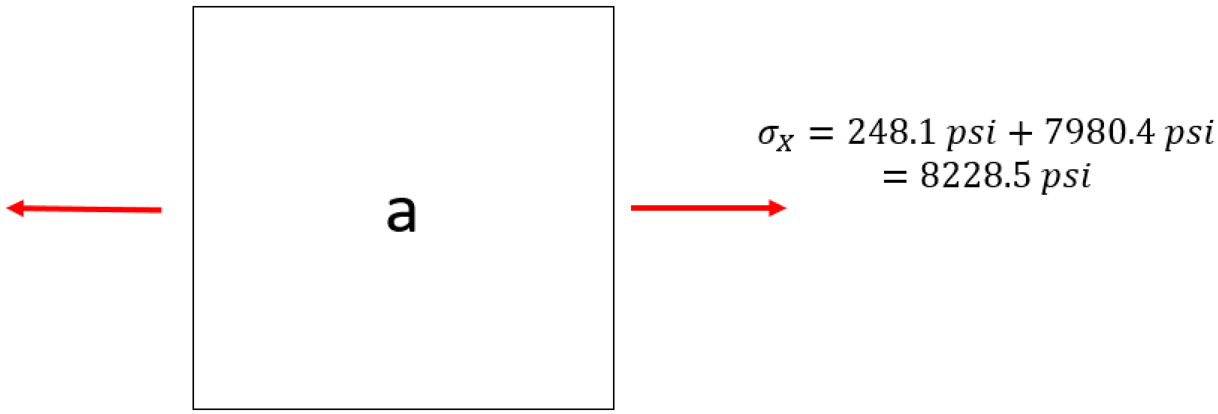


Figure 170. Applied Stress at a on Section E-E

In summary, a at section E-E has 8228.5 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{8230} = 5.2$$

<u>Stress at b</u>

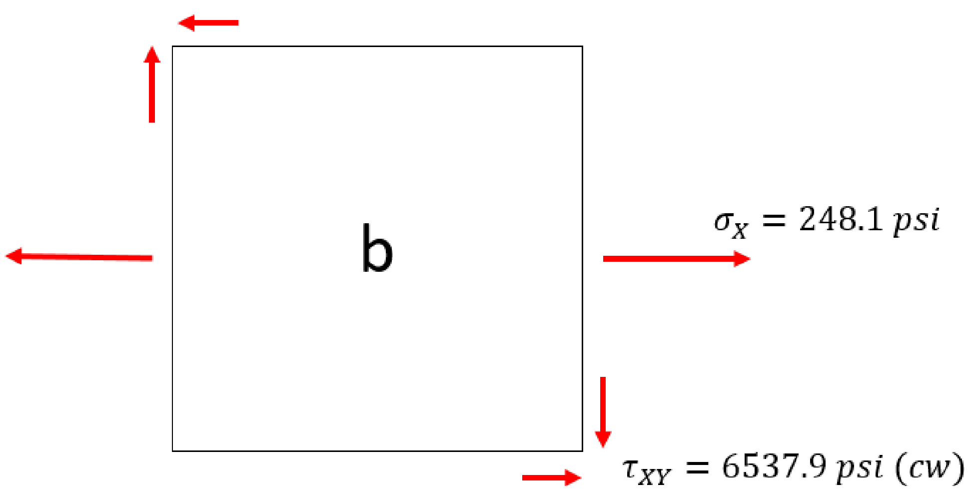


Figure 171. Applied Stress at b on Section E-E

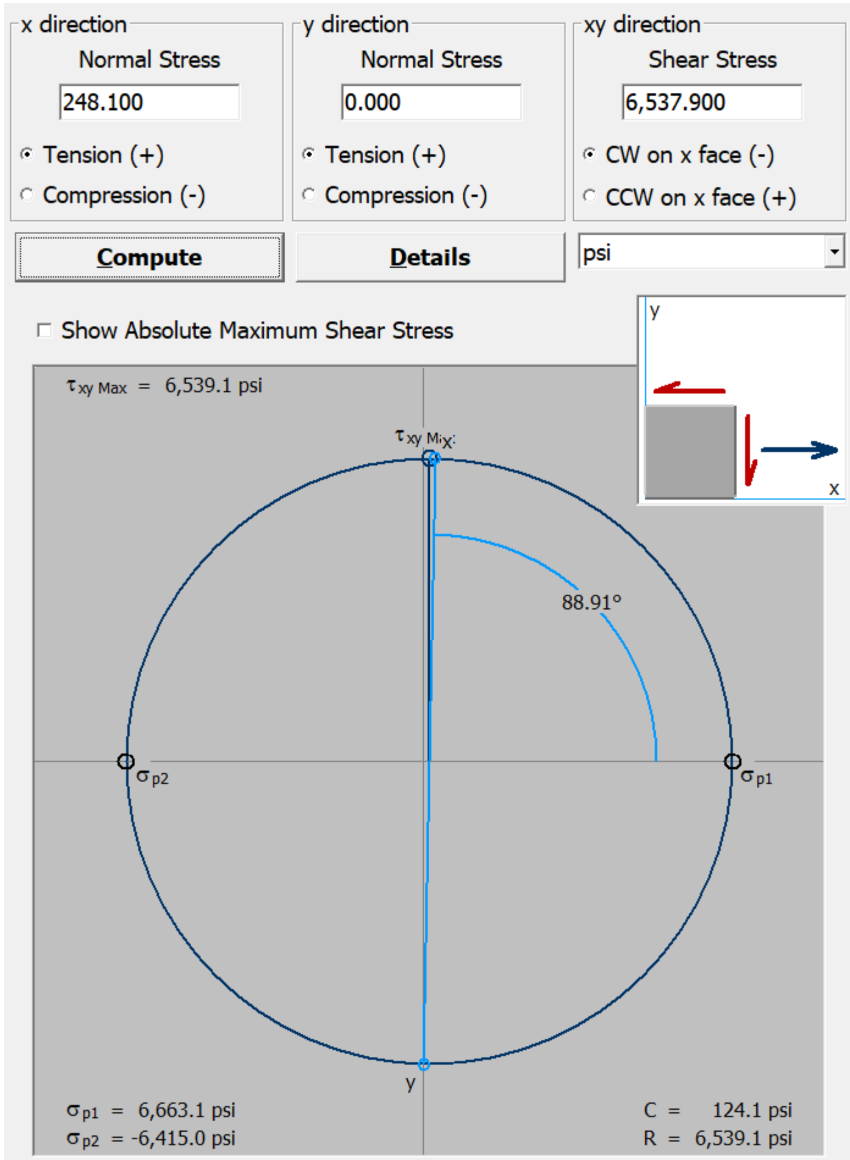


Figure 172. Principal Stress at b on Section E-E

MDET (2 Mott, p. 196)

$$\sigma' = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{6663.1^2 + (-6415)^2 - 6663.1(-6415)} = 11326.6\, psi$$

In summary, b at section E-E has $\sigma' = 11326.6\, psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{11320} = 3.7$$

2.2.5.28 Section F-F Properties

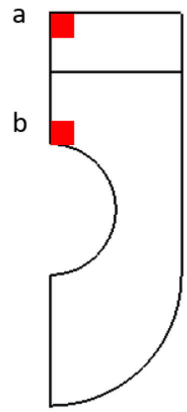


Figure 173. Locations analyzed

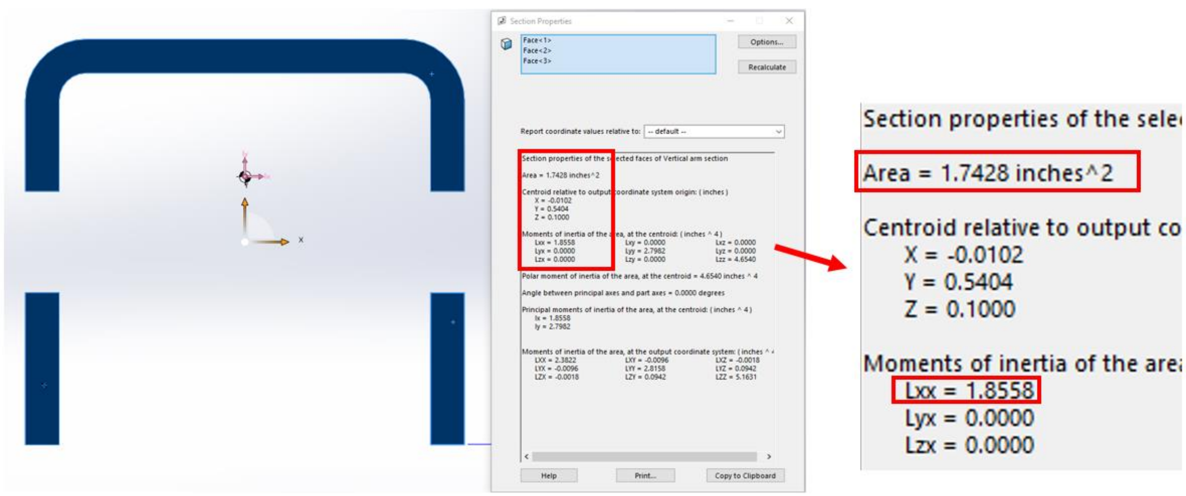


Figure 174. Section F-F Properties

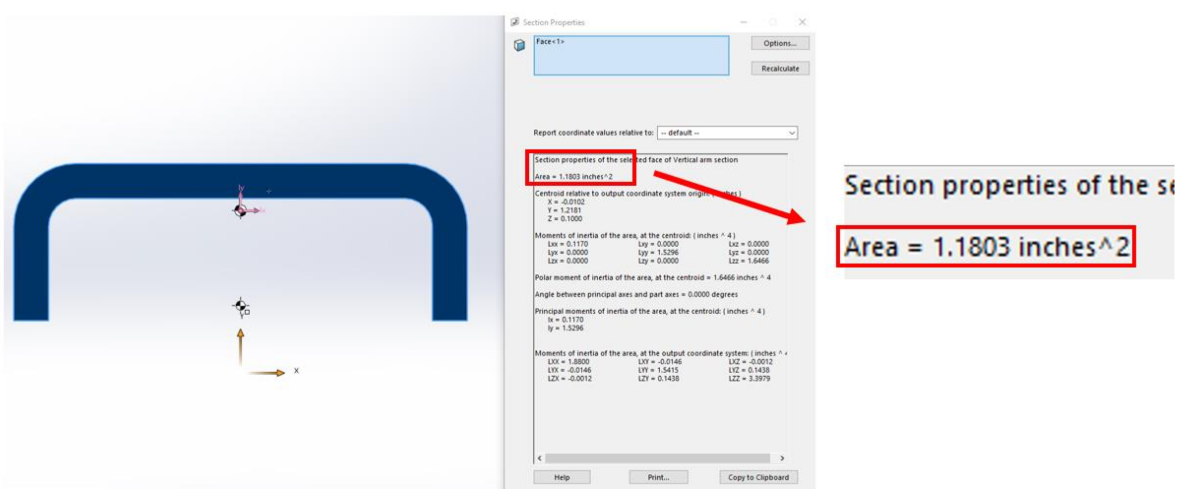


Figure 175. A_P at b on Section F-F

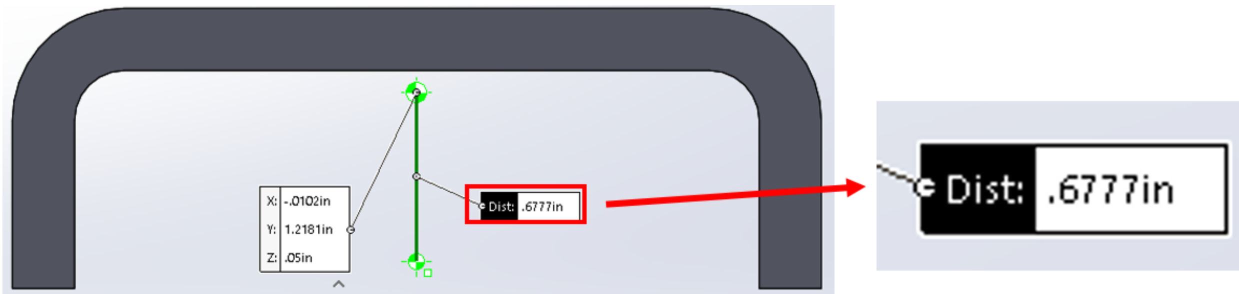


Figure 176. $\overline{Y}$ at b on Section F-F

2.2.5.29 Section F-F Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{525.44\ lb}{1.7428\ \text{in}^2} = 301.5\ \ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.5.30 Section F-F Transverse Shear Stress

Transverse shear stress applies to at b.

$$Q = A_P \cdot \overline{Y}$$

$$= 1.1803\ in^2 \times 0.6777\ in$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{7057.3\ lb\ \times 0.7999\ in^3}{1.8558\ \ \text{in}^4\ \times 0.5\ in}$$

$$= 6083.8\ \ psi$$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.5.31 Section F-F Analysis

Stress at a

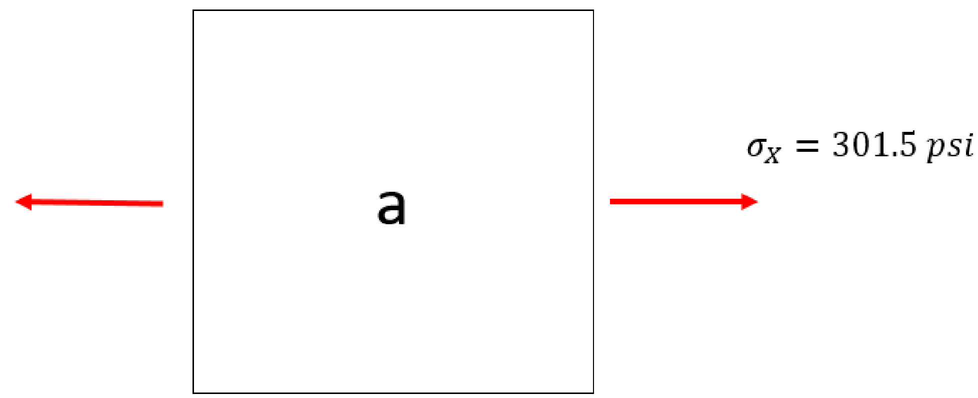


Figure 177. Applied Stress at a on Section F-F.

In summary, a at section F-F has 301.5 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{300} = 143.3$$

Stress at b

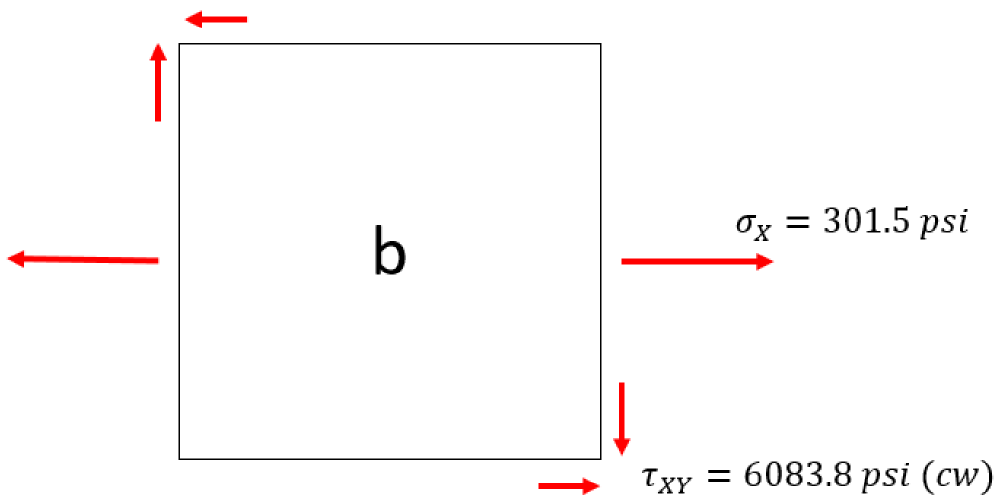


Figure 178. Applied Stress at b on Section F-F

Figure 179. Principal Stress at b on Section F-F

MDET (2 Mott, p. 196)

$$\sigma' = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{6236.4^2 + (-5934.9)^2 - 6236.4(-5934.9)} = 10541.7\ psi$$

In summary, b at section F-F has $\sigma' = 10541.7\ psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{10500} = 4.0$$

2.2.5.32 Tear Out Stress on C

Hole D, E, and I are excluded because these holes have relatively much wider areas and less force is applied.

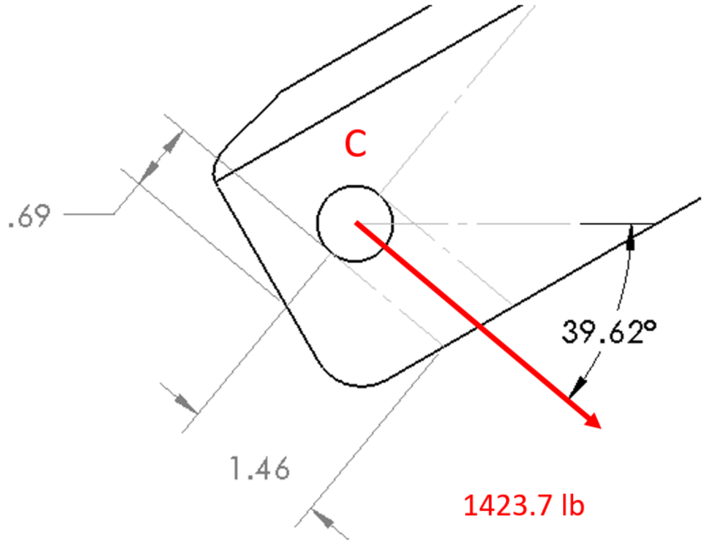


Figure 180. Vector Force on Hole C

<u>Hole C</u>

$$Vertor\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{1096.70^2 + 907.91^2}$$

$$= 1423.7\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{907.91}{1096.70}\right)$$

$$= 39.62°$$

Two plates share the force. Therefore, only half of the force, 711.9 lb is used to calculate tear out stress.

$$A_s = d \times t = 1.46 \times 0.25 = 0.365\ in^2$$

$$\tau = \frac{F}{2 \cdot A_S} = \frac{711.9}{2 \times 0.365} = 975.2\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{980} = 25.3$$

$$A_t = d \times t = 0.69 \times 0.25 = 0.1725\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_T} = \frac{711.9}{2 \times 0.1725} = 2063.5\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{2060} = 20.8$$

2.2.5.33 Tear Out Stress on J

Hole J

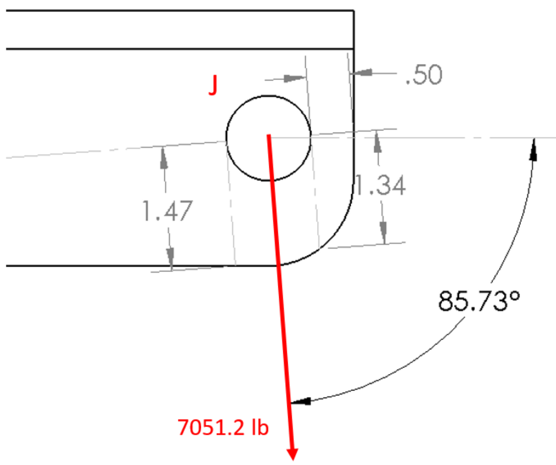


Figure 181. Vector Force on Hole J

$$Vector\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{525.44^2 + 7031.58^2}$$

$$= 7051.2\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{7031.58}{525.44}\right)$$

$$= 85.73°$$

Two plates share the force. Therefore, only half of the force, 3525.6 lb is used to calculate tear out stress.

$A_s = d \times t = 1.34 \times 0.25 = 0.335\ in^2$

$$\tau = \frac{F}{2 \cdot A_s} = \frac{3525.6}{2 \times 0.335} = 5262.1\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{5262.1} = 4.7$$

$A_t = d \times t = 0.5 \times 0.25 = 0.125\ in^2$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{3525.6}{2 \times 0.125} = 14102.4\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{14100} = 3.0$$

2.2.6 Bridge Plate

2.2.6.1 General Information

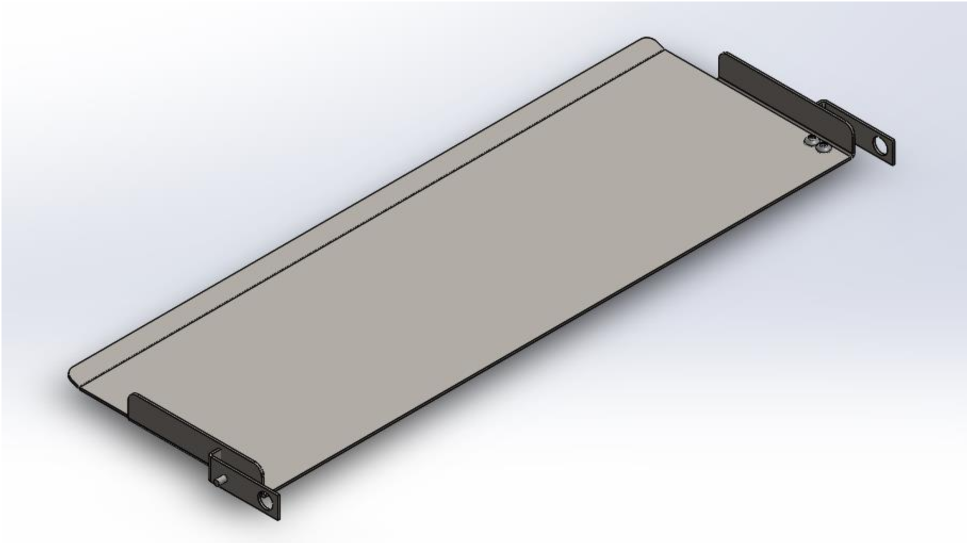


Figure 182. Bridge Plate

The bridge plate is a component protecting a wheelchair user not to fall into the ground. This component has two points, K_2 and L, which are connected with other components. Distance between the two places is 2.43 inches and only weight of the component, 33.1 lbs, applies to the component except for forces applied to two places. It causes negligible shear force and bending moment. Rather, tear-out and bending stress have to be reviewed. Therefore, only tear-out and bending stress are calculated to verify the safety of the part. When the lift is down, bigger vector forces apply to the component. The forces are shared with two brackets. Only half of the forces are applied to each bracket. The following table shows the recalculated forces.

Table 6. Recalculated Forces

Location	Force (lb)	Half Force (lb)
K_{X2}	7.55	3.77
K_{Y2}	318.54	159.27
L_X	16.64	8.32
L_Y	355.49	177.75

2.2.6.2 Tear Out Stress on L

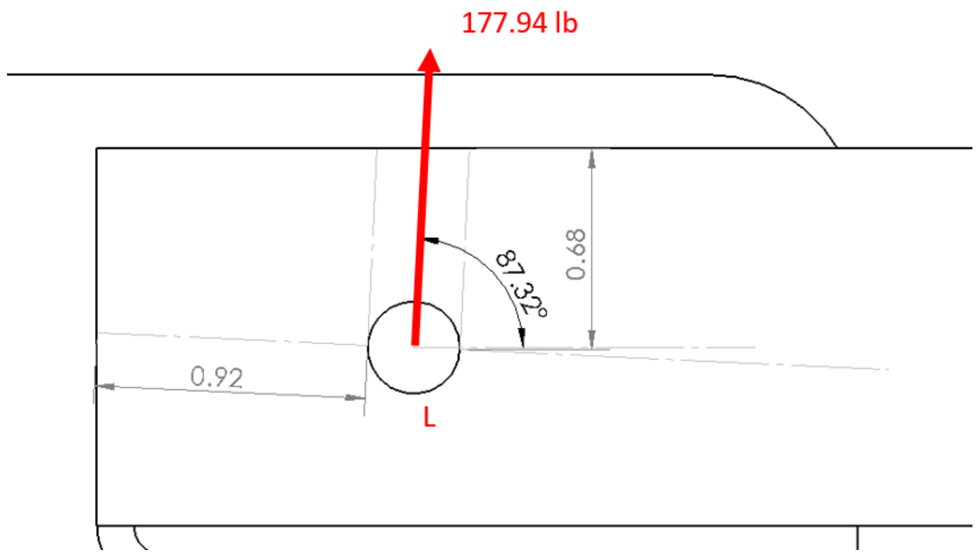


Figure 183. Vector Force on L

<u>Location L</u>

$$Vertor\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{8.32^2 + 177.75^2}$$

$$= 177.94\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{177.75}{8.32}\right)$$

$$= 87.32°$$

$$A_s = d \times t = 0.68 \times 0.125 = 0.085\ in^2$$

$$\tau = \frac{F}{2 \cdot A_S} = \frac{177.94}{2 \times 0.085} = 1046.7\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{1000} = 24.8$$

$$A_t = d \times t = 0.92 \times 0.125 = 0.115\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{177.94}{2 \times 0.115} = 773.7\ \ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{800} = 53.7$$

2.2.6.3 Tear Out Stress on K_2

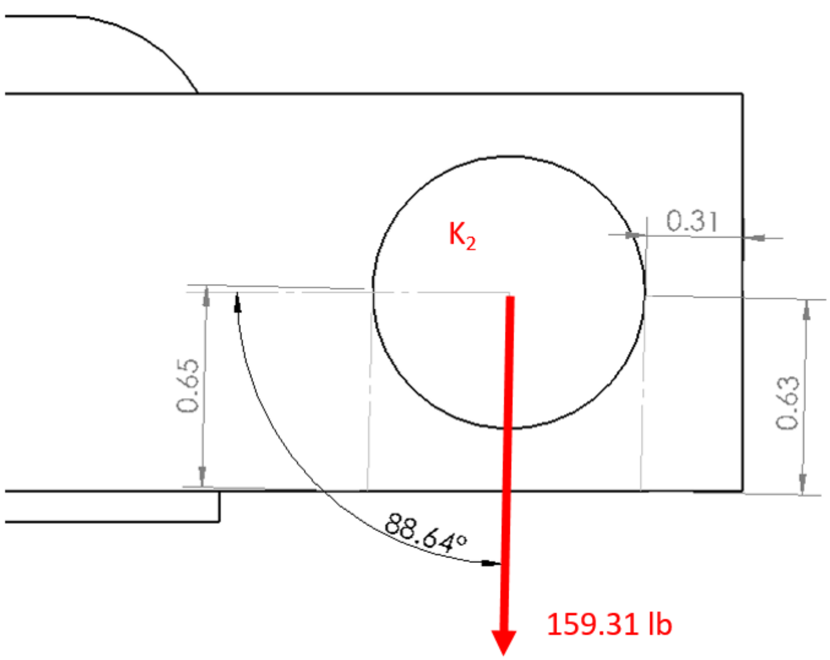


Figure 184. Vector Force on Hole K_2

Hole K_2

$$Vector\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{3.77^2 + 159.27^2}$$

$$= 159.31\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{159.27}{3.77}\right)$$

$$= 88.64°$$

$$A_s = d \times t = 0.63 \times 0.125 = 0.07875\ in^2$$

$$\tau = \frac{F}{2 \cdot A_s} = \frac{159.31}{2 \times 0.07875} = 1011.5\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{1000} = 24.8$$

$$A_t = d \times t = 0.31 \times 0.125 = 0.03875\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{159.31}{2 \times 0.03875} = 2055.6\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{2100} = 20.4$$

2.2.6.4 Bearing Stress on L

$$\sigma_{b_{Pin}} = \frac{F}{A_{b_{Slot}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{177.94}{0.125 \times 0.3125}$$

$$= 4555.3\ psi$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, psi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$

$$N = \frac{S_y}{\sigma} = \frac{43000}{4600} = 9.3$$

2.2.6.5 Bearing Stress on K_2

$$\sigma_{b_{Hole\ K_2}} = \frac{F}{A_{b_{Pin}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{159.31}{0.125 \times 0.875}$$

$$= 1456.5\ psi$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, psi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{1500} = 28.6$$

2.2.7 Vertical Pivot Arm

2.2.7.1 General Information

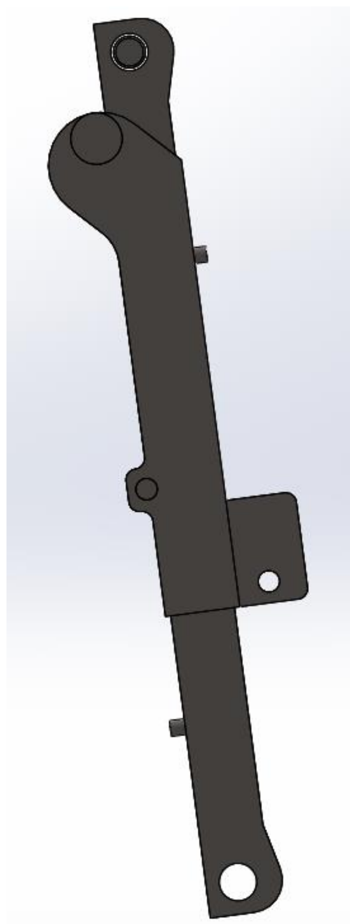


Figure 185. Vertical Pivot Arm

Vertical pivot arm connects horizontal pivot arm, bridge plate and platform. This assembly consists of two profiles and a gas spring between two profiles, which arises difficulty to decide cross-section area. Therefore, the assembly was assumed as a single part. Besides, only one profile's cross-section was used to calculate stress. Moreover, it is also assumed that all forces apply to a selected single profile, which causes higher stress. However, it means that if the calculation is within the safety factor, this assembly is safe. When the lift is down, the higher forces apply to the member. Therefore, the components are analyzed when the lift is down position. The member is tilted 74.2 degrees when force was analyzed. Therefore, it is required to rotate 74.2 degrees of counterclockwise direction to perform the stress analysis. In addition to that, two members support the forces, which means only half of the forces are applied to the component.

Table 7. Revised Forces

Location	Force (lb)	Half Force (lb)
H_X	383.27	191.64
H_Y	1375.23	687.61
K_{X1}	418.09	209.05
K_{Y1}	978.59	489.29
F_M	359.84	179.92

2.2.7.2 Force Revision

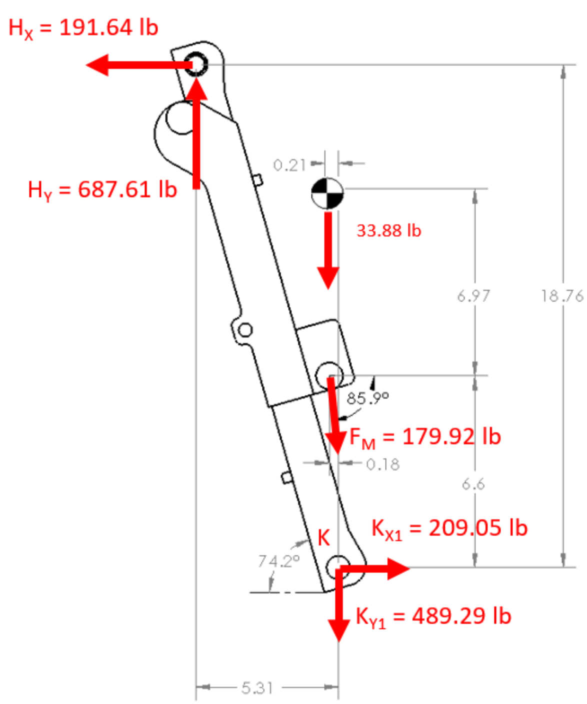


Figure 186. Applied Forces on Tilted Member

$H'_X = -H_Y \times \cos 15.8 - H_X \times \sin 15.8$

$= -687.61 \times \cos 15.8 - 191.64 \times \sin 15.8$

$= -713.81\ lb$

$H'_Y = H_Y \times \cos 74.2 - H_X \times \sin 74.2$

$= 687.61 \times \cos 74.2 - 191.64 \times \sin 74.2$

$= 2.823\ lb$

$Weight_X = 33.88 \times \sin 74.2 = 32.6\ lb$

$Weight_Y = -33.88 \times \cos 74.2 = -9.22\ lb$

$F_X = F_M \times \sin 78.3 = 179.92 \times \sin 78.3 = 176.18\ lb$

$F_Y = -F_M \times \cos 78.3 = -179.92 \times \cos 78.3 = -36.49\ lb$

$K'_{X1} = K_{X1} \times \cos 74.2 + K_{Y1} \times \sin 74.2$

$= 209.05 \times \cos 74.2 + 489.29 \times \sin 74.2$

$= 527.72\ lb$

$K'_{Y1} = K_{X1} \times \sin 74.2 - K_{Y1} \times \cos 74.2$

$= 209.05 \times \sin 74.2 - 489.29 \times \cos 74.2$

$= 67.93\ lb$

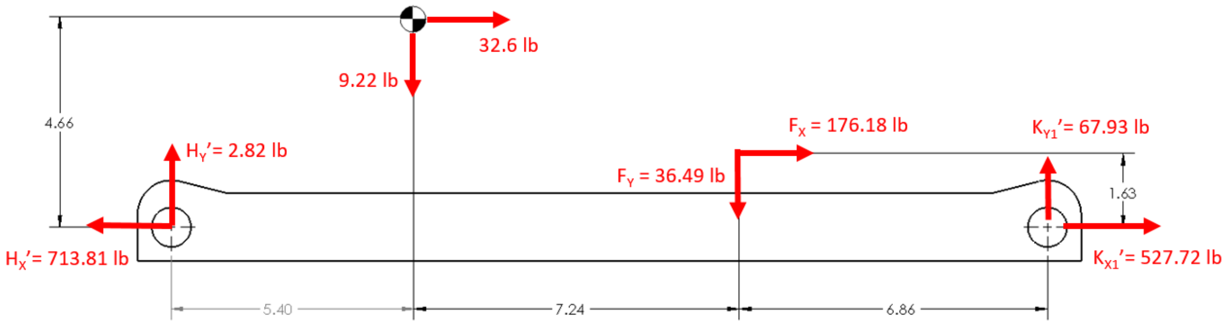


Figure 187. Revised Forces

2.2.7.3 Shear Force and Bending Moment

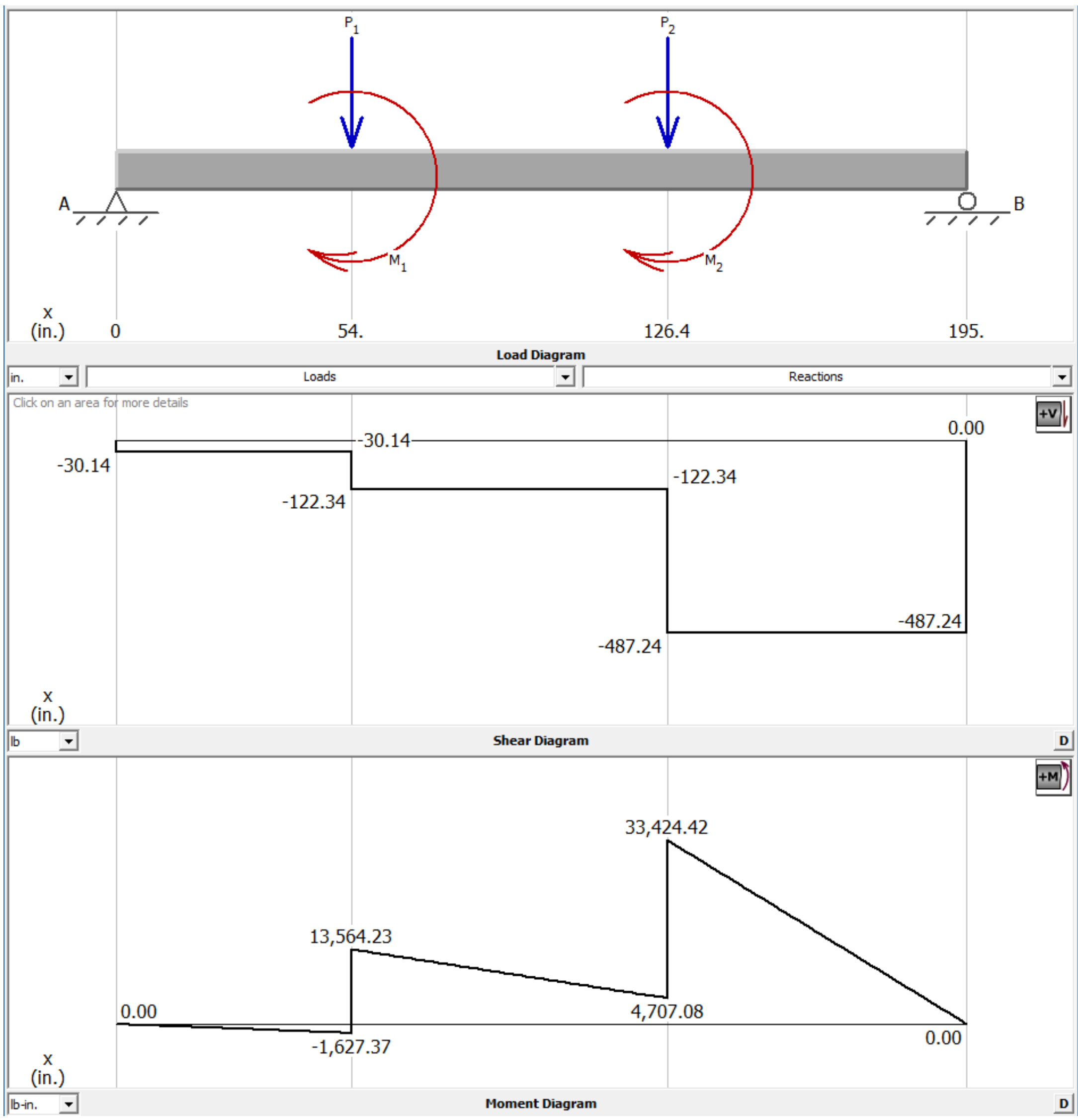


Figure 188. Shear Force and Bending Moment on Vertical Pivot Arm

Due to the redundant equations in force analysis, there are minor errors and it causes the part isn't in an equilibrium state. MD Solid adjusts this error by changing reaction forces on the selected support locations. Distances and forces on the graph are adjusted as well, which are ten times bigger than it is because MD Solid can't read below two decimal places. Therefore, shear forces are ten times smaller and bending moments are a hundred times less than the data on the graph.

2.2.7.4 Section Separation

The following figure shows the sections to be analyzed, which places are likely to have the highest stress.

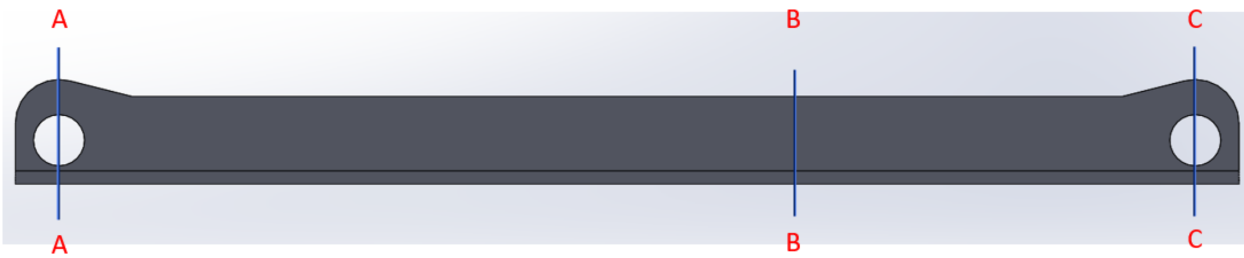


Figure 189. Sections to be Analyzed

2.2.7.5 Section A-A Properties

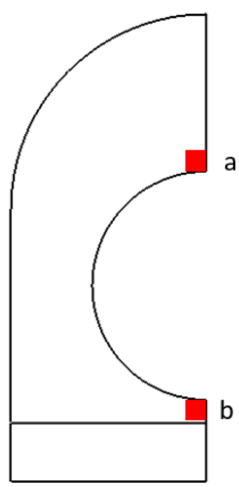


Figure 190. Locations analyzed

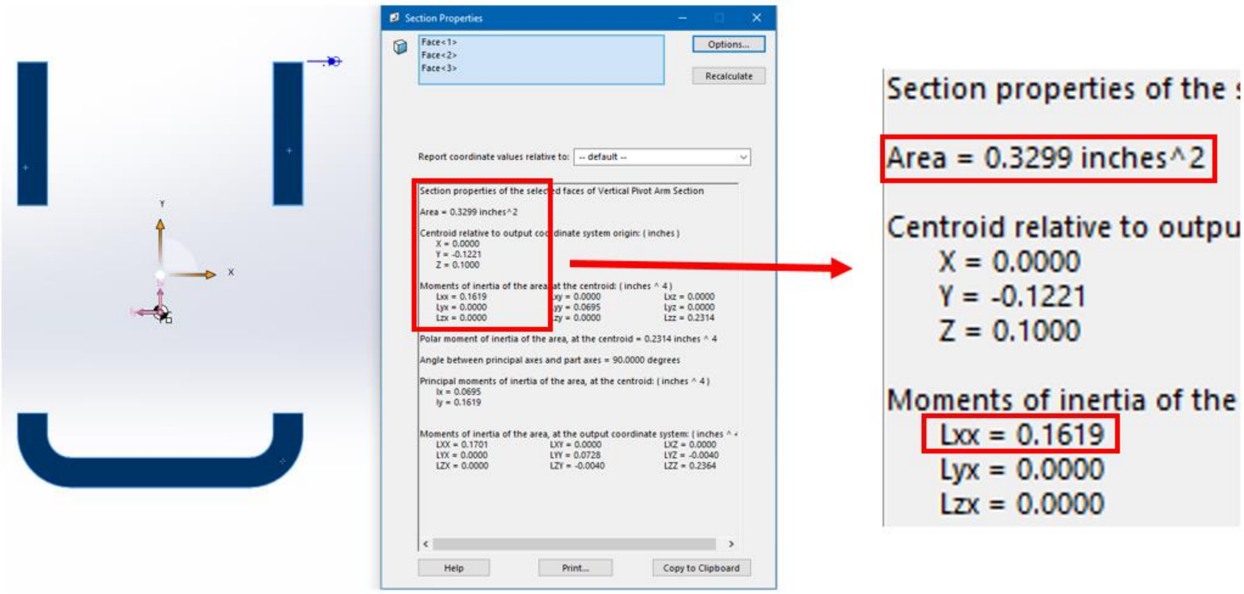


Figure 191. Section A-A Properties

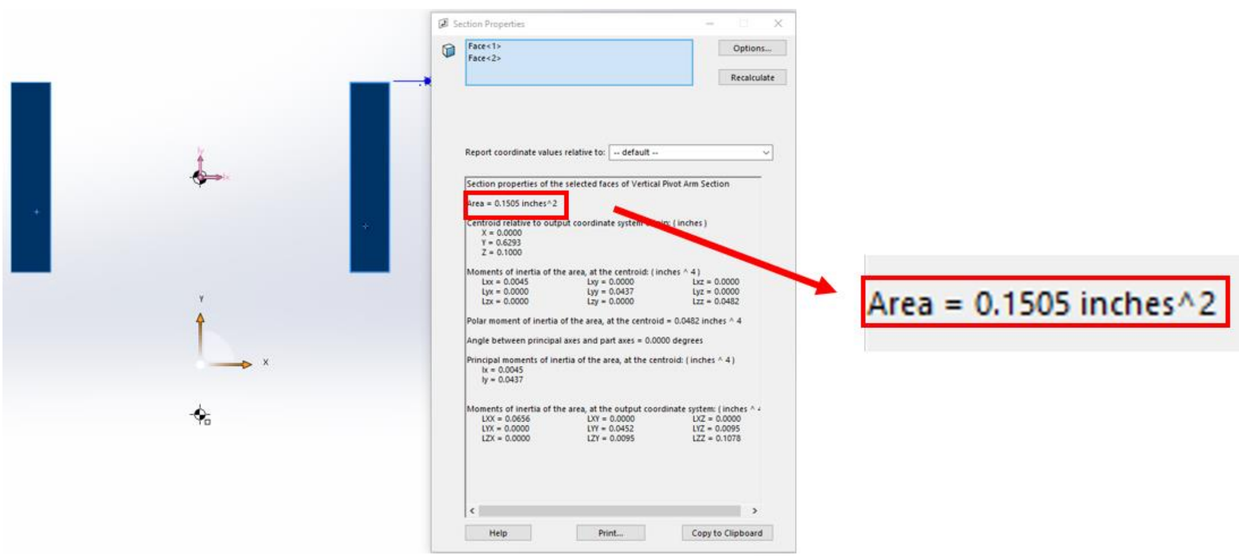


Figure 192. A_P at a on Section A-A

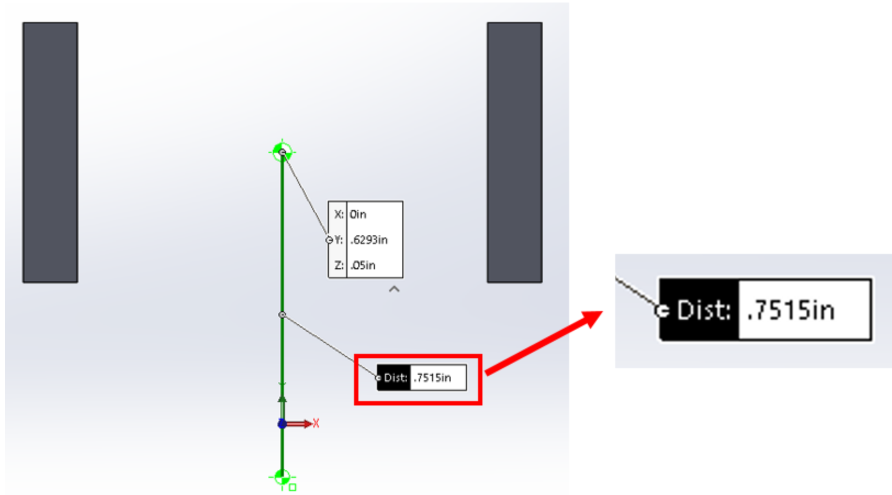


Figure 193. $\overline{Y}$ at a on Section A-A

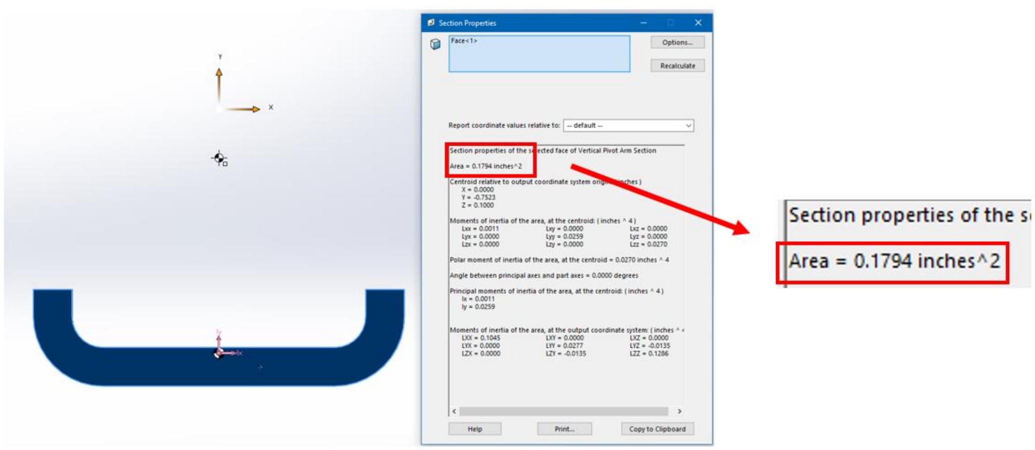


Figure 194. A_P at b on Section A-A

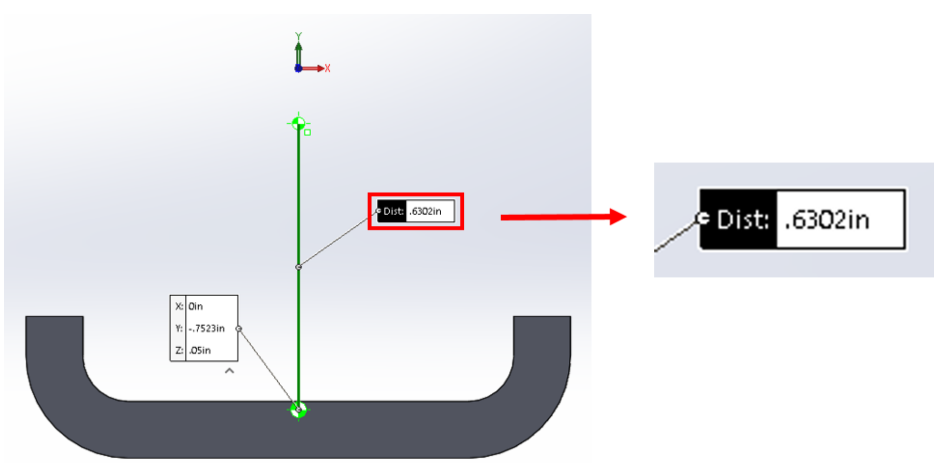


Figure 195. $\overline{Y}$ at b on Section A-A

2.2.7.6 Section A-A Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{713.81\ lb}{0.3299\ \mathrm{in}^2} = 2163.72\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.7.7 Section A-A Transverse Shear Stress

Transverse shear stress applies to at a and b.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.1505\ in^2 \times 0.7515\ in$$

$$= 0.1131 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{3.01\ lb\ \times 0.1131\ in^3}{0.1619\ \mathrm{in}^4\ \times 0.25\ in}$$

$= 8.41\ psi$ (at a)

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

$$Q = A_P \cdot \overline{Y}$$

$$= 0.1794\ in^2 \times 0.6302 in$$

$$= 0.1131 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$\tau = \frac{VQ}{It}$

$= \frac{3.01\ lb\ \times 0.1131\ in^3}{0.1619\ \text{in}^4\ \times 0.25\ in}$

$= 8.41\ psi$ (at b)

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

Therefore, shear stress at a and b have the same value.

2.2.7.8 Section A-A Analysis

a and b at the section A-A has the same stress types and magnitude. In addition to that, shear stress is close to zero, which is negligible. Therefore, the combined stress analysis method wasn't used on section A-A analysis. Rather, only axial stress was used to verify safety.

In summary, a and b at section A-A has 2163.72 psi axial stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$N = \frac{S_y}{\sigma} = \frac{43000}{2200} = 19.5$

2.2.7.9 Section B-B Properties

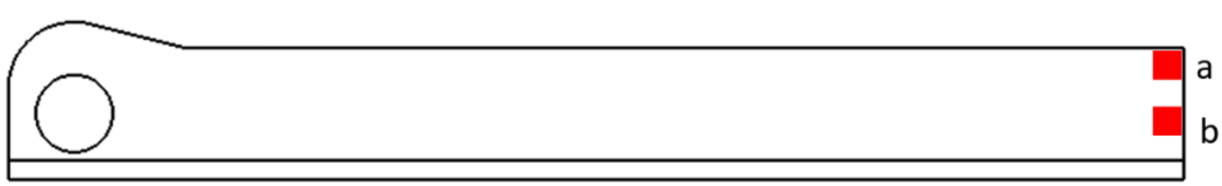


Figure 196. Locations analyzed

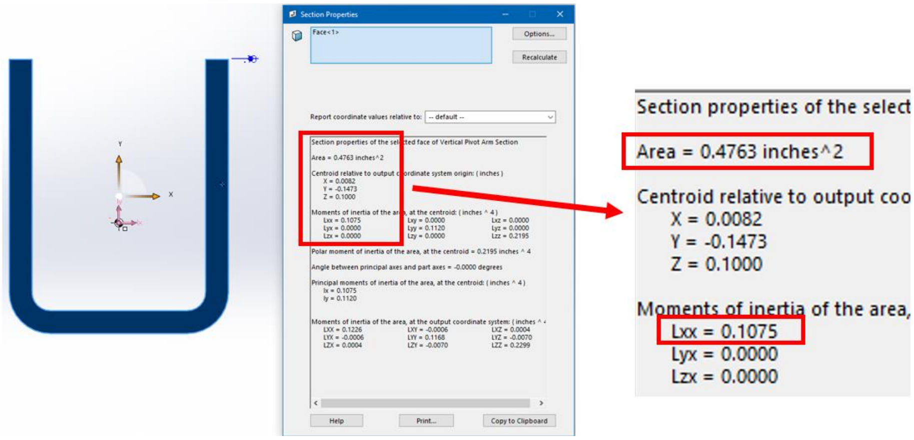


Figure 197. Section B-B Properties

Axial Tensile and bending moment stress apply to at a on section B-B.

Axial Tensile and transverse shear stress apply to at b on section B-B.

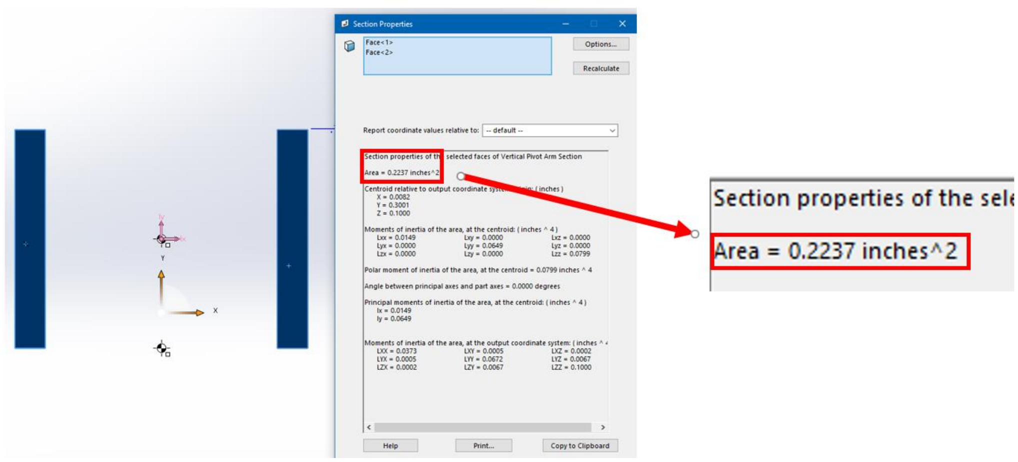


Figure 198. A_P at b on Section B-B

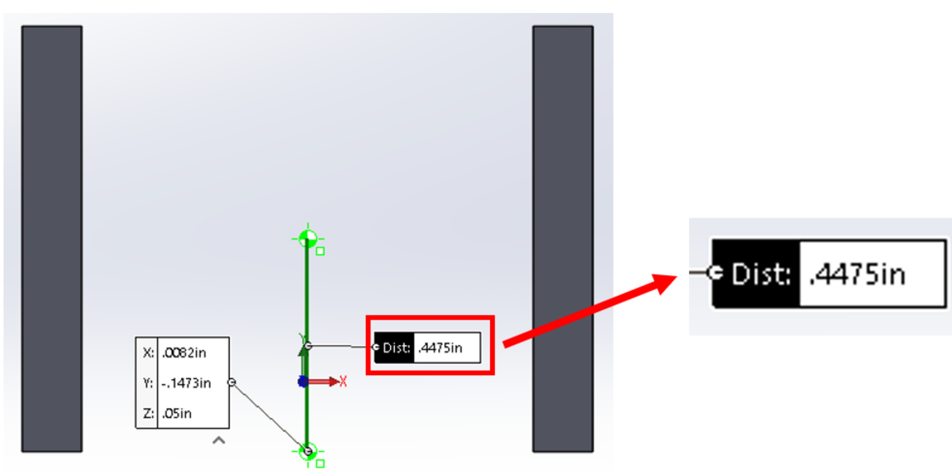


Figure 199. $\overline{Y}$ at b on Section B-B

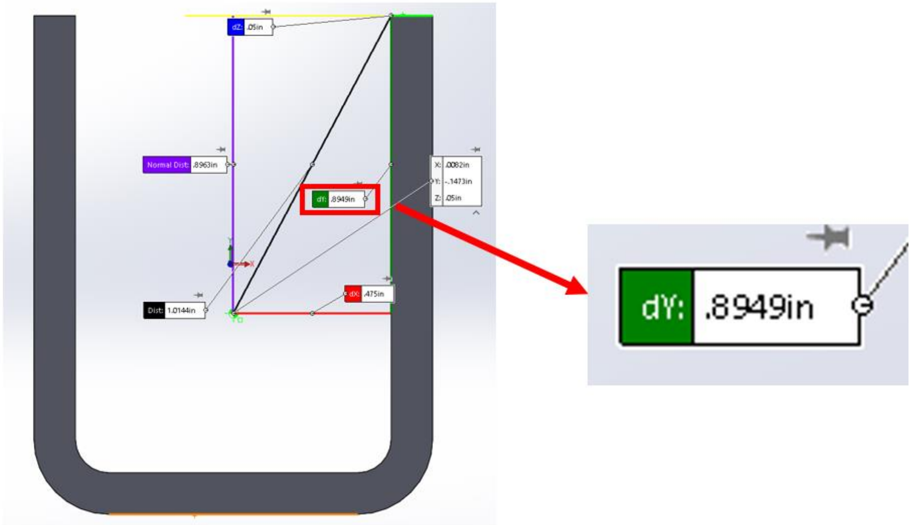


Figure 200. c at b on Section B-B

2.2.7.10 Section B-B Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{681.21\ lb}{0.4763\ \text{in}^2} = 1430.21\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.7.11 Section B-B Bending Stress

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

$$= \frac{334.24\ lb - in\ \times 0.8949\ in}{0.1075\ \text{ in}^4}$$

$$= 2782.43\ psi\ (Tension\ at\ a)$$

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

There is no bending stress at b because b is located on the central axis.

2.2.7.12 Section B-B Transverse Shear Stress

Transverse shear stress applies to at b.

$Q = A_P \cdot \overline{Y}$

$= 0.2237\ in^2 \times 0.4475\ in$

$= 0.1001\ in^3$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$\tau = \frac{VQ}{It}$

$= \frac{48.24\ lb\ \times 0.1001\ in^3}{0.1075\ \mathrm{in}^4\ \times 0.25\ in}$

$= 179.68\ psi$

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

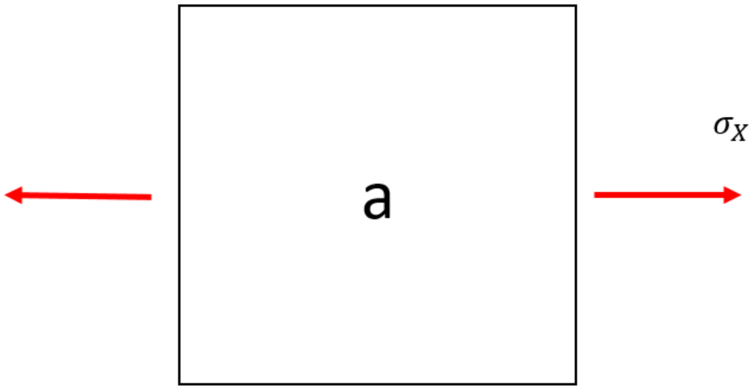
$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

2.2.7.13 Section B-B Analysis

<u>Stress at a</u>



$$\sigma_X = 1430.21\ psi + 2782.43\ psi = 4212.64\ psi$$

Figure 201. Applied Stress at a on Section B-B.

In summary, a at section B-B has 4212.64 psi stress.

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{4200} = 10.2$$

Stress at b

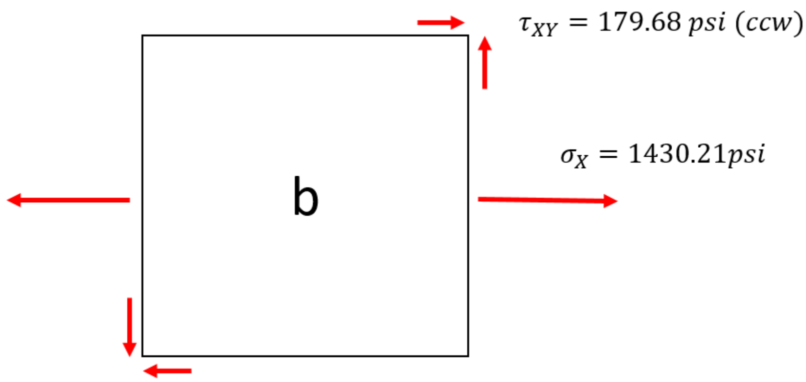


Figure 202. Applied Stress at b on Section B-B.

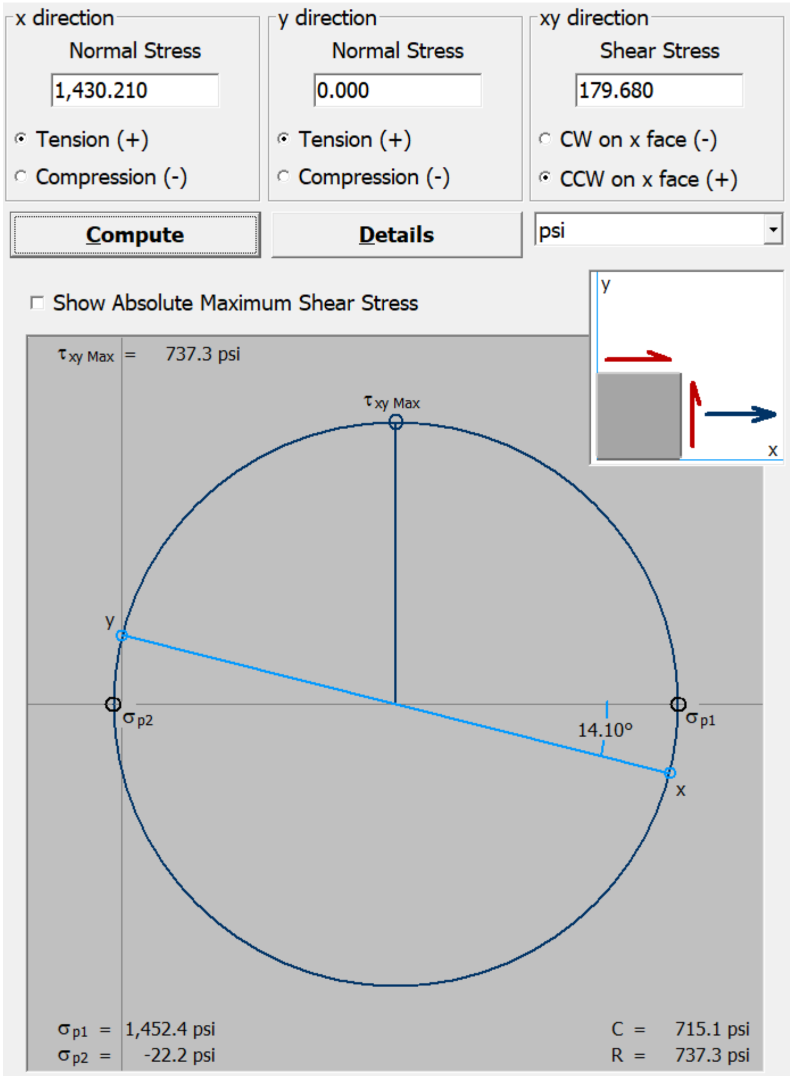


Figure 203. Principal Stress at b on Section B-B

<u>MDET</u> (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{1452.4^2 + (-22.2)^2 - 1452.4(-22.2)} = 1463.63\, psi$$

In summary, b at section B-B has $\sigma' = 1463.63\, psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{1500} = 28.6$$

2.2.7.14 Section C-C Properties

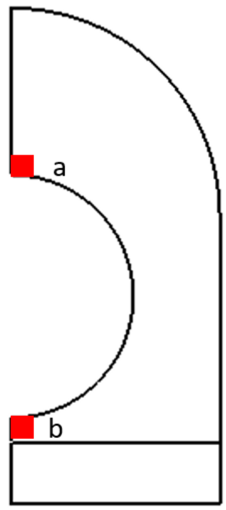


Figure 204. Locations analyzed

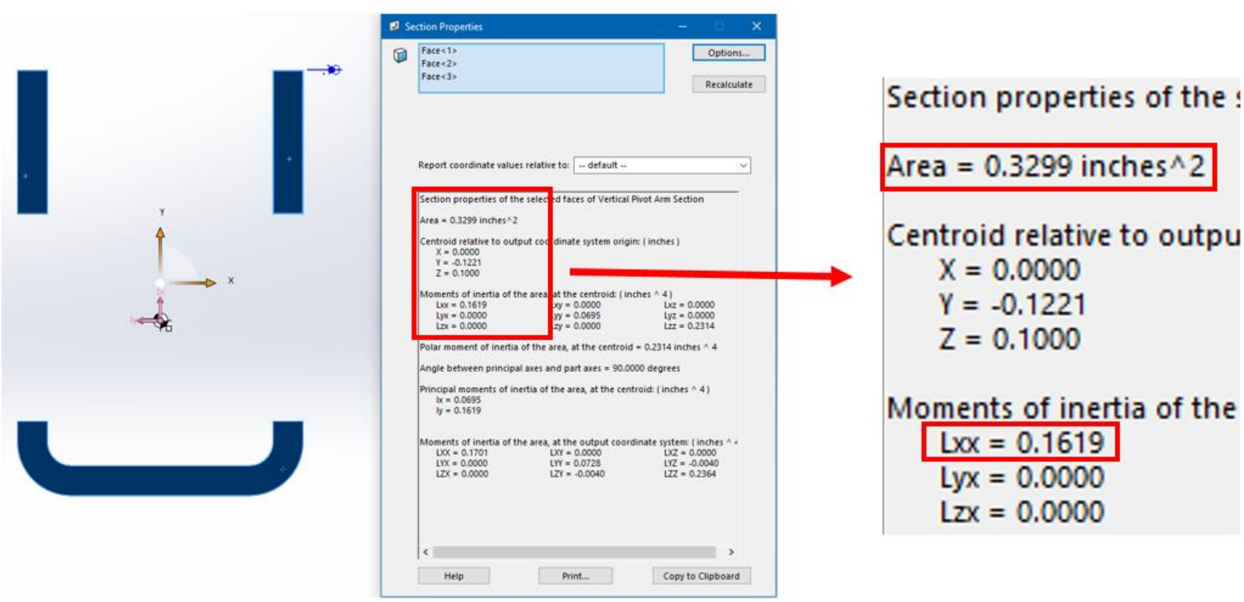


Figure 205. Section C-C Properties

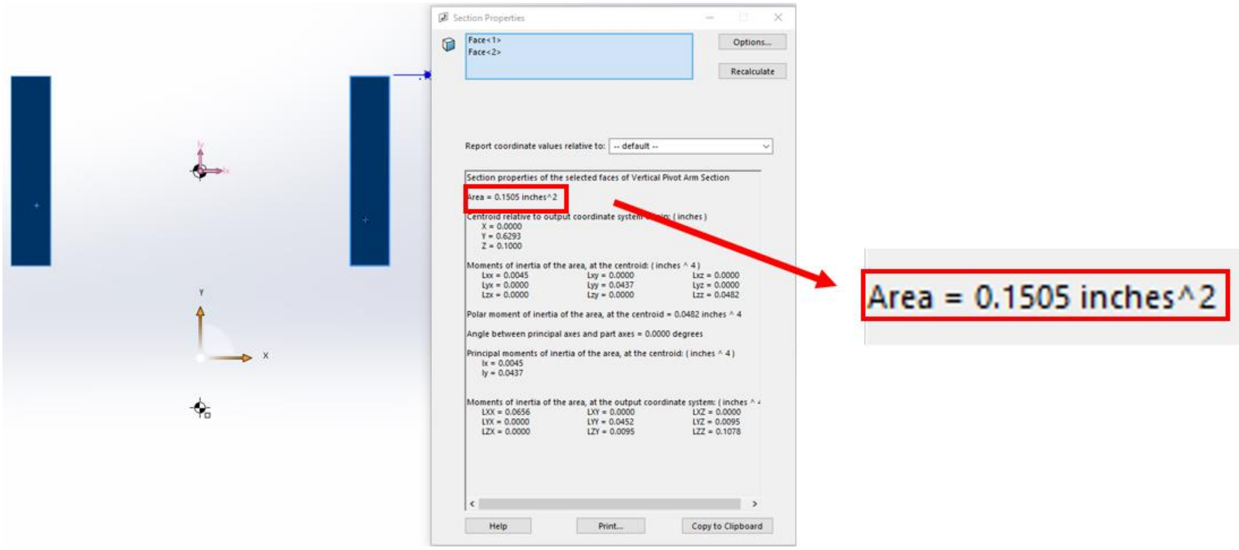


Figure 206. A_P at a on Section C-C

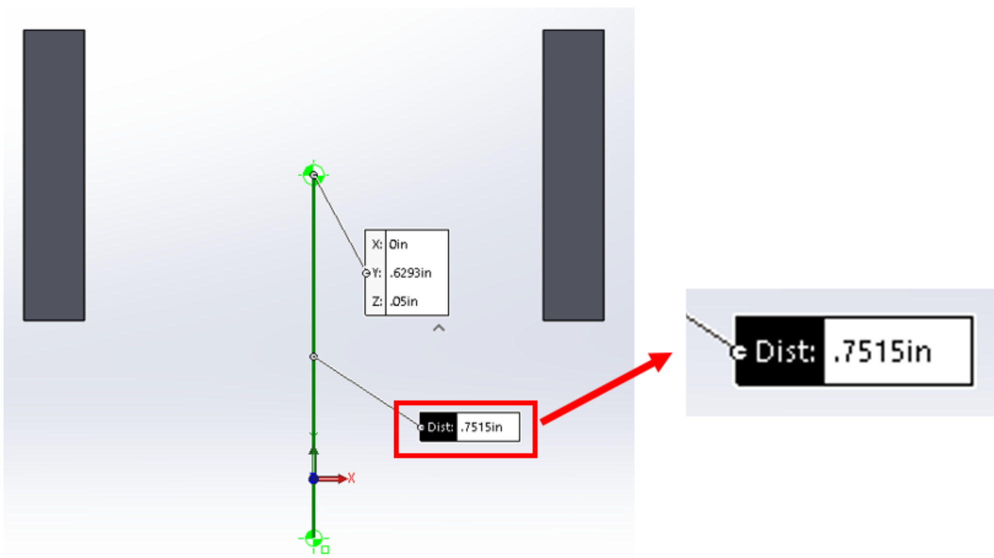


Figure 207. $\overline{Y}$ at a on Section C-C

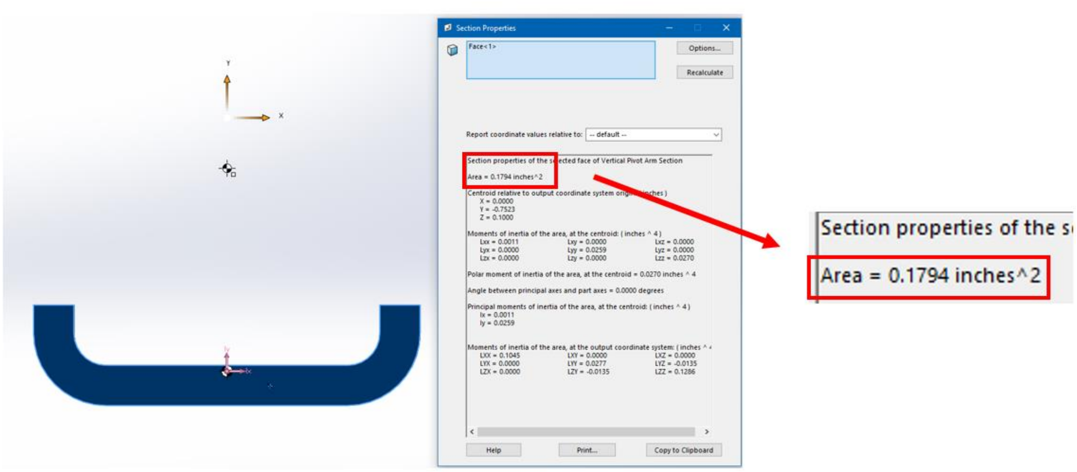


Figure 208. A_P at b on Section C-C

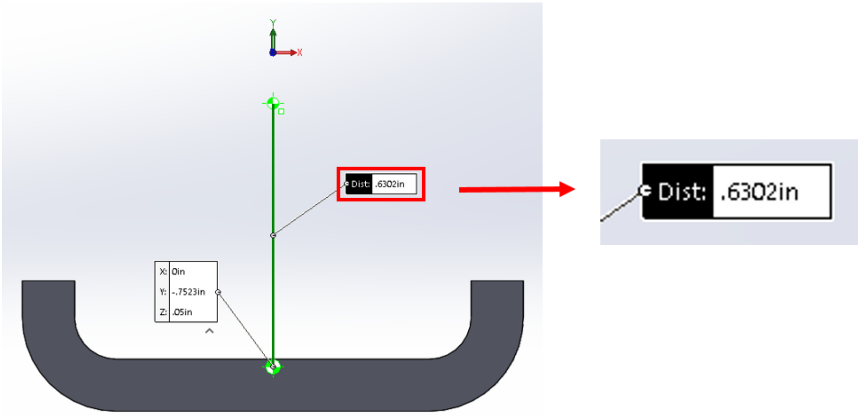


Figure 209. $\overline{Y}$ at b on Section C-C

2.2.7.15 Section C-C Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{527.72\ lb}{0.3299\ \text{in}^2} = 1599.64\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.7.16 Section C-C Transverse Shear Stress

Transverse shear stress applies to at a and b.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.1505\ in^2 \times 0.7515\ in$$

$$= 0.1131 in^3$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$$\tau = \frac{VQ}{It}$$

$$= \frac{48.72\ lb\ \times 0.1131\ in^3}{0.1619\ \text{in}^4\ \times 0.25\ in}$$

$= 136.14\ psi$ (at a)

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section, in$

$Q = A_P \cdot \overline{Y}$

$= 0.1794\, in^2 \times 0.6302 in$

$= 0.1131 in^3$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

$\tau = \frac{VQ}{It}$

$= \frac{48.72\ lb\ \times 0.1131\ in^3}{0.1619\ \mathrm{in}^4\ \times 0.25\ in}$

$= 136.14\ psi$ (at b)

Where, (1 Mott, p. 462)

$\tau = Shear\ stress, psi$

$V = Vertical\ shearing\ force, lb$

$I = Moment\ of\ inertia, in^4$

$t = Thickness\ of\ the\ cross\ section\ , in$

Therefore, shear stress at a and b have the same value.

2.2.7.17 Section C-C Analysis

a and b at the section C-C has the same stress types and magnitude. Therefore, only one location was calculated.

<u>Stress at a</u>

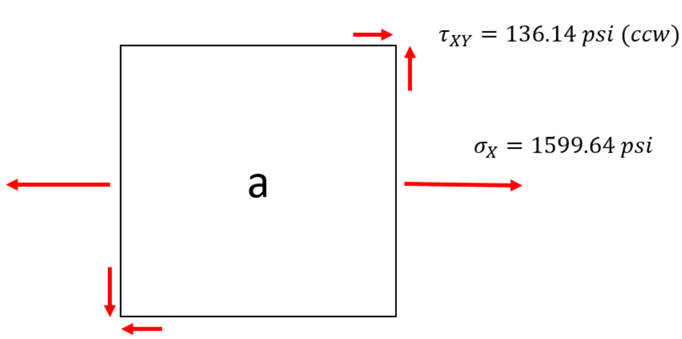


Figure 210. Applied Stress at a on Section C-C.

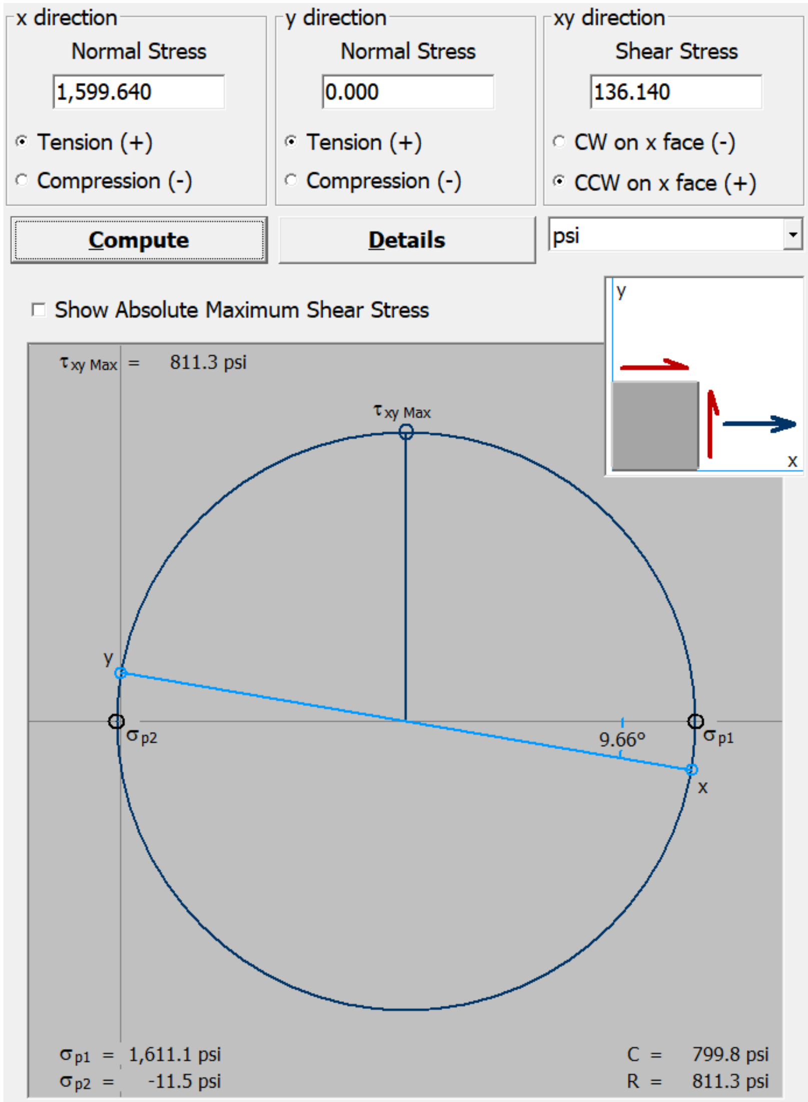


Figure 211. Principal Stress at b on Section B-B

MDET (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{1611.1^2 + (-11.5)^2 - 1611.1(-11.5)} = 1616.88\, psi$$

In summary, a and b at section C-C has $\sigma' = 1616.88\, psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{43000}{1600} = 26.8$$

2.2.7.18 Tear Out Stress on H

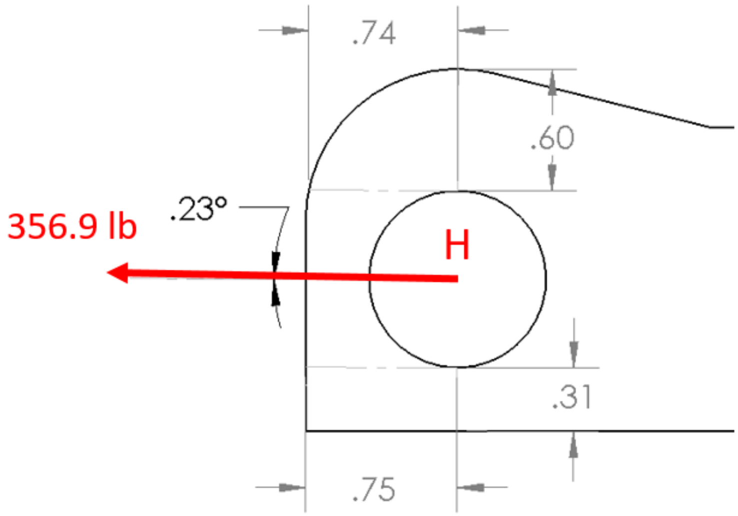


Figure 212. Vector Force on Hole H

<u>Hole H</u>

$$Vertor\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{713.81^2 + 2.82^2}$$

$$= 713.82\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{2.82}{713.81}\right)$$

$$= 0.23°$$

Two plates share the force. Therefore, only half of the force, 356.9 lb is used to calculate tear out stress.

$$A_s = d \times t = 0.74 \times 0.125 = 0.0925\ in^2$$

$$\tau = \frac{F}{2 \cdot A_S} = \frac{356.9}{2 \times 0.0925} = 1929.19\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear-out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{1900} = 13.0$$

$$A_t = d \times t = 0.31 \times 0.125 = 0.03875\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_T} = \frac{356.9}{2 \times 0.03875} = 4605.2\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear-out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{4600} = 9.3$$

2.2.7.19 Tear Out Stress on K_1

Hole K_1

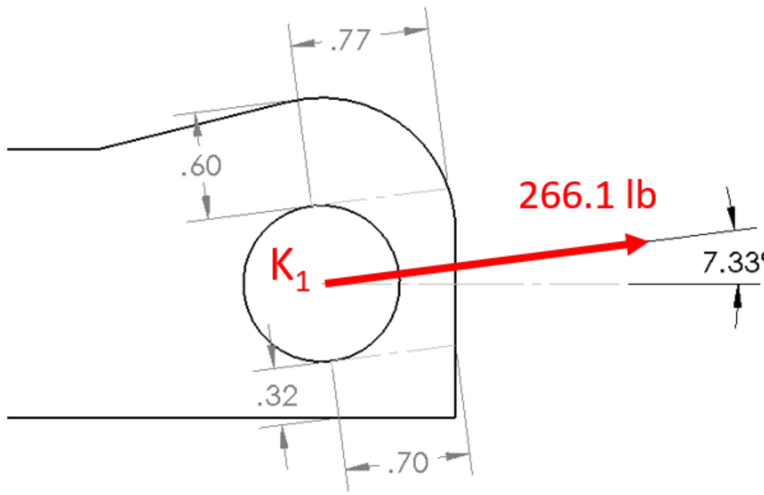


Figure 213. Vector Force on Hole K_1

$$Vector\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{527.72^2 + 67.93^2}$$

$$= 532.1\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{67.93}{527.72}\right)$$

$$= 7.33°$$

Two plates share the force. Therefore, only half of the force, 266.1 lb is used to calculate tear out stress.

$A_s = d \times t = 0.70 \times 0.125 = 0.0875\ in^2$

$$\tau = \frac{F}{2 \cdot A_s} = \frac{266.1}{2 \times 0.0875} = 1520.57\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_{sy}}{\tau} = \frac{0.577 \times S_y}{\tau} = \frac{0.577 \times 43000}{1500} = 16.5$$

$A_t = d \times t = 0.32 \times 0.125 = 0.04\ in^2$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{266.1}{2 \times 0.04} = 3326.25\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{3300} = 13.0$$

2.2.7.20 Bearing Stress on H

$$\sigma_{b_{Hole_H}} = \frac{F}{A_{b_{Pin}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{356.9}{0.125 \times 0.875}$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, psi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

$= 3263.1\, psi$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{3300} = 13.0$$

2.2.7.21 Bearing Stress on K_1

$$\sigma_{b_{Hole\ K_1}} = \frac{F}{A_{b_{Pin}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{266.1}{0.125 \times 0.875}$$

$$= 2432.9\, psi$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, psi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

Material: 1020 Annealed, $S_u = 57ksi, S_y = 43ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{43000}{2400} = 17.9$$

2.2.8 Platform

2.2.8.1 General Information

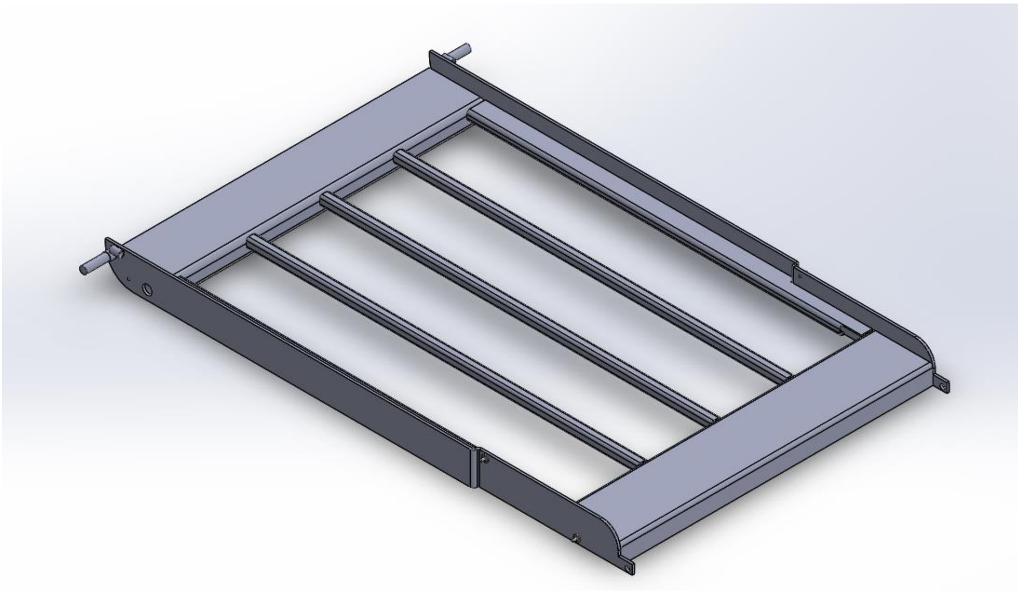


Figure 214.Platform

The platform is an area of a lift where wheelchair and occupant are situated during operation. Several steel tubes and profiles are welded and it is assumed as a single part because of the complexity of cross-section. When the lift is down, the higher forces apply to the member. Therefore, the components are analyzed when the lift is down position.

2.2.8.2 Force

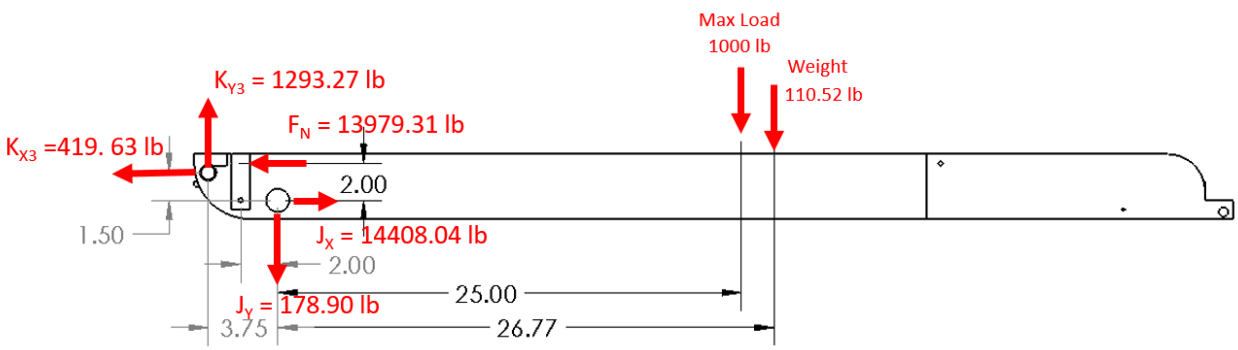


Figure 215. Applied Forces on Platform

2.2.8.3 Shear Force and Bending Moment

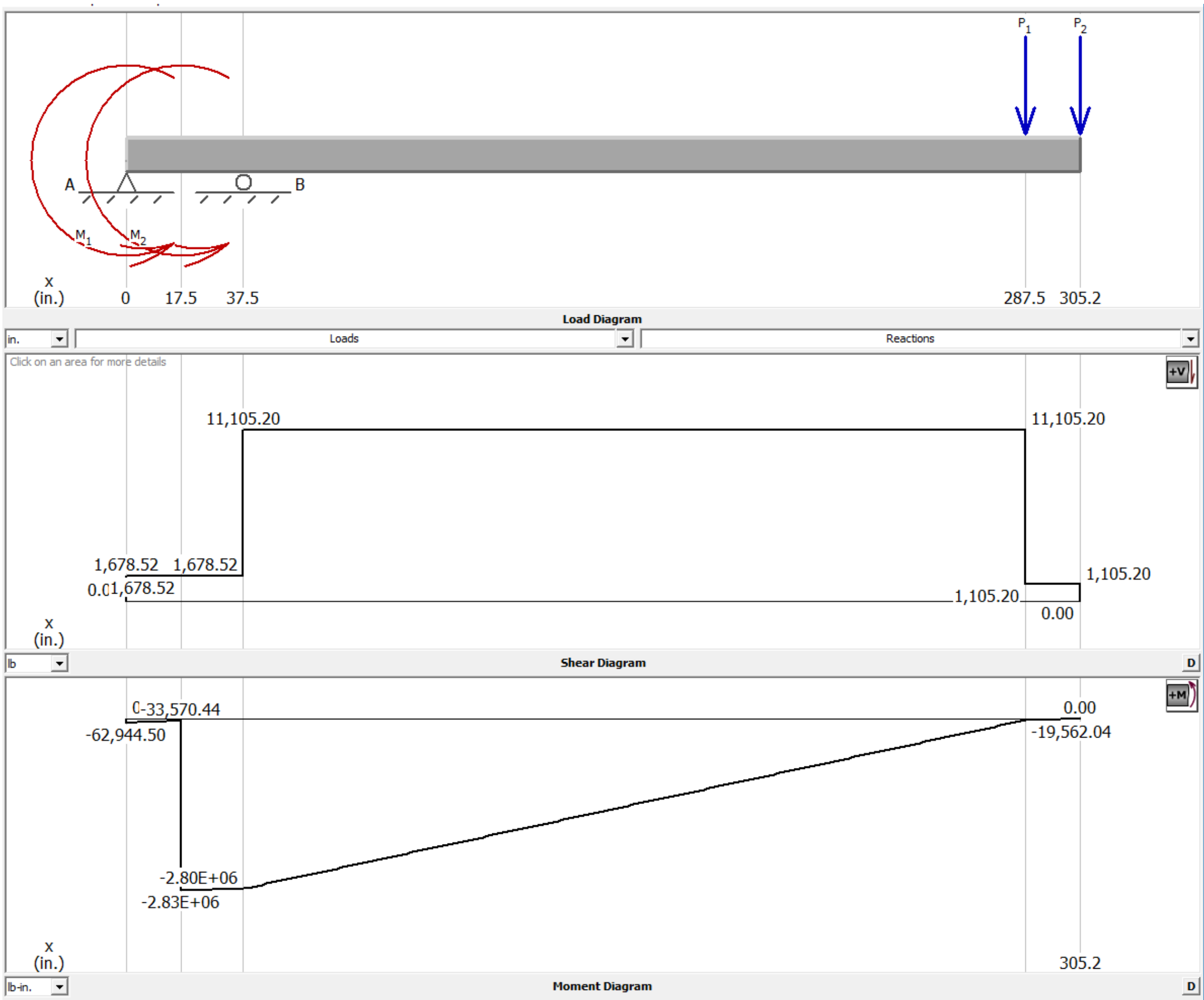


Figure 216. Shear Force and Bending Moment on Platform

Due to the redundant equations in force analysis, there are errors and it causes the part isn't in an equilibrium state. MD Solid adjusts this error by changing reaction forces on the selected support locations. However, reaction force on A is 167.85 lb and on B is 942.7 lb from the MD Solid. These values are far from the manual calculation. Therefore, only shear forces and bending moment are used from the MD Solids. Other forces apply to a member are used from the manual calculation.

Distances and forces on the graph are adjusted as well, which are ten times bigger than it is because MD Solid can't read below two decimal places. Therefore, shear forces are ten times smaller and bending moments are a hundred times less than the data on the graph. This shear forces and bending moments are located on the X-axis of hole J.

2.2.8.4 Section Separation

The following figure shows the sections to be analyzed. Section A-A has both the highest shear force and bending moment. Therefore, only this place was selected to be analyzed.

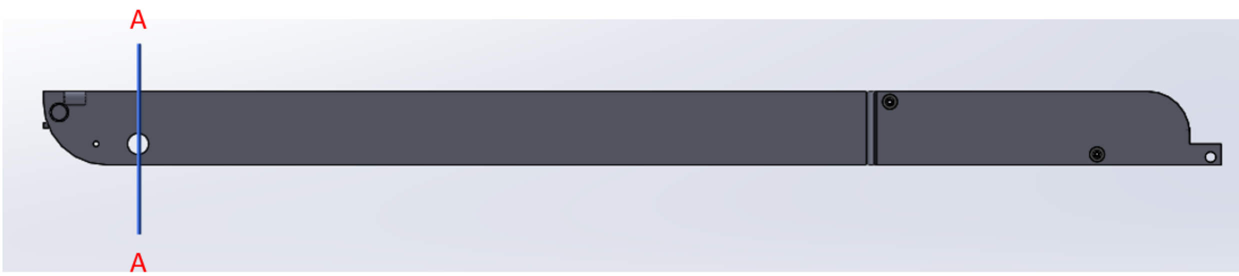


Figure 217. Sections to be Analyzed

2.2.8.5 Section A-A Properties

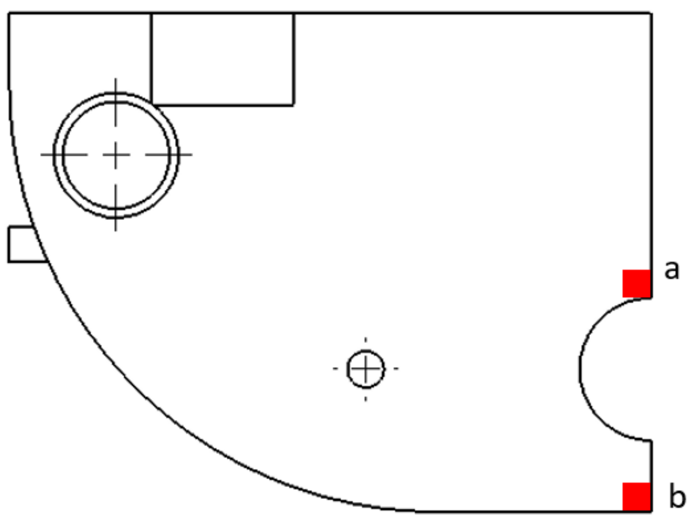


Figure 218. Locations analyzed

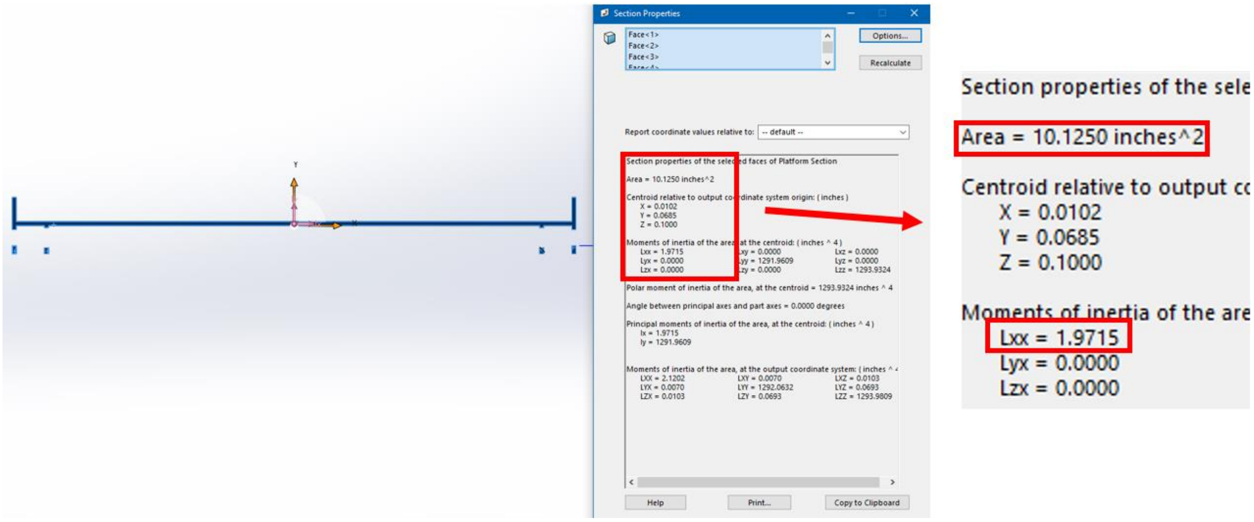


Figure 219. Section A-A Properties

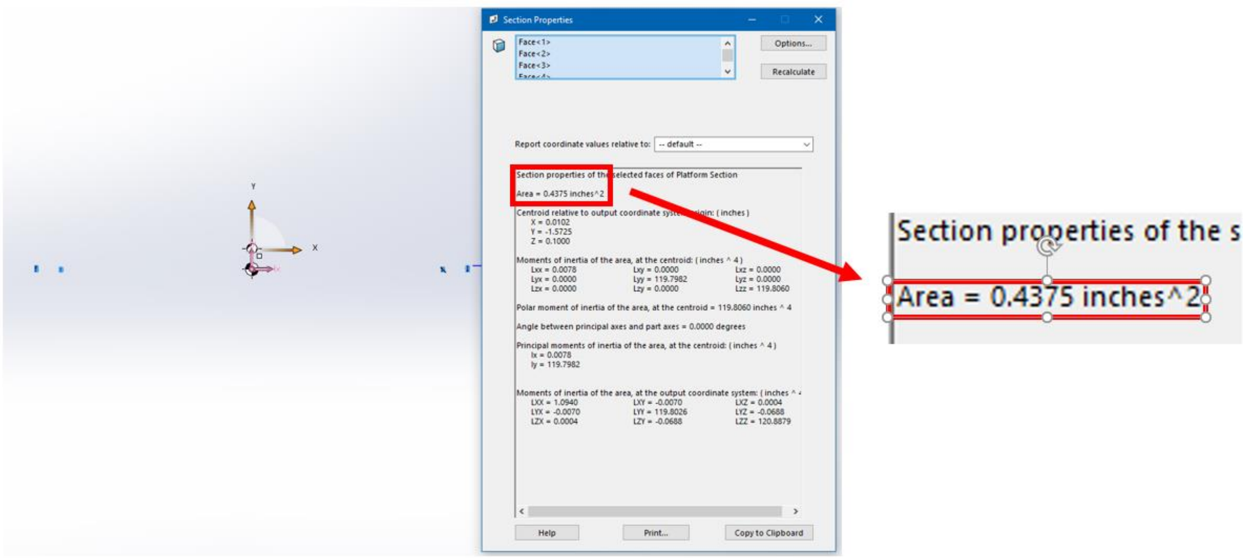


Figure 220. A_P at a on Section A-A

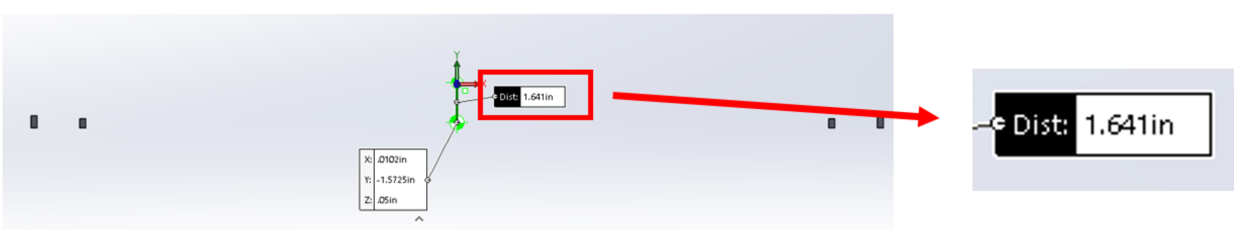


Figure 221. $\overline{Y}$ at a on Section A-A

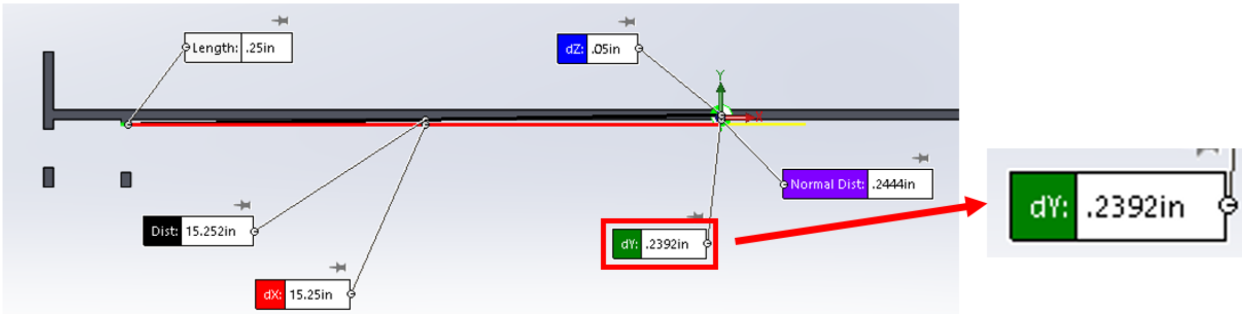


Figure 222. c at a on Section A-A

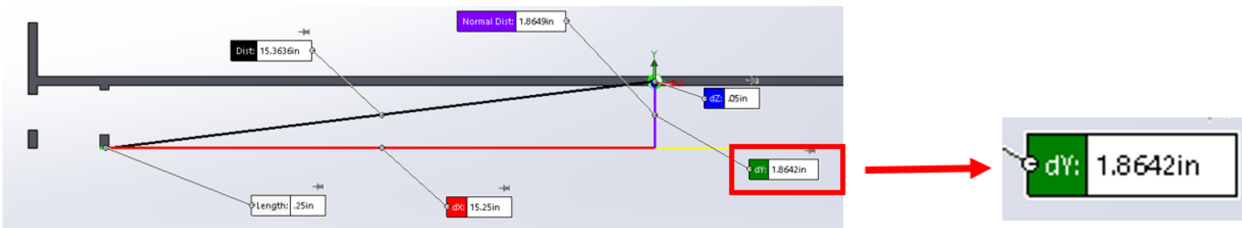


Figure 223. c at b on Section A-A

2.2.8.6 Section A-A Axial Tensile Stress

$$\sigma = \frac{F}{A} = \frac{14408.04\ lb}{10.125\ \text{in}^2} = 1423.02\ psi$$

Where, (1 Mott, p. 23)

$\sigma = Axial\ stress, psi$

$F = Force, lbs$

$A = Area, in^2$

2.2.8.7 Section A-A Transverse Shear Stress

Transverse shear stress applies to at a.

$$Q = A_P \cdot \overline{Y}$$

$$= 0.4375\ in^2 \times 1.641\ in$$

$$= 0.7179 in^3$$

$$\tau = \frac{VQ}{It}$$

$$= \frac{1110.5\ lb\ \times 0.7179\ in^3}{1.9715\ \text{in}^4\ \times 1\ in}$$

$$= 404.38\ psi$$

Where, (1 Mott, p. 462)

$Q = First\ moment\ of\ area, in^3$

$A_P = Area\ of\ a\ part\ of\ the\ cross$

$section\ that\ lies\ away\ from\ the\ axis, in^2$

$\overline{Y} = Distance\ from\ neutral\ axis\ to\ centroid\ of\ area, in$

2.2.8.8 Section A-A Bending Stress

Where, (1 Mott, p. 403)

$\sigma = Axial\ stress, ksi$

$M = Bending\ moment, lb - in$

$c = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

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

$$= \frac{28000\ lb - in\ \times 0.2392\ in}{1.9715\ \text{in}^4}$$

$$= 3397.2\ psi\ (Compression\ at\ a)$$

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

$$= \frac{28000\ lb - in\ \times 1.8642\ in}{1.9715\ \text{in}^4}$$

$$= 26476.08\ psi\ (Compression\ at\ b)$$

2.2.8.9 Section A-A Analysis

Stress at a

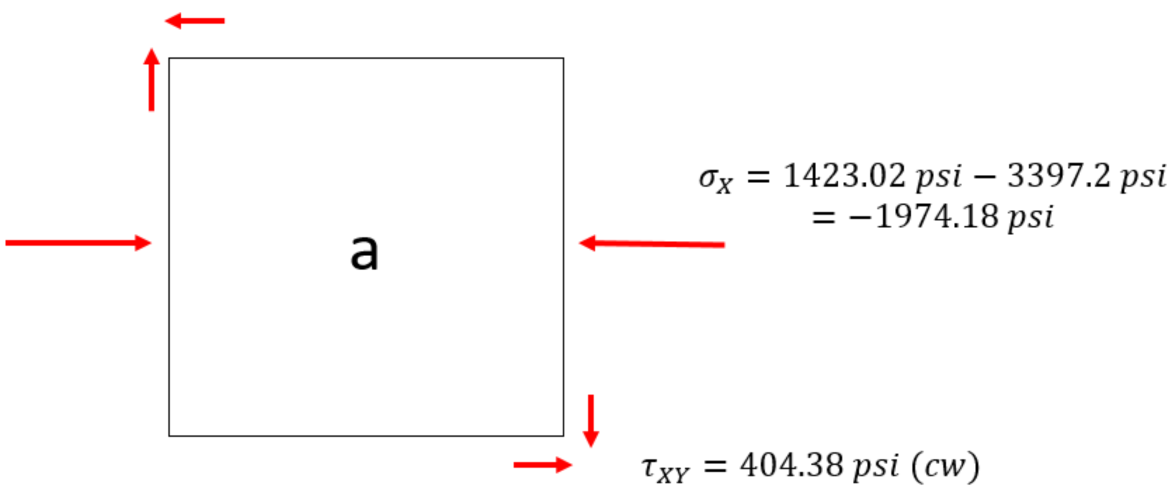


Figure 224. Applied Stress at a on Section A-A.

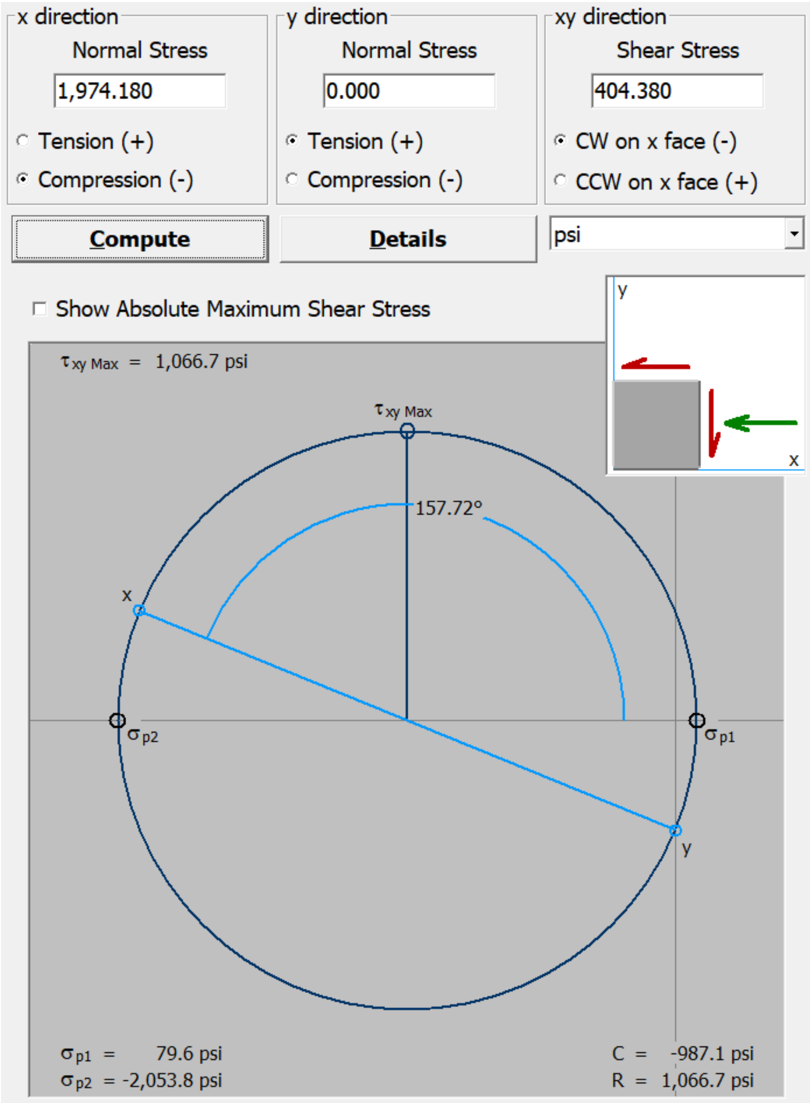


Figure 225. Principal Stress at a on Section A-A

<u>MDET</u> (2 Mott, p. 196)

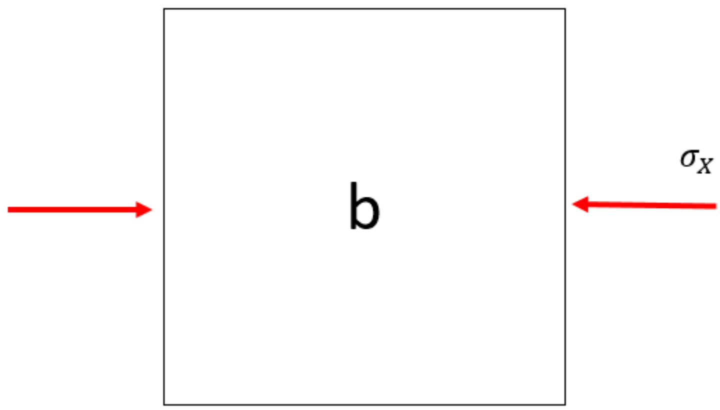
$$\sigma' = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{79.6^2 + (-2053.8)^2 - 79.6(-2053.8)} = 2094.73\ psi$$

In summary, a at section A-A has $\sigma' = 2094.73\ psi$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{2100} = 39$$

<u>Stress at b</u>



$$\sigma_X = 1423.02\,psi - 26476.08\,psi$$
$$= -25053.06\,psi$$

Figure 226. Applied Stress at b on Section A-A.

In summary, b at section A-A has 25053.06 psi axial stress.

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{25100} = 3.2$$

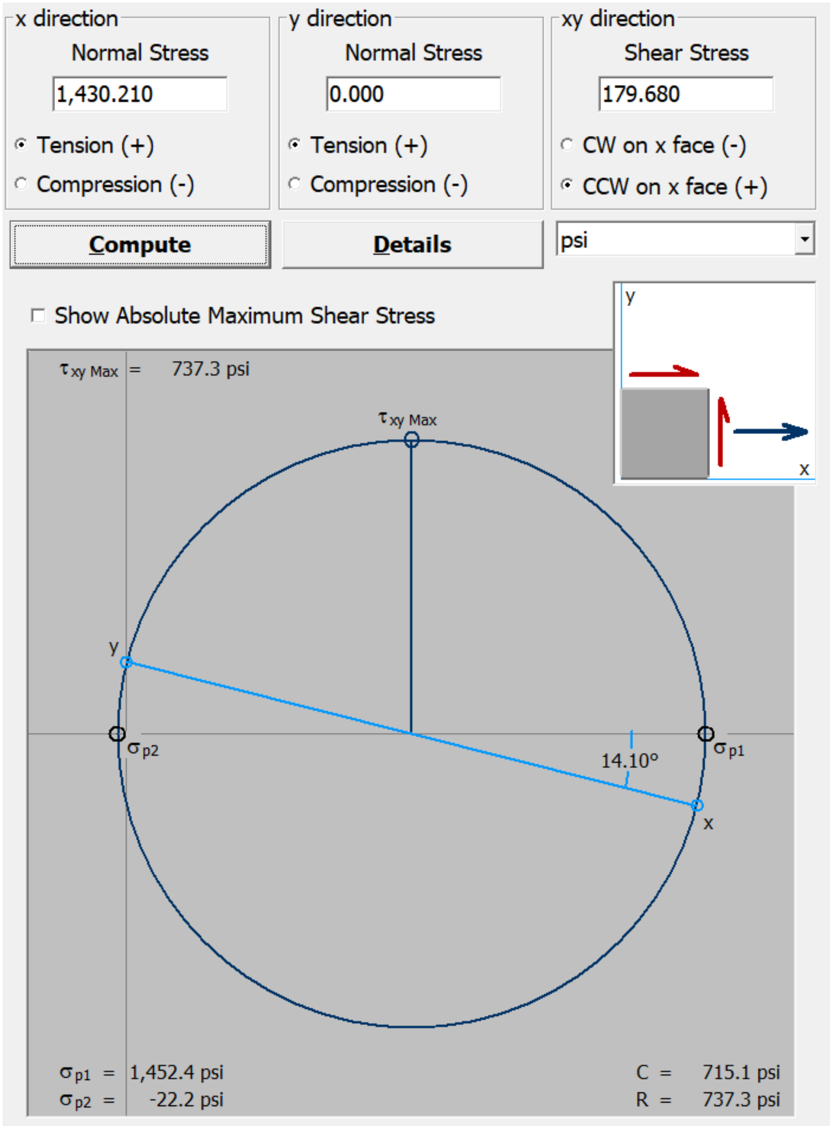


Figure 227. Principal Stress at b on Section A-A

MDET (2 Mott, p. 196)

$$\sigma' = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 - \sigma_1 \cdot \sigma_2} = \sqrt{1452.4^2 + (-22.2)^2 - 1452.4(-22.2)} = 1463.63\ psi$$

In summary, b at section B-B has $\sigma' = 1463.63\ psi$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{1500} = 54.6$$

2.2.8.10 Tear Out Stress on J

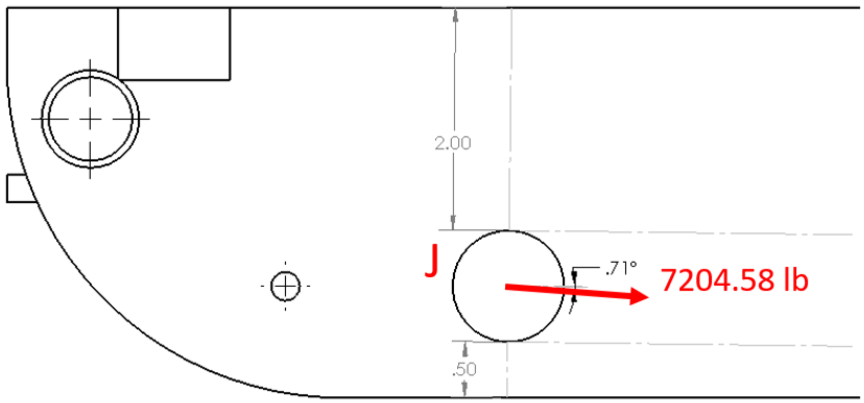


Figure 228. Vector Force on Hole J

Hole H

$$Vertor\ Force = \sqrt{(X - directional\ force)^2 + (Y - directional\ force)^2}$$

$$= \sqrt{7204.02^2 + 89.45^2}$$

$$= 7204.58\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\ force}{X - directional\ force}\right)$$

$$= \tan^{-1}\left(\frac{89.45}{7204.02}\right)$$

$$= 0.71°$$

Four plates share the force. Therefore, only one-quarter of the force, 1801.15 lb is used to calculate tear out stress. The area in shear tear-out stress is along the x-axis, which has quite a large area. Therefore, shear tear-out stress is not necessary.

$A_t = d \times t = 0.5 \times 0.25 = 0.125\ in^2$

$$\sigma = \frac{F}{2 \cdot A_T} = \frac{1801.15}{2 \times 0.125} = 7204.6\ psi$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear-out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{7200} = 11.3$$

2.2.8.11 Tear Out Stress on K3

Hole K3

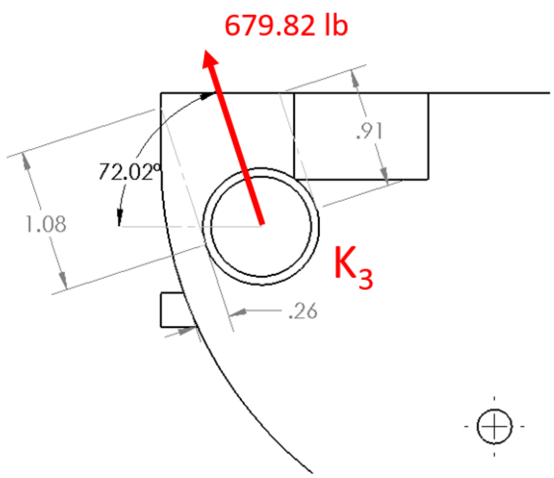


Figure 229. Vector Force on K3

$$Vector\ Force = \sqrt{(X-directional\ force)^2 + (Y-directional\ force)^2}$$

$$= \sqrt{209.82^2 + 646.63^2}$$

$$= 679.82\ lb$$

$$Angle = \tan^{-1}\left(\frac{Y - directional\,force}{X - directional\,force}\right)$$

$$= \tan^{-1}\left(\frac{646.63}{209.82}\right)$$

$$= 72.02°$$

Two plates share the force. Therefore, only half of the force, 339.9 lb is used to calculate tear out stress.

$$A_s = d \times t = 0.91 \times 0.25 = 0.2275\ in^2$$

$$\tau = \frac{F}{2 \cdot A_s} = \frac{339.9}{2 \times 0.2275} = 747.03\ psi$$

Where, (1 Mott, p. 27)

$A_s = Area\ in\ shear\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{750} = 109.3$$

Where, (1 Mott, p. 27)

$A_t = Area\ in\ tensile\ tear - out\ stress, in^2$

$d = Dept, in$

$t = Tickness, in$

$$A_t = d \times t = 0.26 \times 0.25 = 0.065\ in^2$$

$$\sigma = \frac{F}{2 \cdot A_t} = \frac{339.9}{2 \times 0.065} = 2614.62\ psi$$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{2600} = 31.5$$

2.2.8.12 Bearing Stress on J

$$\sigma_{b_{Hole_J}} = \frac{F}{A_{b_{Pin}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{1801.15}{0.25 \times 1}$$

$$= 7204.6\ psi$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, psi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{7200} = 11.3$$

2.2.8.13 Bearing Stress on K3

$$\sigma_{b_{Hole\ K_3}} = \frac{F}{A_{b_{Pin}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{339.9}{0.25 \times 0.75}$$

$$= 1812.8\ psi$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, psi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

Material: 1040 Cold drawn, $S_u = 97ksi, S_y = 82ksi$ (1 Mott, A-10)

$$N = \frac{S_y}{\sigma} = \frac{82000}{1800} = 45.5$$

2.2.9 Pin

2.2.9.1 Pin A Information

Pin A connects a tower, a cylinder and a member AC. To calculate maximum stress, the flange bearing is ignored, which causes lowering the stress. The maximum force is applied on x-direction when the lift is down.

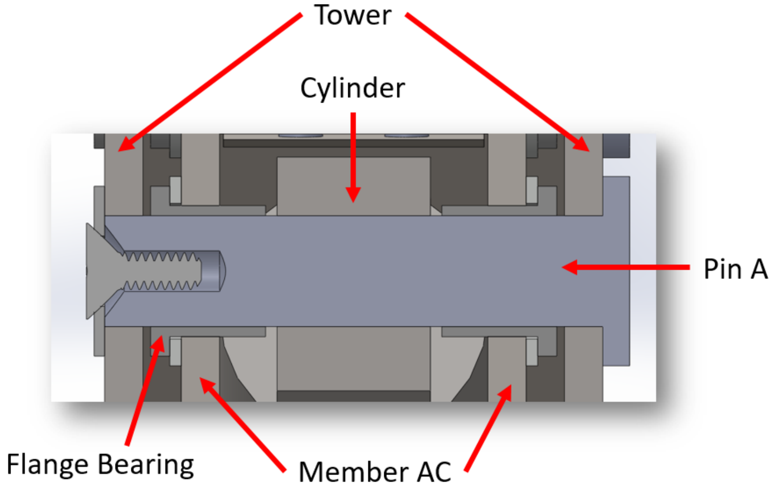


Figure 230. Section View on Pin A

2.2.9.2 Pin A Section Properties

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi (0.75)^2}{4}$$

$$= 0.4418\ in^2$$

Where,
$A = Area, in^2$
$D = Diameter, in$

$$I = \frac{\pi D^4}{64}$$

$$= \frac{\pi (0.75)^4}{64}$$

$$= 0.01553\ in^4$$

Where,
$I = Moment\ of\ inertia, in^4$
$D = Diameter, in$

2.2.9.3 Pin A Applied Forces

When the lift is down, the following force acts on the pin on X-Z direction.

$$AC = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{2635.46}{4}$$

$$= 658.87\ lbs$$

$$F\ cylinder = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{\cos 12° \ \times 6733.63}{2}$$

$$= 3293.24\ lbs$$

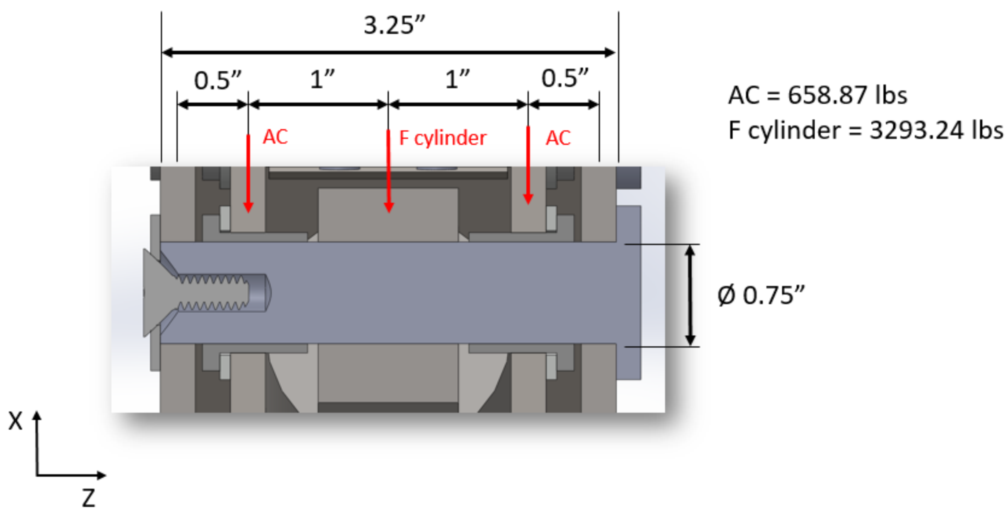


Figure 231. Applied force on pin A

2.2.9.4 Pin A Shear Force and Bending Moment

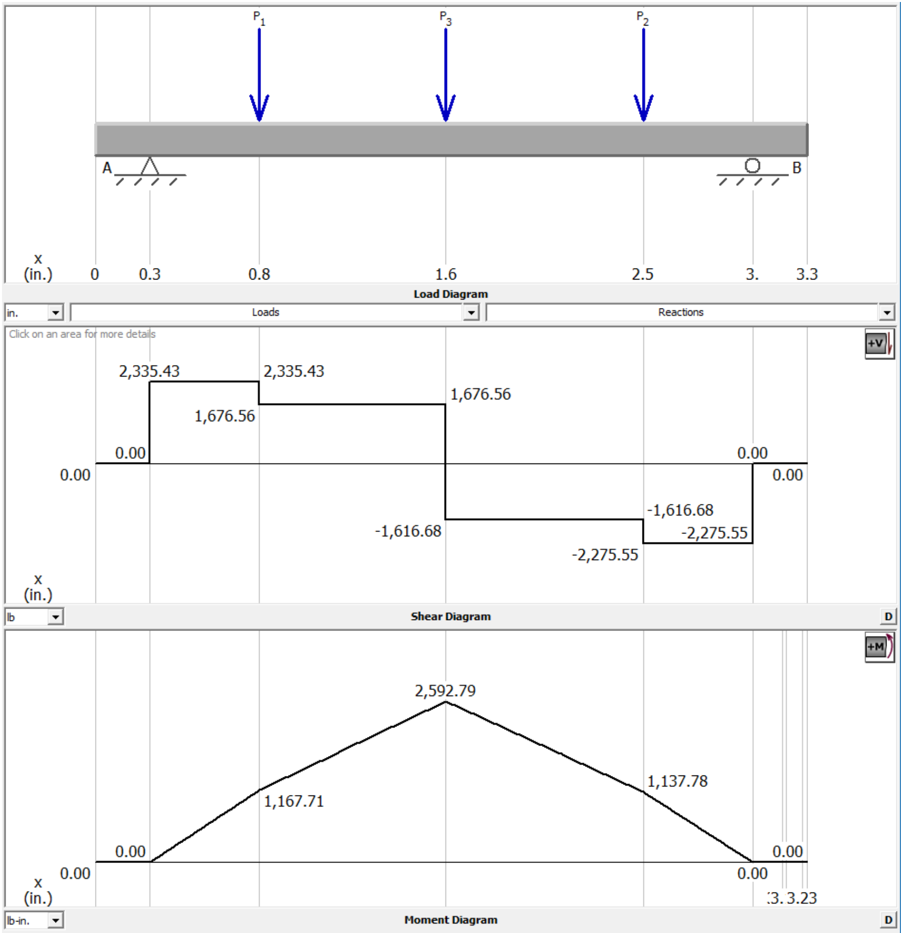


Figure 232. Vertical Shear and Bending Moment on Pin A

MD solid doesn't concern about below two decimal places, which causes small differentiations, but all of the following calculation ignores the small error.

From MD Solid,

$M = 2592.79\ lb - in$

$V = 2335.43\ lb$

Where,

$M = Bending\ moment, lb - in$

$V = Shear\ force, lb$

2.2.9.5 Pin A Bending Stress

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

$$= \frac{2592.79 \times 0.375}{0.01553}$$

$$= 62607.61\ psi$$

$$= \mathbf{62.6\ \mathit{ksi}}$$

Where, (1 Mott, p. 403)

$\sigma_{Max} = Maximum\ stress, ksi$

$M = Bending\ moment, lb - in$

$C = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

2.2.9.6 Pin A Direct Shear stress

$$\tau_{Max} = \frac{V}{2A}$$

$$= \frac{2335.43}{2 \times 0.4418}$$

$$= 2643.09\ psi$$

$$= \mathbf{2.6\ \mathit{ksi}}$$

Where, (1 Mott, p. 27)

$\tau_{Max} = Maximum\ shear\ stress, ksi$

$V = Shear\ force, lb$

$A = Area, in^2$

2.2.9.7 Pin A Bearing Stress

$$\sigma_{b_{cylinder}} = \frac{F}{A_{b_{cylinder}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{3293.24}{0.75 \times 1}$$

$$= 4390.99\ psi$$

$$= \mathbf{4.4\mathit{ksi}}$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, ksi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

$$\sigma_{b_{Member\ AC}} = \frac{F}{A_{b_{Member\ AC}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{658.87}{0.75 \times 0.25}$$

$$= 3513.97\ psi$$

$$= \mathbf{3.5\ ksi}$$

2.2.9.8 Pin A Analysis

Selected Material: 1340 OQT 700, Su = 221ksi, Sy = 197ksi (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{197}{62.6} = 3.14$$

2.2.9.9 Pin B information

Pin B connects a tower and a member BD. To calculate maximum stress, the flange bearing is ignored, which causes lowering the stress. The maximum force is applied on x-direction when the lift is down.

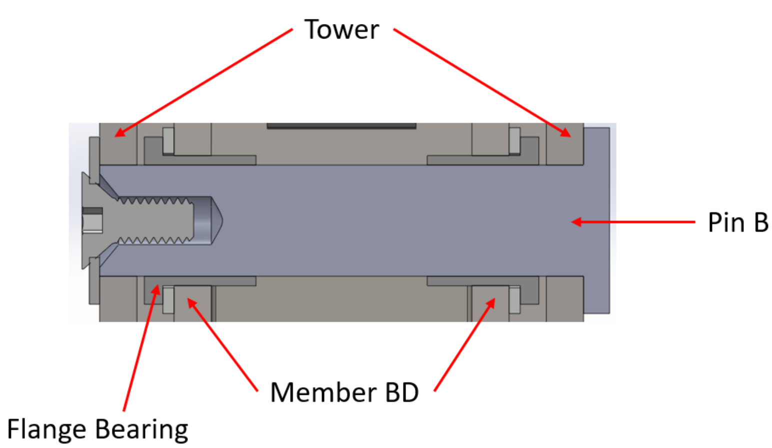


Figure 233. Section View on Pin B

2.2.9.10 Pin B Section Properties

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi (0.75)^2}{4}$$

$$= 0.4418\ in^2$$

Where,
$A = Area, in^2$
$D = Diameter, in$

$$I = \frac{\pi D^4}{64}$$

$$= \frac{\pi (0.75)^4}{64}$$

$$= 0.01553\ in^4$$

Where,
$I = Moment\ of\ inertia, in^4$
$D = Diameter, in$

2.2.9.11 Pin B Applied Forces

When the lift is down, the following force acts on the pin on X-Z direction.

$$BD = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{9221.24}{4}$$

$$= 2305.49\ lbs$$

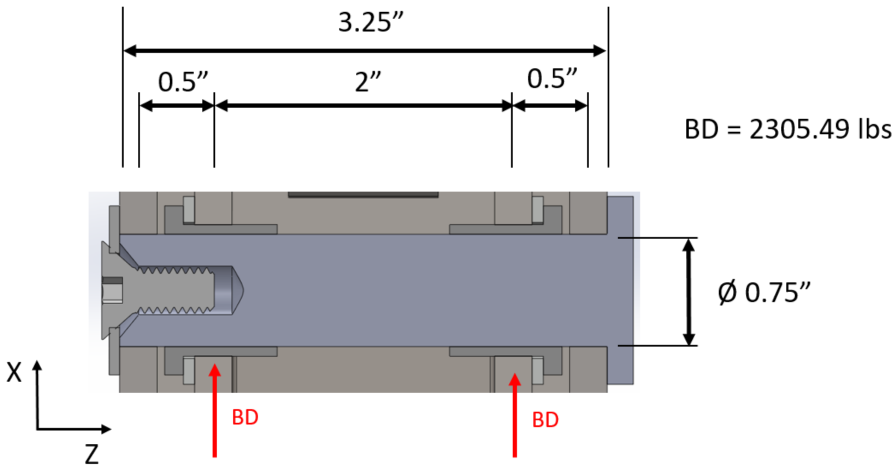


Figure 234. Applied force on Pin B

2.2.9.12 Pin B Shear Force and Bending Moment

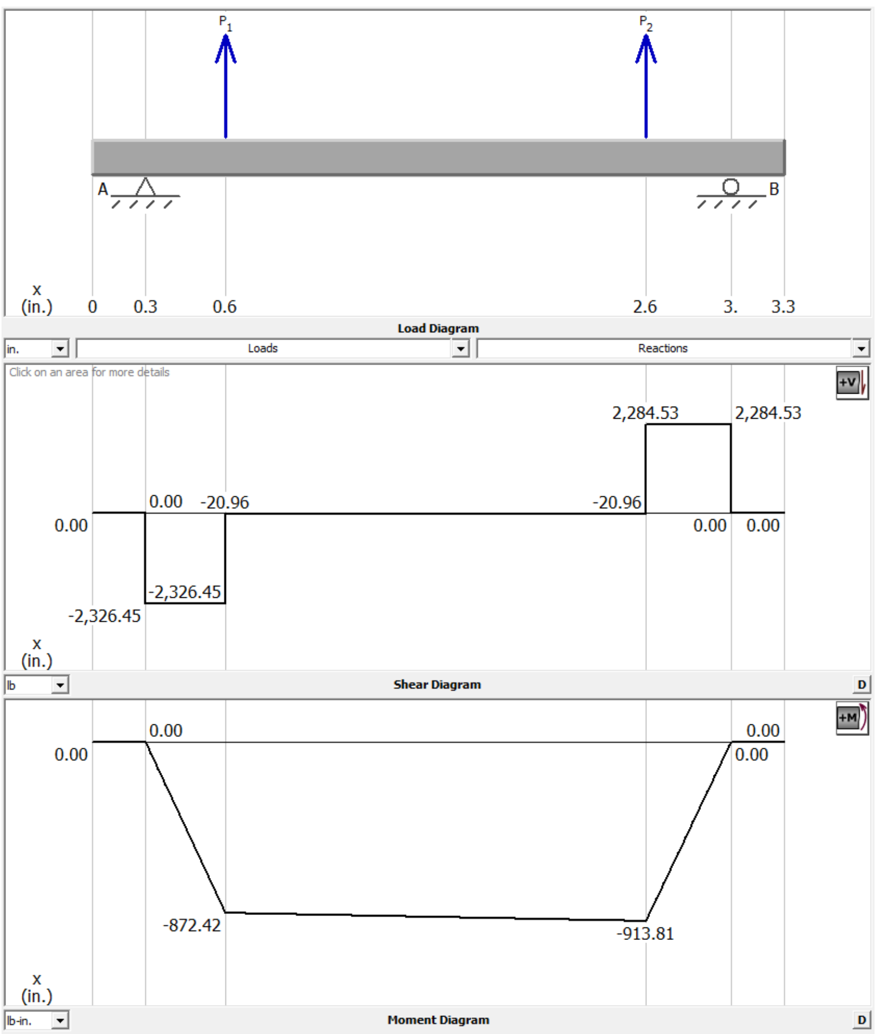


Figure 235. Shear Force and Bending Moment on Pin B

From MD Solid,

$M = 913.81\ lb - in$

$V = 2326.45\ lb$

Where,
$M = Bending\ moment, lb - in$
$V = Shear\ force, lb$

2.2.9.13 Pin B Bending Stress

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

$$= \frac{913.81 \times 0.375}{0.01553}$$

$$= 22065.60\ psi$$

$$= \mathbf{22.1\ ksi}$$

Where, (1 Mott, p. 403)
$\sigma_{Max} = Maximum\ stress, ksi$
$M = Bending\ moment, lb - in$
$C = Perpendicular\ distance\ to\ the\ neutral\ axis, in$
$I = Moment\ of\ inertia, in^4$

2.2.9.14 Pin B Direct Shear stress

$$\tau_{Max} = \frac{V}{2A}$$

$$= \frac{2326.45}{2 \times 0.4418}$$

$$= 2632.92\ psi$$

$$= \mathbf{2.6\ ksi}$$

Where, (1 Mott, p. 27)
$\tau_{Max} = Maximum\ shear\ stress, ksi$
$V = Shear\ force, lb$
$A = Area, in^2$

2.2.9.15 Pin B Bearing Stress

$$\sigma_{b_{Member\ BD}} = \frac{F}{A_{b_{Member\ BD}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{2305.49}{0.75 \times 0.25}$$

$$= 12295.95\ psi$$

$$= \mathbf{12.3\ ksi}$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, ksi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

2.2.9.16 Pin B Analysis

Selected Material: 1340 OQT 700, Su = 221ksi, Sy = 197ksi (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{197}{22.1} = 8.9$$

2.2.9.17 Pin C information

Pin C connects a vertical arm and a member AC. To calculate maximum stress, the flange bearing is ignored, which causes lowering the stress. The maximum force is applied on along the member AC when the lift is Up, which is tilted by 50.6 degrees clockwise on the x-axis on the x-y plane.

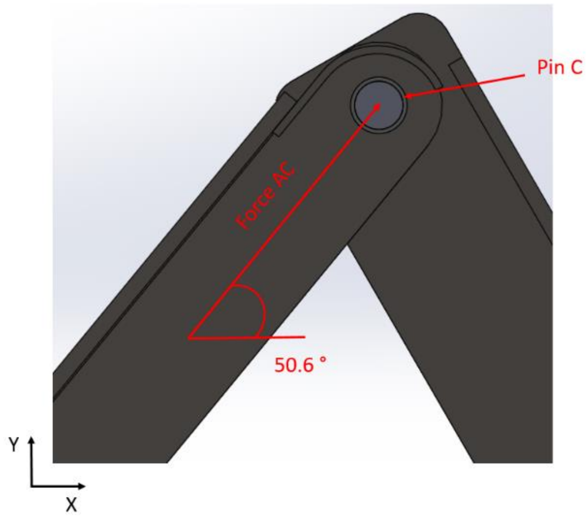


Figure 236. Pin C and Direction of Maximum Force

$$F_{C_{Resultant}} = \sqrt{{F_{Cx}}^2 + {F_{Cy}}^2}$$

$$= \sqrt{1798.52^2 + 2189.55^2}$$

$$= 2833.51\ lbs \angle 50.6°$$

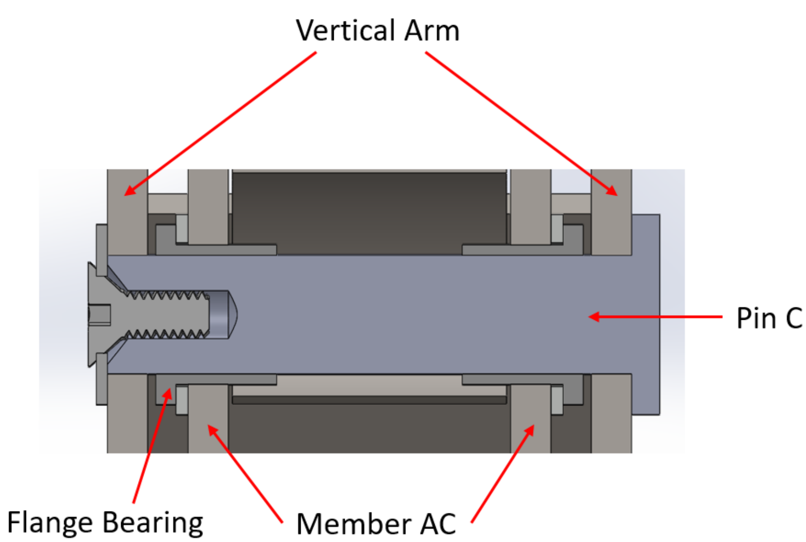


Figure 237. Section View on Pin C

2.2.9.18 Pin C Section Properties

$$A = \frac{\pi D^2}{4}$$

Where,

$A = Area, in^2$

$D = Diameter, in$

$$= \frac{\pi (0.75)^2}{4}$$

$$= 0.4418\ in^2$$

$$I = \frac{\pi D^4}{64}$$

Where,

$I = Moment\ of\ inertia, in^4$

$D = Diameter, in$

$$= \frac{\pi (0.75)^4}{64}$$

$$= 0.01553\ in^4$$

2.2.9.19 Pin C Applied Forces

When the lift is up, the following force acts on the pin on X-Z direction.

$$AC = \frac{Force\ (Resultant)}{\#\ of\ force\ holding\ points}$$

$$= \frac{2833.51}{4}$$

$$= 708.38\ lbs$$

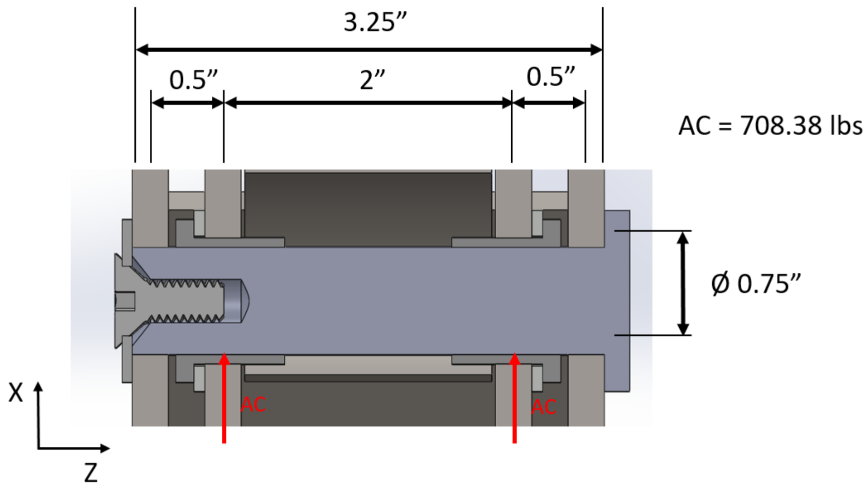


Figure 238. Applied Force on Pin C

2.2.9.20 Pin C Shear Force and Bending Moment

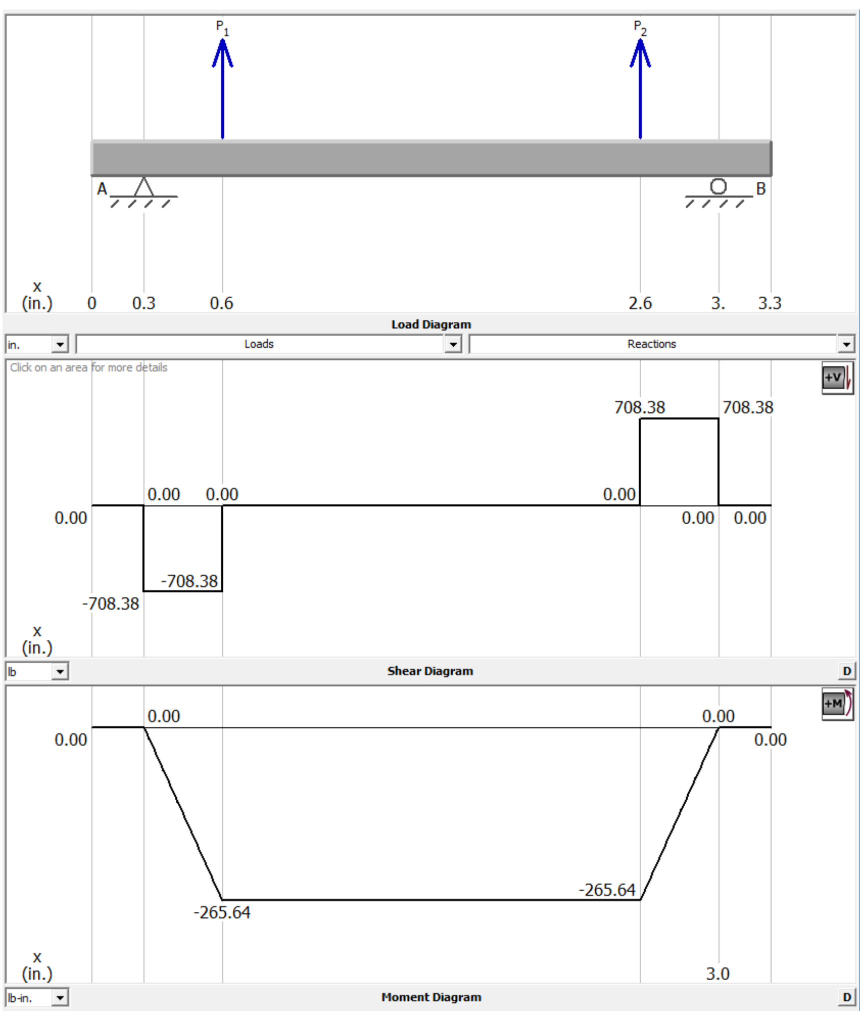


Figure 239. Shear Force and Bending Moment on Pin C

From MD Solid,

$M = 265.64\ lb - in$

$V = 708.38\ lb$

Where,

$M = Bending\ moment, lb - in$

$V = Shear\ force, lb$

2.2.9.21 PinC Bending Stress

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

$$= \frac{265.64 \times 0.375}{0.01553}$$

$$= 6414.36\ \ psi$$

$$= \mathbf{6.4\ ksi}$$

Where, (1 Mott, p. 403)

$\sigma_{Max} = Maximum\ stress, ksi$

$M = Bending\ moment, lb - in$

$C = Perpendicular\ distance\ to\ the\ neutral\ axis, in$

$I = Moment\ of\ inertia, in^4$

2.2.9.22 Pin C Direct Shear stress

$$\tau_{Max} = \frac{V}{2A}$$

$$= \frac{708.38}{2 \times 0.4418}$$

$$= 801.70\ psi$$

$$= \mathbf{0.8 ksi}$$

Where, (1 Mott, p. 27)

$\tau_{Max} = Maximum\ shear\ stress, ksi$

$V = Shear\ force, lb$

$A = Area, in^2$

2.2.9.23 Pin C Bearing Stress

$$\sigma_{b_{Member\ AC}} = \sigma_{b_{Vertical\ Arm}} = \frac{F}{A_{b_{Member\ BD}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{708.38}{0.75 \times 0.25}$$

$$= 3778.03\ psi$$

$$= \mathbf{3.8\ ksi}$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, ksi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

2.2.9.24 Pin C Analysis

Selected Material: 1340 OQT 700, Su = 221ksi, Sy = 197ksi (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{197}{6.4} = 30.7$$

2.2.9.25 Pin D Information

Pin D connects a vertical arm, a cylinder and a member BD. To calculate maximum stress, the flange bearing is ignored, which causes lowering the stress. It is hard to decide where the maximum force is applied. Therefore, possible directions are calculated to compare with.

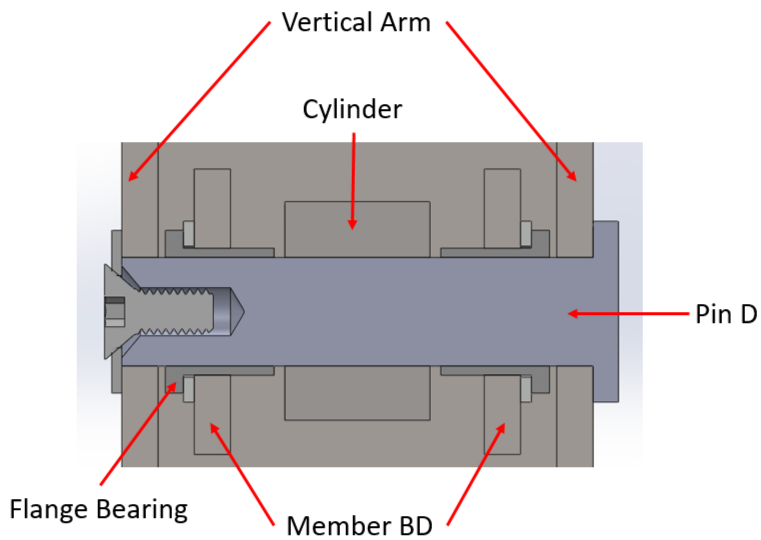


Figure 240. Section View on Pin D

2.2.9.26 Pin D Section Properties

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi(0.75)^2}{4}$$

$$= 0.4418\ in^2$$

Where,
$A = Area, in^2$
$D = Diameter, in$

$$I = \frac{\pi D^4}{64}$$

$$= \frac{\pi(0.75)^4}{64}$$

$$= 0.01553\ in^4$$

Where,
$I = Moment\ of\ inertia, in^4$
$D = Diameter, in$

2.2.9.27 Pin D Applied Forces (Case 1)

When the lift is down, the following force acts on the pin on X-Z direction.

$$BD = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{9221.94}{4}$$

$$= 2305.49\ lb$$

$$F\ cylinder = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{\cos 12^\circ\ \times 6733.63}{2}$$

$$= 3293.24\ lbs$$

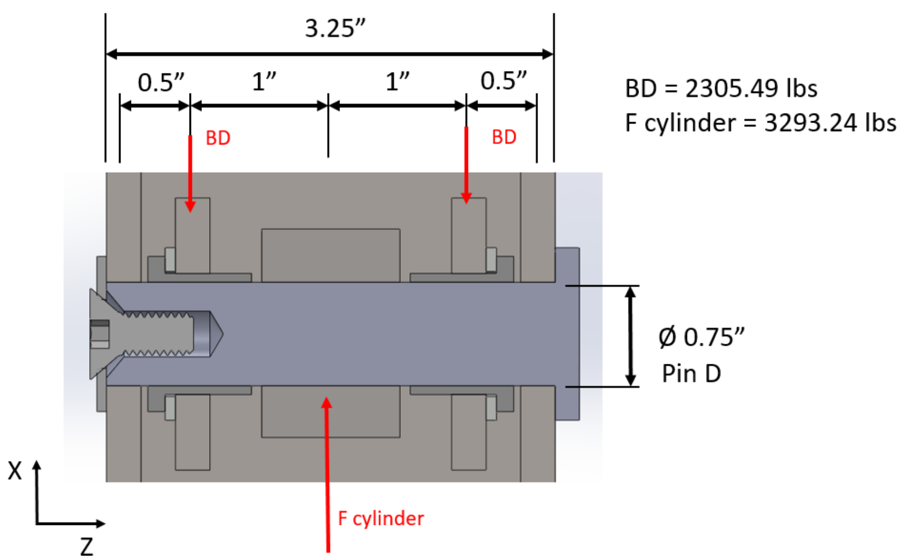


Figure 241. Applied Force on Pin D on X-Z Direction

2.2.9.28 Pin D Shear Force and Bending Moment (Case 1)

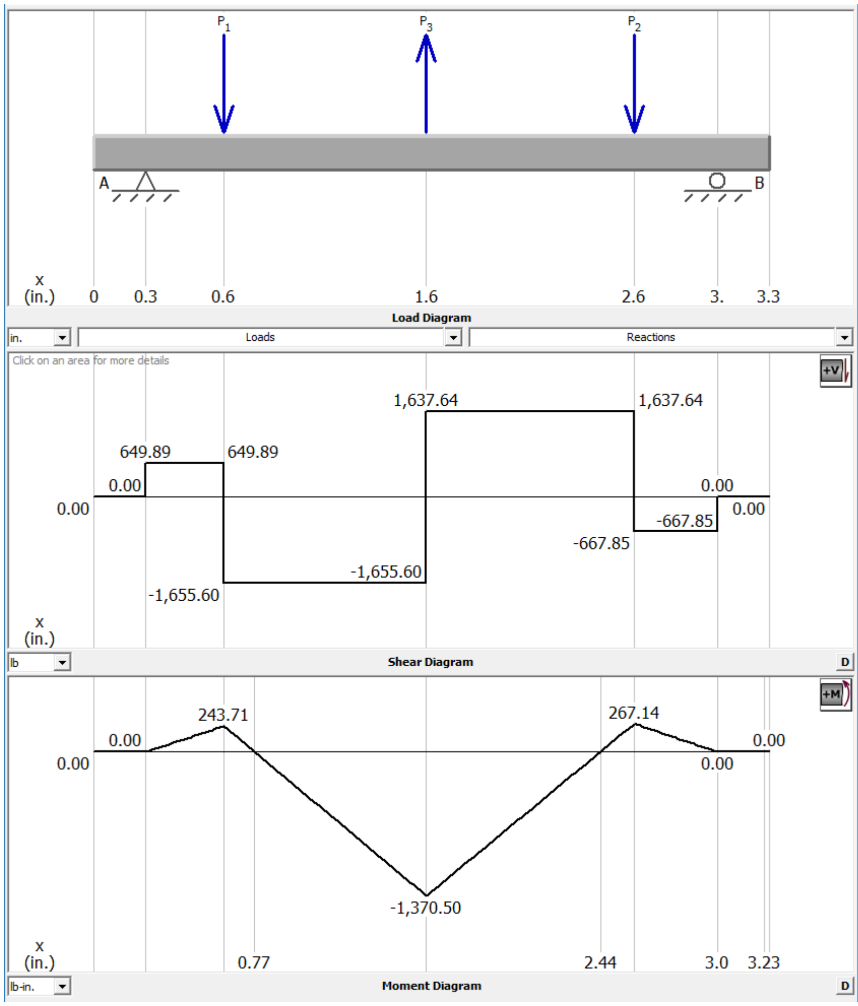


Figure 242. Vertical Shear and Bending Moment on Pin D on X-Z Direction

Where,

$M = Bending\ moment, lb - in$

$V = Shear\ force, lb$

From MD Solid,

$M = 1370.50\ lb - in$

$V = 1637.64\ lb$

2.2.9.29 Pin D Applied Forces (Case 2)

When the lift is up, the following force acts on the pin on Y-Z direction.

$$F_{BD_y} = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{Sin\ 50.6° \times 7278.66}{4}$$

$$= 1406.12$$

$$F\ cylinder_y = \frac{Force}{\#\ of\ force\ holding\ points}$$

$$= \frac{Sin\ 35.8° \times 3478.73}{2}$$

$$= 1017.45\ lbs$$

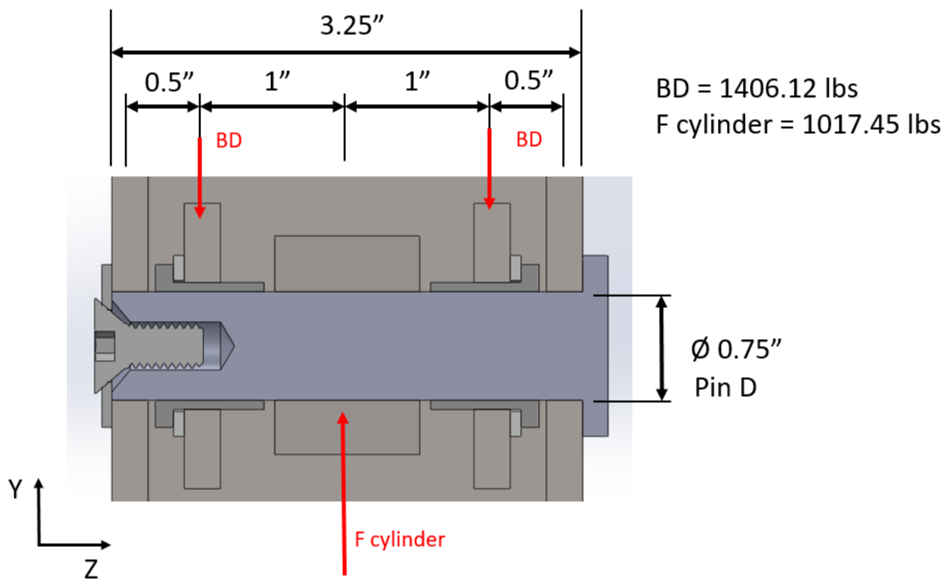


Figure 243. Applied Force on Pin D on Y-Z Direction

2.2.9.30 Pin D Shear Force and Bending Moment (Case 2)

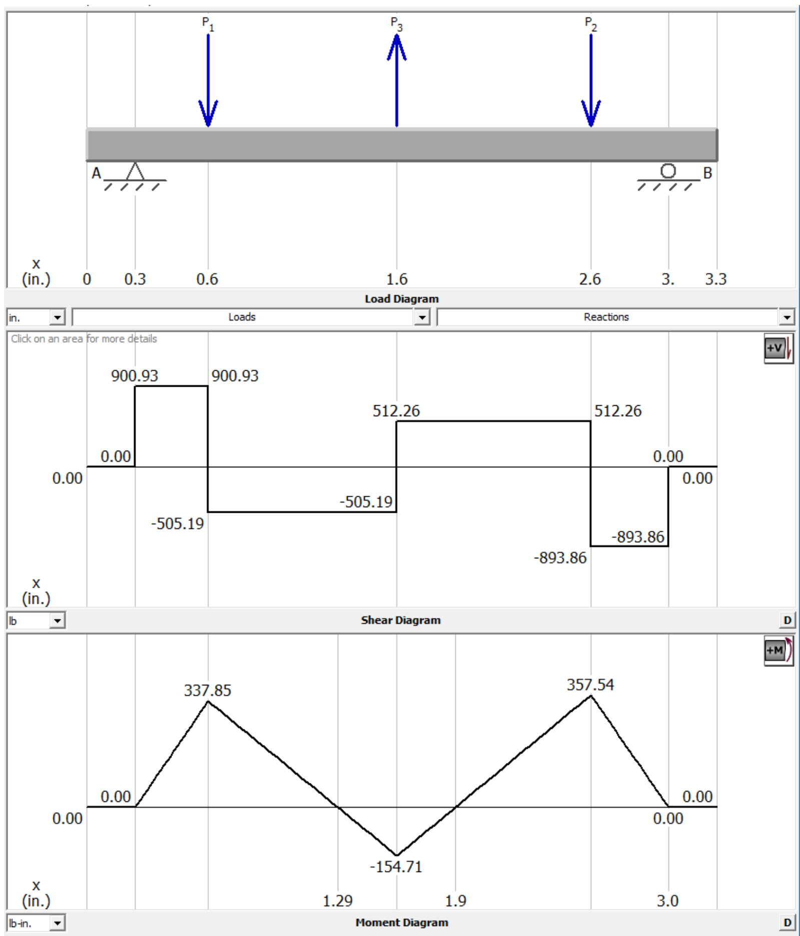


Figure 244. Vertical Shear and Bending Moment on Pin D on Y-Z Direction

From MD Solid,

$M = 357.54\ lb - in$

$V = 900.93\ lb$

Where,

$M = Bending\ moment, lb - in$

$V = Shear\ force, lb$

2.2.9.31 Pin D Selection of Shear Force and Bending Moment

Comparing both situations, both maximum bending moment and shear force are acting on x-direction when the lift is down. Therefore, the following bending moment and shear force are used to calculate stress.

$$M = 1370.50\ lb - in$$

$$V = 1637.64\ lb$$

2.2.9.31 Pin D Bending Stress

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

$$= \frac{1370.50 \times 0.375}{0.01553}$$

$$= 33093.21\ \ psi$$

$$= \mathbf{33.1\ ksi}$$

Where, (1 Mott, p. 403)
$\sigma_{Max} = Maximum\ stress, ksi$
$M = Bending\ moment, lb - in$
$C = Perpendicular\ distance\ to\ the\ neutral\ axis, in$
$I = Moment\ of\ inertia, in^4$

2.2.9.32 Pin D Direct Shear stress

$$\tau_{Max} = \frac{V}{2A}$$

$$= \frac{1637.64}{2 \times 0.4418}$$

$$= 1853.37\ psi$$

$$= \mathbf{1.9\ ksi}$$

Where, (1 Mott, p. 27)
$\tau_{Max} = Maximum\ shear\ stress, ksi$
$V = Shear\ force, lb$
$A = Area, in^2$

2.2.9.33 Pin D Bearing Stress

$$\sigma_{b_{Member\ BD}} = \frac{F}{A_{b_{Member\ BD}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{2305.49}{0.75 \times 0.25}$$

$$= 12295.95\ psi$$

$$= \mathbf{12.3}\ \boldsymbol{ksi}$$

Where, (1 Mott, p. 173)

$\sigma_b = Bearing\ stress, ksi$

$F = Bearing\ load, lb$

$A_b = w \times l = Cross\ section\ area, in^2$

$w = Width, in$

$l = Length, in$

$$\sigma_{b_{Cylinder}} = \frac{F}{A_{b_{Cylinder}}}$$

$$= \frac{F}{w \times l}$$

$$= \frac{3293.24}{0.75 \times 1}$$

$$= 4390.99\ psi$$

$$= \mathbf{4.4}\ \boldsymbol{ksi}$$

2.2.9.34 Pin D Analysis

Selected Material: 1340 OQT 700, Su = 221ksi, Sy = 197ksi (1 Mott, A-10)

$$N = \frac{S_y}{\sigma'} = \frac{197}{33.1} = 5.9$$

2.2.9.35 Pin Analysis Table

The analysis of the other pins has the same process, and it is organized with a table which shows diameter, area, inertia, maximum stress, material and safety factor.

Table 8. Pin Analysis Table

	Diameter (in)	Area (in^2)	Intertia (in^4)	Max Bending Stress (ksi)	Max Shear Stress (ksi)	Max Bearing Stress (ksi)	Selected Material	Yield Strength (ksi)	Safety Factor
Pin A	0.75	0.4418	0.01553	62.6	2.6	4.4	1340 OQT 700	197	3.15
Pin B	0.75	0.4418	0.01553	22.1	2.6	12.3	1341 OQT 700	197	8.91
Pin C	0.75	0.4418	0.01553	6.4	0.8	3.8	1342 OQT 700	197	30.78
Pin D	0.75	0.4418	0.01553	33.1	1.9	12.3	1343 OQT 700	197	5.95
Pin E	0.75	0.4418	0.01553	21.1	1.6	3.1	1344 OQT 700	197	9.34
Pin H	0.75	0.4418	0.01553	15.6	2.1	3.7	1345 OQT 700	197	12.63
Pin J	0.75	0.4418	0.01553	64.8	8.9	15.2	1346 OQT 700	197	3.04
Pin K	1.00	0.7854	0.04909	13.4	2.6	4.4	1347 OQT 700	197	14.70
Pin L	0.31	0.0767	0.00047	3.5	0.3	1.2	1020 ANNEALED	43	12.29

3.0 Conclusion

From the force and stress analysis, all components of the wheelchair lift are within safety factor three. Pin J has the cloest safety facor 3.04. Besides, most of the parts have more than five safety factor. Therefore, the wheelchair lift is acceptable regarding the Americans with Disabilities Act.

4.0 Recommendations

Some components have higher safety factors, which can be modified to reduce weight. For example, the top parallel arm and bottom parallel arm profiles' thickness can be thinner. It reduces cost and weight.

5.0 Reference

1 Mott, R. L. (n.d.). Sixth Edition Applied Strength of Material.

2 Mott, R. L. (n.d.). Machine Elements in Mechanical Design Fifth Edition.

Online Matrix Calculator (http://www.bluebit.gr/matrix-calculator/)

Mcmaster-Carr (https://www.mcmaster.com/)

6.0 Time Log

6.1 Summary

Total 408.5 hours were used to get a project done. The month the most much time was used is Feburary. Report is the work task most much time used.

Table 9. Work Hours - Month

Month	Hour
Jan	43
Feb	93
Mar	87
Apr	21
May	85.5
Jun	77.5
Jul	1.5

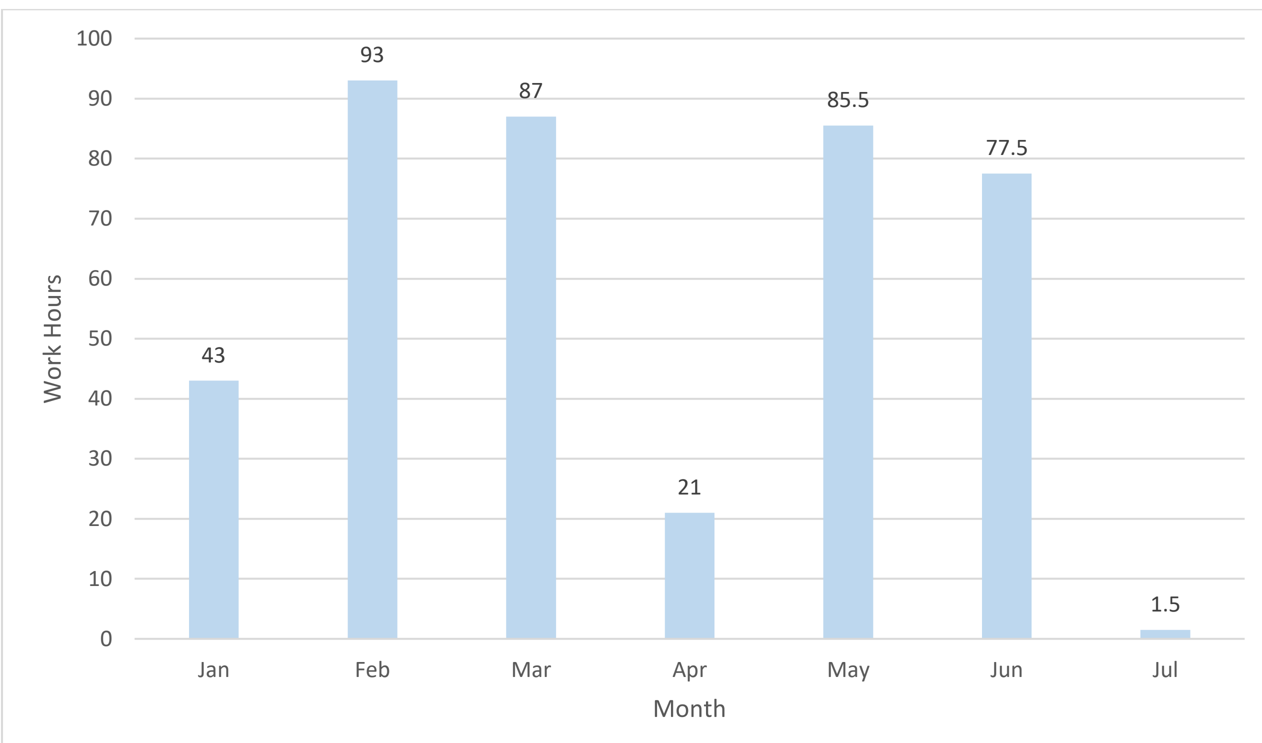


Figure 245. Work Hours - Month

Table 10. Work Hour - Work Type

Type	Hour	Percent
Force Analysis	83	20.3%
Stress Analysis	62	15.2%
3D Design	57.5	14.1%
Drawing	54.5	13.3%
Report	111	27.2%
Others	40.5	9.9%
Total	408.5	100.0%

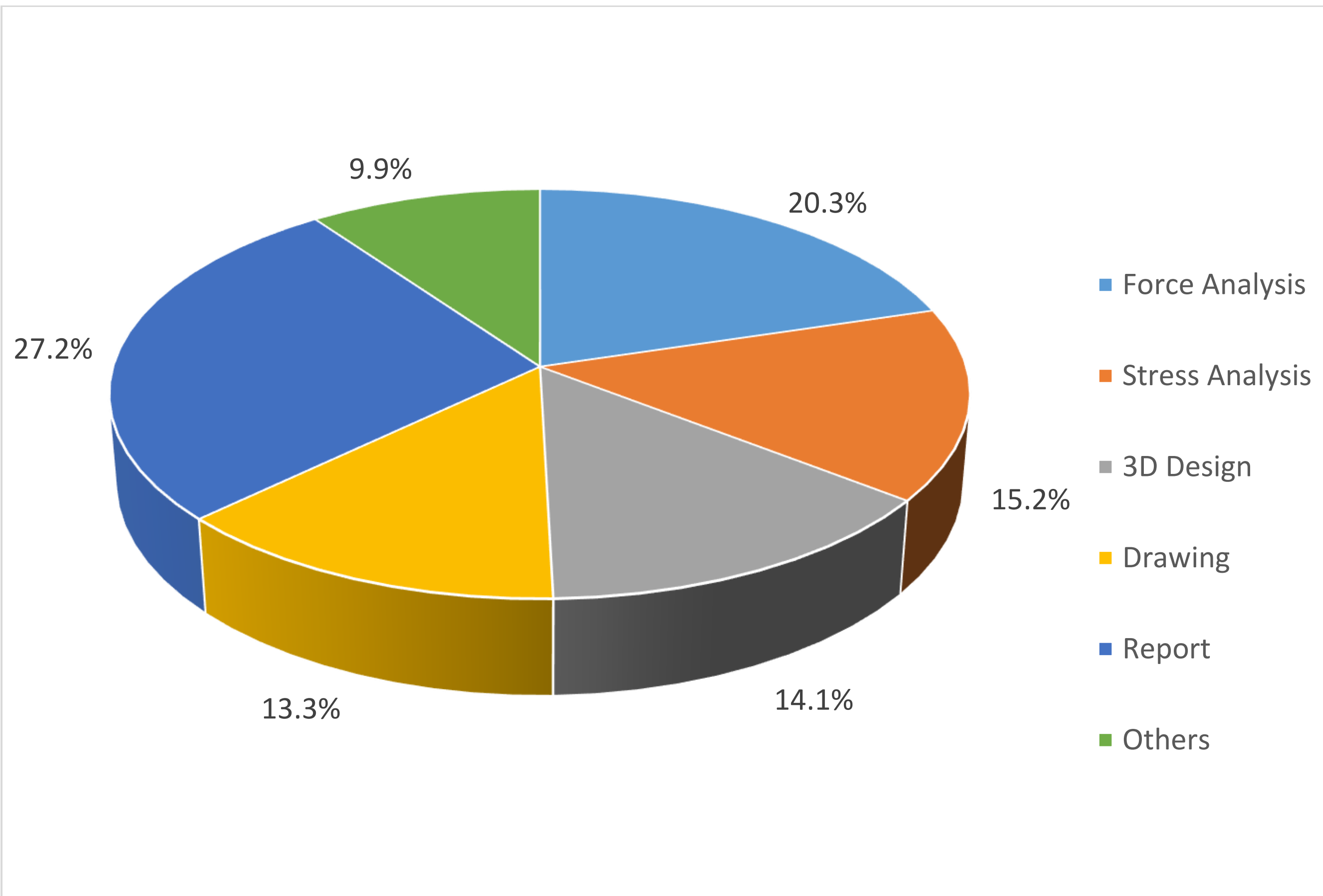


Figure 246. Work hours - Work Type

6.2 Time log table

Table 11. Time Log

Date	Time (hrs)	Activity
12-Jan	3	Selected manufacturer and model
14-Jan	4	Created documents for proposal
15-Jan	5	Revised Images files, numbering parts
16-Jan	4	Organize and finalize proposal document
18-Jan	5	Visited the company that has actual machine and measured it
21-Jan	2	3D Modeling (Basic Part design)
23-Jan	3	3D Modeling (Basic Part design + Assembly)
24-Jan	3	3D Modeling (Basic Part design + Assembly)
25-Jan	4	3D Modeling (Mechnical Assembly: Slot)
26-Jan	5	3D Modeling (Omitted Mechanical Assebmly)
28-Jan	2	3D Modeling (Cylinder and modified some compoents)
30-Jan	3	3D Modeling (Bushing assembly)
3-Feb	8.5	Restart 3D Modeling (Top Parallel Arm, Bottom Parallel Arm, Vertical Arm, Hand rail)
4-Feb	6	3D Modeling (Platform)
5-Feb	4	3D Modeling (Platform Roll Stop)
7-Feb	6	Free Body Diagram, Progress Report, Sketch Drawing
9-Feb	2	Set up Configuration and Add materials
12-Feb	1.5	FBD Diagram and Force Analysis
13-Feb	3	FBD Diagram and Force Analysis
14-Feb	5	FBD Diagram and Force Analysis, 3D Design Modification
15-Feb	5.5	3D Design Modification, FBD Diagram Modification
16-Feb	8	Force Analysis
19-Feb	2.5	Force Analisys (Lift Up)
22-Feb	9	Force Analisys (Lift Up), 3D design change
23-Feb	11	Force Anlaysis (Lift Down), 3D design Fastener Add
24-Feb	11	3D Fastener Add
25-Feb	1	Stress Analysis
28-Feb	9	Stress Analysis
1-Mar	10	3D Design + Stress Analysis
3-Mar	10.5	3D Design
7-Mar	2.5	Force Analaysis
8-Mar	4	Force Analaysis
9-Mar	10	Force Analaysis
10-Mar	9	Force Analaysis
12-Mar	0.5	Force Analaysis
13-Mar	1.5	Progress report, drawing, sample calculation
14-Mar	2	Force Analaysis
16-Mar	8	Force Analaysis
18-Mar	1	Force Analaysis
19-Mar	2	Stress Analysis
20-Mar	7	Stress Analysis

Date	Time (hrs)	Activity
21-Mar	3	Stress Analysis
27-Mar	6	Stress Analysis
28-Mar	2	Stress Analysis
29-Mar	2	Drawing
30-Mar	6	Stress Analysis
3-Apr	4	Stress Analysis
4-Apr	1	Stress Analysis
7-Apr	3	Drawing, Cost and Part list
10-Apr	5	Drawing, Stress Analsysis
11-Apr	4	Costing
13-Apr	3	Progress Report, Time Log, File organizing
28-Apr	1	Drawing
4-May	3	Drawing
7-May	1	Schedule and Force Analysis
8-May	6	Force Analysis
9-May	4	Report- Force Analysis
10-May	2	Report- Force Analysis
11-May	8	Report- Force Analysis
12-May	9.5	Report- Force Analysis
13-May	7.5	Report- Force Analysis
15-May	2.5	Report - Top Parallel Arm, Bottom Parallel Arm
16-May	2	Drawing
23-May	6	Introduction, Report (Vertical Pivot Arm)
24-May	3	Report (Vertical Pivot Arm)
25-May	8	Report (Vertical Pivot Arm)
26-May	7.5	Report (Handrail)
27-May	2.5	Drawing
29-May	5	Drawing
30-May	5	Drawing
31-May	3	Drawing
1-Jun	7.5	Drawing
2-Jun	4	Drawing (5.3.1)
6-Jun	8	Drawing List, Drawing
7-Jun	6	Drawing
8-Jun	7.5	Drawing, Report
9-Jun	3	Report
13-Jun	0.5	Report
20-Jun	3	REPORT
21-Jun	1.5	REPORT
22-Jun	3	REPORT
23-Jun	8.5	REPORT
24-Jun	5	Report
25-Jun	6	Report
26-Jun	4.5	Report
27-Jun	6.5	Report
28-Jun	3	Report
10-Jul	1.5	Report
Total	408.5	

7.0 Drawing List

7.1 Drawing List

Table 12. Drawing List

#	DWG #	Title	Description	Size
1	GA100	WHEELCHAIR LIFT GENERAL ASSEMBLY	WHEELCHAIR LIFT GENERAL ASSEMBLY	C
2	EX100	DISPLACEMENT AND BOUNDARY	DISPLACEMENT AND BOUNDARY	C
3	SA100	TOP PARALLEL ARM ASSEMBLY	TOP PARALLEL ARM ASSEMBLY	B
4	D101	TOP PARALLEL ARM	ARM-PARALLEL TOP 48 IN FTG R	B
5	D102	CAP	CAP-PARALLEL ARM	B
6	D103	WASHER .906 ID	WASHER-0.906 ID X 1.23 OD X 0.075 TH ZINC	B
7	D104	BEARING FLANGE	BEARING-FLANGE-0.75 X 0.375 -12FDU06	B
8	SA200	BOTTOM PARALLEL ARM ASSEMBLY	BOTTOM PARALLEL ARM ASSEMBLY	B
9	D201	BOTTOM PARALLEL ARM	ARM-PARALLEL BOTTOM	B
10	SA300-01	VERTICAL ARM ASSEMBLY (LEFT)	VERTICAL ARM ASSEMBLY (LEFT)	B
11	SA300-02	VERTICAL ARM ASSEMBLY (RIGHT)	VERTICAL ARM ASSEMBLY (RIGHT)	B
12	WA301	VERTICAL ARM WELDMENT	VERTICAL ARM WELDMENT ASSEMBLY	B
13	D301-01	VERTICAL CHANNEL PART 1	VMT-VERTICAL CHANNEL PART 1	B
14	D301-02	VERTICAL CHANNEL PART 2	VMT-VERTICAL CHANNEL PART 2	B
15	SA400-01	PIVOT ARM ASSEMBLY (LEFT)	PIVOT ARM ASSEMBLY (LEFT)	C
16	SA400-02	PIVOT ARM ASSEMBLY (RIGHT)	PIVOT ARM ASSEMBLY (RIGHT)	C
17	D402	ROTATING PIVOT SLIDE ARM PART 1	ROTATING PIVOT SLIDE ARM PART 1	B
18	D403	ROTATING PIVOT SLIDE ARM PART 2	ROTATING PIVOT SLIDE ARM PART 2	B
19	D404	PLATFORM SLIDE	SLIDE-UHMW-PLATFORM SLIDE	B
20	D405	OUTER FOLD ARM	OUTER FOLD ARM	B
21	D406-01	INNER FOLD ARM TYPE 1	(RIGHT) INNER FOLD ARM	B
22	D406-02	INNER FOLD ARM TYPE 2	(LEFT) INNER FOLD ARM	B
23	D407	PIVOT ARM SLOT	PIVOT ARM SLOT	B
24	SA500	PLATFORM ASSEMBLY	PLATFORM ASSEMBLY	C
25	SSA501	PLATFORM BODY SUB ASSEMBLY	S-Sub (1) PLATFORM BODY SUB ASSEMBLY	C
26	WA501	PLATFORM BODY WELDMENT	S-Sub (2) PLATFORM BODY WELDMENT	C
27	D501-01	SIDE WALL TYPE 1	PLATFORM SIDE WALL TYPE 1	B
28	D501-02	SIDE WALL TYPE 2	PLATFORM SIDE WALL TYPE 2	B
29	D501-03	BOTTOM PLATE TYPE 1	PLATFORM BOTTOM PLATE TYPE 1	B
30	D501-04	BOTTOM PLATE TYPE 2	PLATFORM BOTTOM PLATE TYPE 2	B

#	DWG #	Title	Description	Size
31	D501-05	MACHINED PROFILE TYPE 1	PLATFORM MACHINED PROFILE TYPE 1	B
32	D501-06	MACHINED PROFILE TYPE 2	PLATFORM MACHINED PROFILE TYPE 2	B
33	D501-07	PROFILE TUBE	PLATFORM PROFILE TUBE	B
34	D501-08	SUPPORT PLATE	PLATFORM SUPPORT PLATE	B
35	D501-09	STEPPED PIN	PLATFORM STEPPED PIN	B
36	D501-10	STOPPER SUPPORT	STOPPER SUPPORT	B
37	SSA502	BRIDGE PLATE SUB ASSEMBLY	BRIDGE PLATE SUB ASSEMBLY	C
38	D502-01	BRIDGE PLATE	BRIDGE PLATE	B
39	D502-02	BRIDGE PLATE BRACKET TYPE 1	(LEFT) BRIDGE PLATE BRACKET	B
40	D502-03	BRIDGE PLATE BRACKET TYPE 2	(RIGHT) BRIDGE PLATE BRACKET	B
41	SSA503	ROLL STOP ALUM SUB ASSEMBLY	ROLL STOP ALUM SUB ASSEMBLY	C
42	D503-01	ROLL STOP-ALUM	ROLL STOP-ALUM	B
43	D503-02	LATCH ROLL STOP TYPE 1	(LEFT) BKT-LATCH ROLL STOP	B
44	D503-03	LATCH ROLL STOP TYPE 2	(RIGHT) BKT-LATCH ROLL STOP	B
45	SSA504	ROLL STOP ACTIVATION FOOT SUB ASSEMBLY	S-Sub (1) ROLL STOP ACTIVATION FOOT ASSEMBLY	C
46	WA504	ACTIVATION FOOT WELDMENT	S-Sub (2) ROLL STOP ACTIVATION FOOT WELDMENT	B
47	D504-01	ACTIVATION FOOT	ROLL STOP ACTIVATION FOOT	B
48	D504-02	ACTIVATION FOOT WELDMENT PART	ROLL STOP ACTIVATION FOOT WELDMENT PART	B
49	D504-03	LATCH-ROLL STOP PLATE TYPE 1	(LEFT) LATCH-ROLL STOP PLATE	B
50	D504-04	LATCH-ROLL STOP PLATE TYPE 2	(RIGHT) LATCH-ROLL STOP PLATE	B
51	D505	STOP BLOCK	STOP BLOCK	B
52	SA600-01	TOWER ASSEMBLY (LEFT)	(LEFT) TOWER ASSEMBLY	B
53	SA600-02	TOWER ASSEMBLY (RIGHT)	(RIGHT) TOWER ASSEMBLY	B
54	D601	TOWER	TOWER	B
55	SA700	HANDRAIL ASSEMBLY	HANDRAIL ASSEMBLY	C
56	D701	HANDRAIL CONNECTOR	HANDRAIL CONNECTOR	B
57	D702	BENDED PIPE	HANDRAIL PIPE	B
58	D703	RUBBER CAP	HANDRAIL RUBBER CAP	B
59	D801	PIN TYPE 1	PIN TYPE 1	B
60	D802	PIN TYPE 2	PIN TYPE 2	B
61	D803	PIN TYPE 3	PIN TYPE 3	B

7.2 Part Numbering System

Table 13. Part Numbering System

NUMBERING SYSTEM			
NAME	NUMBER		DESCRIPTION
SA			SUB ASSEMBLY
SSA			SUB-SUB ASSEMBLY
D			DETAILED DRAWING
WA			WELDMENT ASSEMBLY
GA			GENERAL ASSEMBLY
EX			EXTENTS DRAWING
	XXX-XX		ASSEMBLY NUMBER
		0	FINAL ASSEMBLY
		1	TOP PARALLER ARM ASSEMBLY
		2	BOTTOM PARALLER ARM ASSEMBLY
		3	VERTICAL ARM ASSEMBLY
		4	PIVOT ARM ASSEMBLY
		5	PLATFORM ASSEMBLY
		6	TOWER ASSEMBLY
		7	HANDRAIL ASSEMBLY
		8	PIN
	XXX-XX		SUB ASSEMBLY PART NUMBER
	XXX-XX		SUB-SUB ASSEMBLY PART NUMBER

8.0 Appendices

8.1 Matrix for Lift-Up Force Calculation

8.2 Matrix for Lift-Down Force Calculation

Table 14. Matrix for Lift-Up Force Calculation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
EQN #	C_X	C_Y	D_X	D_Y	E_{X1}	E_{Y1}	E_{X2}	E_{Y2}	E_{X3}	E_{Y3}	F_F	GI	H_X	H_Y	J_X	J_Y	K_{X1}	K_{Y1}	K_{X2}	K_{Y2}	K_{X3}	K_{Y3}	L_X	L_Y	F_M	F_N	**Answer**
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1798.52
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2189.55
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1798.52
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3589.56
5	0	0	0	0	-1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	33.1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	133.393
12	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	407.013
13	0	0	0	0	-1	0	0	0	0	0	0.1736	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-100
14	0	0	0	0	0	1	0	0	0	0	-0.9848	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
15	0	0	0	0	0	0	1	0	0	0	-0.1736	-0.4939	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	-1	0	0	0.9848	0.8695	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	18.4
17	0	0	0	0	0	0	-1.6	-9.07	0	0	6.23	3.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55.568
18	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	0	0	-0.6239	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	-0.7815	0	33.88
20	0	0	0	0	0	0	0	0	0	0	0	0	18.76	-5.31	0	0	0	0	0	0	0	0	0	0	4.2600	0	-7.1148
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0.6239	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0.7815	0	0
23	-1	0	1	0	0	0	0	0	-1	0	0	0.4939	0	0	-1	0	0	0	0	0	0	0	0	0	0	1	0
24	0	-1	0	1	0	0	0	0	0	-1	0	-0.8695	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	150
25	22.75	4.05	-14	0	0	0	0	0	0	0	0	4.712	0	0	-21.86	0	0	0	0	0	0	0	0	0	0	19.86	-1288.5
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	-1	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1110.52
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1.5	-3.75	0	0	0	2	27958.62

Table 15.Matrix for Lift-Down Force Calculation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
EQN #	C_X	C_Y	D_X	D_Y	E_{X1}	E_{Y1}	E_{X2}	E_{Y2}	E_{X3}	E_{Y3}	F_F	GI	H_X	H_Y	J_X	J_Y	K_{X1}	K_{Y1}	K_{X2}	K_{Y2}	K_{X3}	K_{Y3}	L_X	L_Y	F_M	F_N	**Answer**
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2635.46
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2635.46
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1400
5	0	0	0	0	-1	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	-1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	33.1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	18.867
12	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	407.013
13	0	0	0	0	-1	0	0	0	0	0	0.1736	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-100
14	0	0	0	0	0	1	0	0	0	0	-0.9848	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
15	0	0	0	0	0	0	1	0	0	0	-0.1736	-0.4939	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	-1	0	0	0.9848	0.8695	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	18.4
17	0	0	0	0	0	0	-1.6	-9.07	0	0	6.23	3.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55.568
18	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	0	0	-0.0715	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	-0.9974	0	33.88
20	0	0	0	0	0	0	0	0	0	0	0	0	18.76	-5.31	0	0	0	0	0	0	0	0	0	0	0.2923	0	-7.1148
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0.0715	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-0.9974	0	0.44
23	-1	0	1	0	0	0	0	0	-1	0	0	0.4939	0	0	-1	0	0	0	0	0	0	0	0	0	0	1	0
24	0	0	0	1	0	0	0	0	0	1	0	-0.8695	0	0	0	1	0	0	0	0	0	0	0	0	0	0	150
25	22.75	0	-14	0	0	0	0	0	0	0	0	4.712	0	0	-21.86	0	0	0	0	0	0	0	0	0	0	19.86	-1942.5
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0	0	-1	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	0	0	0	0	1110.52
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	-3.75	0	0	0	2	27958.62