ME 3614 Mechanical Design I

Design Project

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Introduction

We are assigned to design a light-weight bike rack that can hold 3 bikes, and the rack must be able to last for infinite life time. The rack has three basic section, which is the first horizontal part that holds three bikes on the top, the middle vertical part that extends the first rack from the hitch to a proper height that the bike won't touch the ground and a part that connects the rack with the hitch. In this problem case, we must consider every part separately for all the calculations in order to make the right judgement and find out if it's safe and durable. On the side of safety, this product must have a reasonable high safety factor because of the wide customer range and the product could be used every day. Therefore, it must have a high safety factor.

Summary

After reading the instructions, the first step of the design process is we must design the dimensions, cross-section and choose the material of the whole rack. According to online research, the maximum weight of a bike is 25 lb. and the height is 21 inches. Therefore, three bikes placed on the first rack could produce 75 lb. of force, and the second part of the rack should be longer that 21 inches, so I picked 2 ft. After considering the whole rack I set my dimension to be: section 1 is 1 ft, section 2 is 2 ft and section 3 is 0.25 ft. These are all listed in Appendix A.

For material, I choose stainless steel because I went online and searched same kind of product and found out the most common material was stainless steel. It was mentioned that the hitch has a 2x2 in cross-section, so I designed my rack to have a 2x2 in cross-section. However, after considering the weight of the whole rack, I found out that it was too heavy by just itself, therefore, I designed it to be a square tube which has the outer length of 2 in. After searching on Metalsdepot.com, I found the stainless-steel square tube that they have for sell which has an outer length of 2 in and a wall thickness of 0.25 inches. This tube is perfect for building my rack.

After having selected dimensions, cross-section and material, I started to do all the calculations. The first thing I had to include was all the properties which is included in the Appendix A. the cost of the rack, the weight of the rack and all the material properties of the rack is listed. Then I started to consider all three segments separately and analysis them. The force that I'm using in all analysis is 3 times the actual force to get the maximum force. In Appendix B, the total force is listed, and the analysis of all three segments is there as well. From this part, with the help of V-M diagrams, we could find the Maximum shear force and momentum for segment 1&3. There is no V-M diagram for segment2. For all the analysis, I'm neglecting the self-weight of the rack during the calculation because comparing with the weight of three bikes, the weight of the rack is way smaller, and it would be way easier to not calculate with the weight of rack.

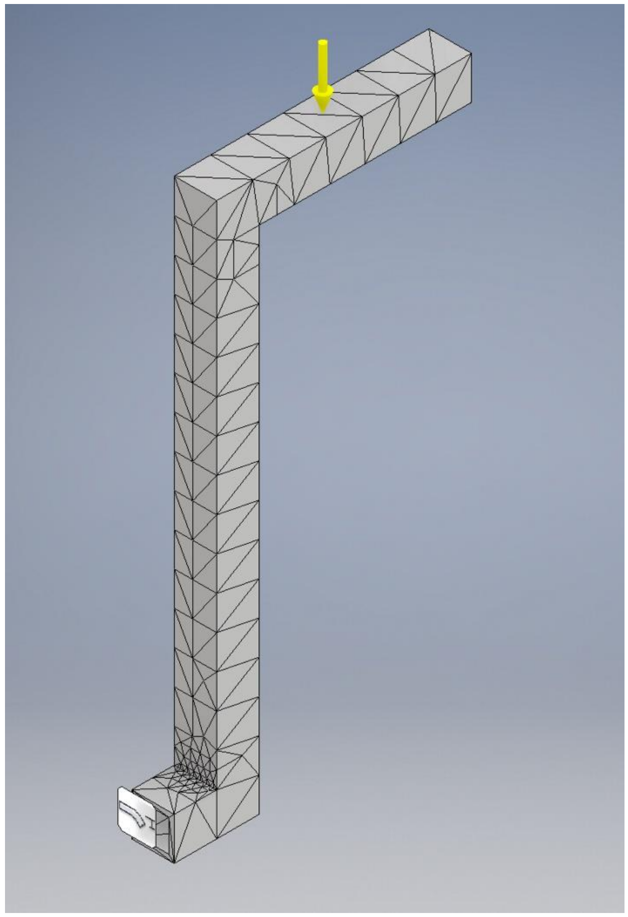
In order to calculate which part is the easiest to break when the rack is fully loaded with three bikes, I used the static failure calculations to find the critical point and elements. The candidates in my mind before calculation was two connection that connects part 1&2, part 2&3 and the connecting point between the hitch and the rack. After calculation, which is shown in Appendix C, I found out that the connecting point at the hitch has the largest critical stress which was caused by the momentum created by three bikes to the x direction as shown in the graphic that I used for analysis. In the calculation, I found that in order to achieve maximum bending momentum, we must choose the point at the edge of the cross-section, so the Y is 1 and Q of the shear stress is 0. Therefore, all the shear stress is 0. At this point, using the MSS, we could find that the safety factor was 10.5209 which is high enough for any product design.

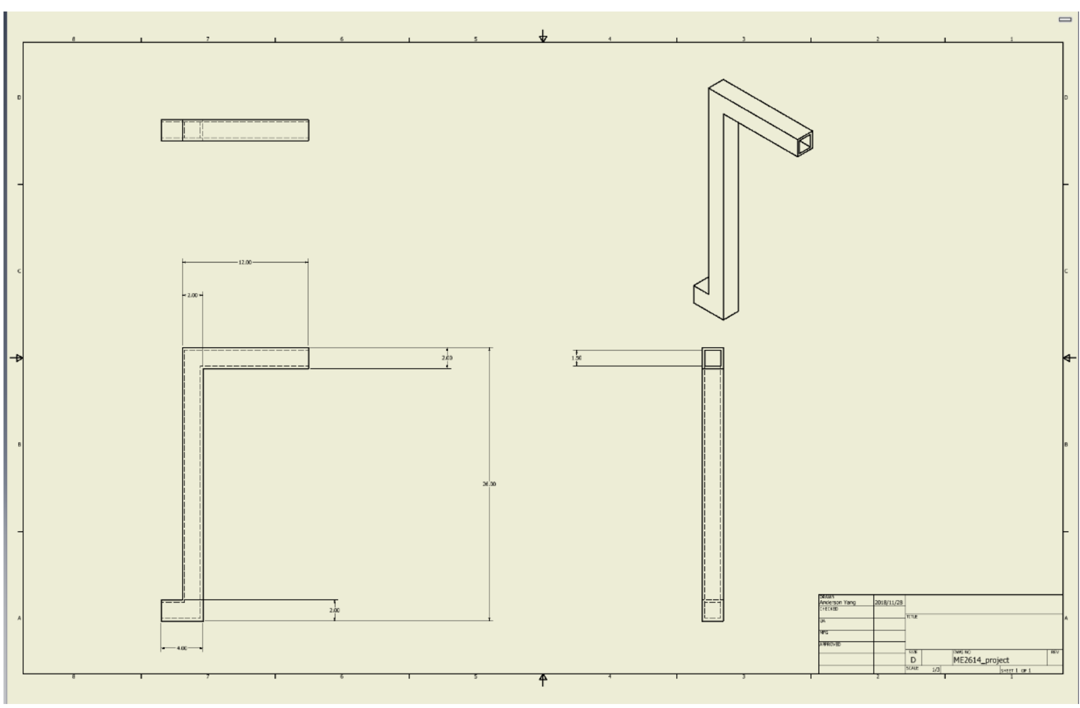
In order to find if the segment 2 could break or not, I used buckling analysis, which is included in Appendix D. After analyzing, the part won't fail due to the applied force on both ends.

At last, I used fatigue failure analysis to find out if the structure is safe again. As shown in Appendix E, using the fatigue failure analysis for ductile material, I got the safety factor for fatigue yielding to be 15.3035 and fatigue fracture 24.9102. Therefore, the structure is safe enough.

Result

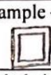
-Sketch





- Hand calculation table

Hand calculations

	Parameters		Results from your design	Units or References	Additional information
Dimensions	Cross section type		(example – circular, square, etc.) 	Include sketch of cross section in the orientation it will be used	
	Cross section dimensions		(include inside and outside dimensions if hollow)	Include units here in	Out 2in thickness 0.25in In 1.5in
	Moment of Inertia		0.911458 in^4 = 4.395535×10^{-5} ft^4	Include units here ft^4	List Appendix showing calculations
	Length of sections	1	1ft	Include units here ft	
		2	2ft	Include units here ft	
		3	0.25ft	Include units here ft	
Materials properties	Material		(name of alloy and any specifics about heat treatment)		
	Approximate cost of material		$8.84	Include hyperlink here $	Based on how many crossbars being built?
	Approximate weight of the rack		18.9858lbf	Include units here lbf	
	Yield strength		39885.4 psi	Include units here psi	Include link or reference to where you found these properties
	Ultimate tensile strength		81946.3 psi	Include units here psi	Include link or reference to where you found these properties
	Young's modulus		~~26~~ 27.6 Mpsi	Include units here Mpsi	Include link or reference to where you found these properties
Static failure	Maximum static load		225	Include units here lbf	
	Location of critical stress element		At the hitch		
	Maximum von Mises stress		σ_1 = 2726.69 psi	Include units here psi	List Appendix showing calculations

	Static factor of safety:	(based of maximum static load) n=15.30351		List Appendix showing calculations
Buckling	Critical slenderness ratio	$(S_r)_1$ = 138.666	Include units here	List Appendix showing calculations
	Slenderness ratio for the relevant section	S_r = 43.9927	Include units here	List Appendix showing calculations
	Johnson or Euler buckling	Johnson.		List Appendix showing calculations
	Buckling critical load	56505.6 lb	Include units here Lbf	List Appendix showing calculations
	Buckling factor of safety	199.246.	Include units here	List Appendix showing calculations
Fatigue failure	Endurance limit of Moore specimen	Se' = 42500	Include units here (is this for ✓infinite life or 50 x 10^7 cycles?) psi	List Appendix showing calculations
	Fully corrected endurance limit	Se = 32597.1	Include units here psi	List Appendix showing calculations & Marin factors
	Fatigue stress concentration factor, Kf	Kf = 1	Include link or reference for Kt here	List Appendix showing Kf calculation
	Alternating stress:	740.573 psi	Include units here	List Appendix showing calculations
	Mean stress:	1481.15 psi	Include units here	List Appendix showing calculations
	Overload type:	(describe which type of overload you considered example – proportional, etc.)	proportional overload	
	Fatigue factor of safety against fatigue fracture:	24.9102		List Appendix showing calculations
	Fatigue factor of safety against fatigue yielding:	15.3035		List Appendix showing calculations

Finite element analysis				
Finite element analysis	Mesh type	Tetrahedron		
	Number of elements	786.		
	Materials	Stainless steel		
	Strength	34000 psi	Include units here psi	
	Young's modulus	27600 psi	Include units here psi	
	Loading conditions	Force		List Appendix showing model with loading conditions
	Boundary conditions	Fixed constraint.		List Appendix showing model with boundary conditions
	Location of critical stress element	Connection of 1 & 2 and 2 & 3	Compare with hand calculation results	List Appendix showing the location
	Maximum von Mises stress	2.49481 ksi / hand calculated 2.22112 ksi	Compare with hand calculation results	List Appendix showing the distribution of von Mises stresses
	Static factor of safety:	(based of maximum static load) 13.63 Min.	Compare with hand calculation results	List Appendix showing calculations

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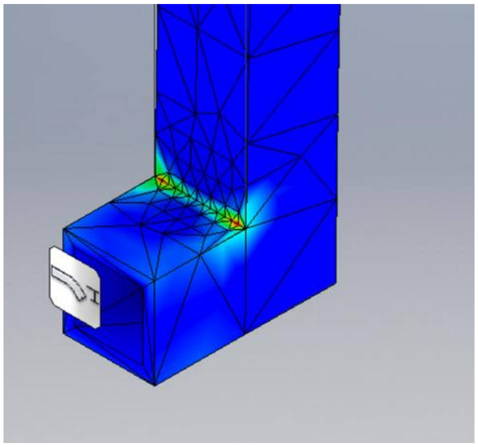
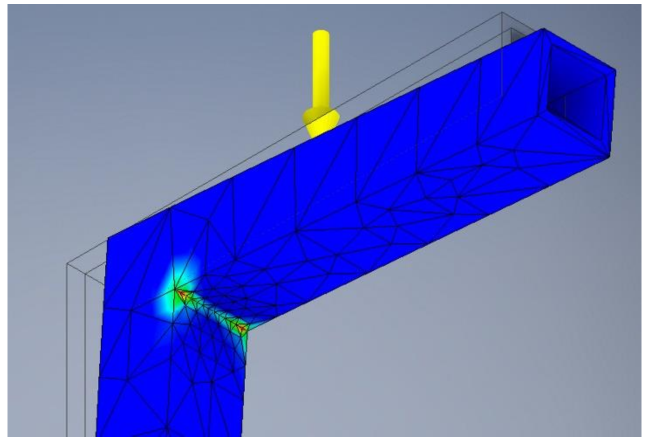
The results of FE analysis is included in Appendix F. The mesh type in inventor is called 'Tetrahedron', and the rack has 786 pieces of mesh. The material is stainless steel and the Young's modulus is 27600 psi. The loading condition is force and the boundary condition is fixed constraint. From the result of the FE analysis, the critical stress element is located at the connection of 1&2 and 2&3 as shown in appendix, but as for hand calculation results, it's located at the hitch. Furthermore, the maximum von mises stress is 2.49481 kpsi in the FE analysis result and from hand calculation, it's 2.22172 kpsi which is close. Finally, the minimum static factor of safety is 13.63. From hand calculation, it's 15.3035, this is above 13.63 which is good.

Discussion

The factor of safety that I choose is 15 because it's higher than 13.63 which came from FE analysis, the maximum of the bikes is 25lb each and 75 lb in total. Therefore, the maximum load is 1125 lb. For the rack that I designed, I'm looking at a very large market which faces all kinds of customers. From selection of material and dimension design, the product is designed to be low cost, wide-customer-range and durable. In this way, more sales quantity could bring the company more profit, on the other hand, low cost and durable could benefit the customers.

For my results, most of the hand-calculation and FE analysis are the same or really close such as the static factors, the von mises stress, principle stress and so on, the results are all listed in Appendix F. However, the only big difference from my hand calculation shown in Appendix C and FE analysis was the critical element location. Due to hand calculation, the critical element is located at the hitch connection, but from FE analysis is at the inner face of the connections of part 1&2 and 2&3 (shown in figure below).





After considering the whole calculating process, the reason for this might be the following:

1) For hand calculation, I ignored the self-weight of the rack.
2) We are not considering the detail structure of the hitch both in the FE analysis and hand calculation.
3) We are not considering other necessary on the rack such as the thing that holds the bike on the rack.

The product still has some limits, such as we are not considering how to hold the bikes from not falling. Also, the hitch part is not considered so we might have problems with connecting the rack to the car. On the other hand, the appearance design of the product could be improved. For safety aspects, the product should include a detailed instruction of how to install the rack and the maximum load it could take.

For manufacture, we have the material in our dimension from Metalsdepot.com and all we need is to get them, weld them together and install the hitch connection and mount to hold the bikes in place. We could also do some safety testing before we send them to the market.

As for the bonus part of the project, we must consider the rack when it's on the car and accelerating or decelerating. I have come up with my solution shown in Appendix G and the FE analysis for it in Appendix H. Due to both results, the part will be safe due to acceleration and deceleration, the safety factors are still high enough with the extra force acting on the horizontal direction.

Conclusion

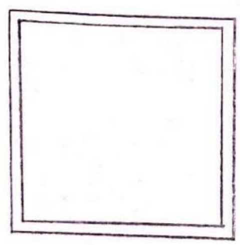
The light-weight bike rack is designed as this, there are some part that needs to be refined, but structure wise, the rack that I have design is really safe and durable with properly use. There will be further improvements on this product before it goes into the market to the public. I personally think that the product on the other hand still need some appearance designs that fits the vehicle to attract more customers.

Appendix

- Appendix A

ME 3614 Project | Page 1

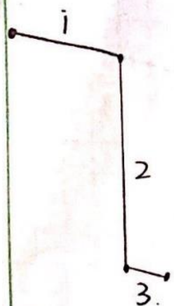
- Dimensions:
  - Cross section type: Square



  - Dimensions of X-section
    Outer length: 2 in , thickness: 0.25 in
    Inner length: 1.5 in
  - Moment of Inertia:
    $I = I_{out} - I_{in} = \frac{1}{12} 2\,in \cdot (2\,in)^3 - \frac{1}{12} 1.5\,in\,(1.5\,in)^3$
    $= 0.911458\,in^4 = 4.395535 \times 10^{-5}\,ft^4$
  - length of sections
    1: 1 ft 2: 2 ft . 3: 0.25 ft
- Materials properties.
  - Material: Stainless steel 304
  - Approximate cost of material :
    Outer diameter = 2 in Inner diameter = 1.5 in length = 3.25 ft
    3.25 ft = 3 ft 3 in ⇒ Metalsdepot ⇒ $156.48
  - Approximate weight of the rack :
    $A_{x\text{-}section} = (\frac{2}{12})^2 - (\frac{1.5}{12})^2 = 0.012153\,ft^2$
    $V = A_{x\text{-}section} \cdot L = 0.012153\,ft^2 \times 3.25\,ft = 0.039497\,ft^3$
    ρ of stainless steel : $480.695\,lb/ft^3$
    $W = \rho \cdot V = 18.9858\,lb$. OR $W = 6.01\,lb/ft \times 3.25\,ft = 19.5325$
  - Yield strength : $S_y = 34000\,psi$ } Metalsdepot.com
  - Ultimate tensile strength : 85000 psi }
  - Young's modulus. 27.6 Mpsi Table A-5

- Appendix B

Page 2



$W_{rack} = 6.01 \times 3.25 \doteq 19.5325\ lb$

$W_{bike} = 25 lb \times 3 = 75 lb$

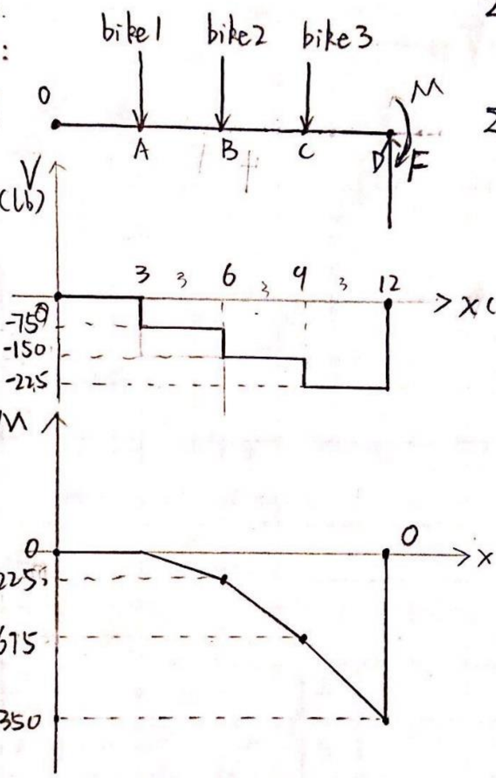
$W_{total} = 94.5325$

$F_{max} = 3 \times W_{total} = 283.598\ lb$

When we consider fluctuating loads

$F \in (93.9858, 187.972\ lb)$

Segment 1:
(without considering weight of rack)



$\Sigma M_D = 0$

$\rightarrow +75 \cdot 3 + 75 \cdot 6 + 75 \times 9 - M = 0$

$M = -1350 lb \cdot in$

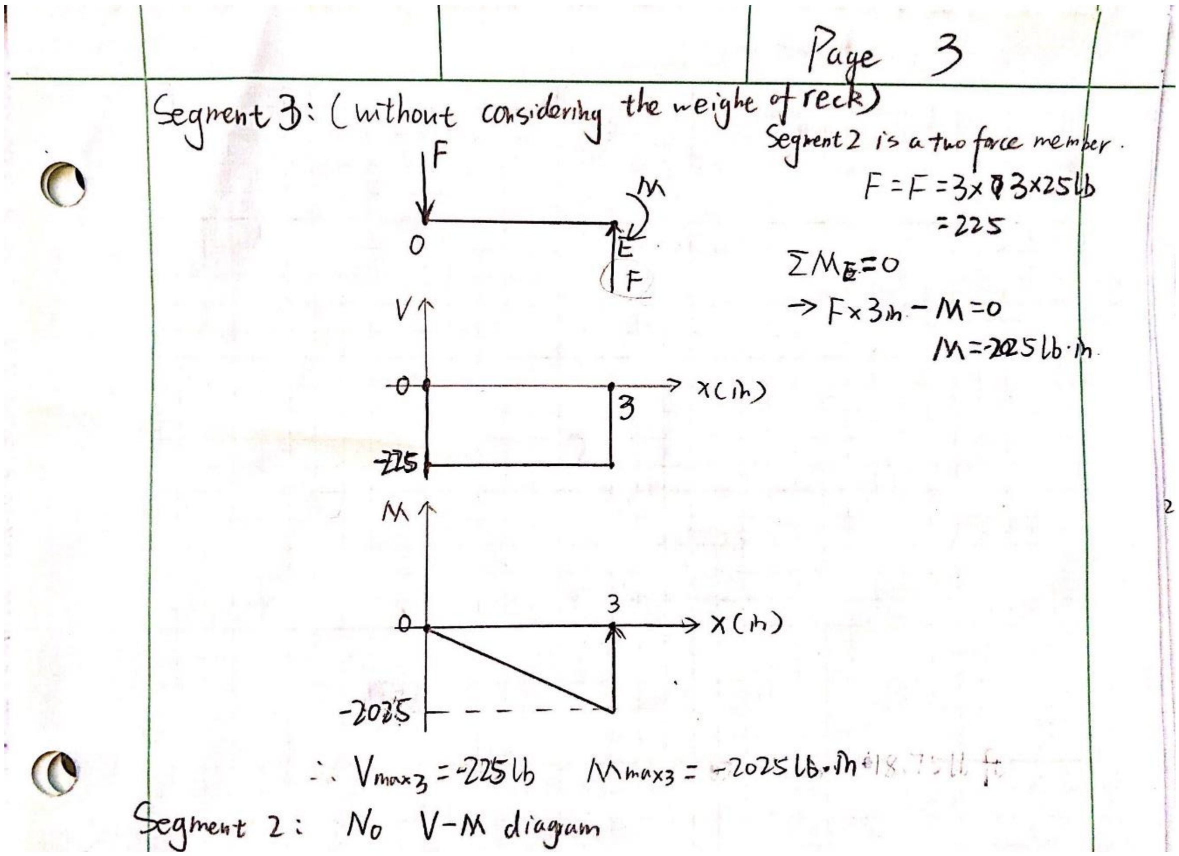
$\Sigma F_y = 0$

$F - W \times 3 = 0$

$F = -225\ lb$

$\therefore V_{max1} = -225 lb$

$M_{max1} = -1350\ lb \cdot in$



Page 3

Segment 3: (without considering the weighe of reck)

Segment 2 is a two force member.

$F = F = 3\times3\times25lb$

$= 225$

$\Sigma M_E = 0$

$\rightarrow F\times3in - M = 0$

$M = -2025 lb\cdot in$

$\therefore V_{max3} = -225 lb \quad M_{max3} = -2025 lb\cdot in$

Segment 2: No V-M diagram

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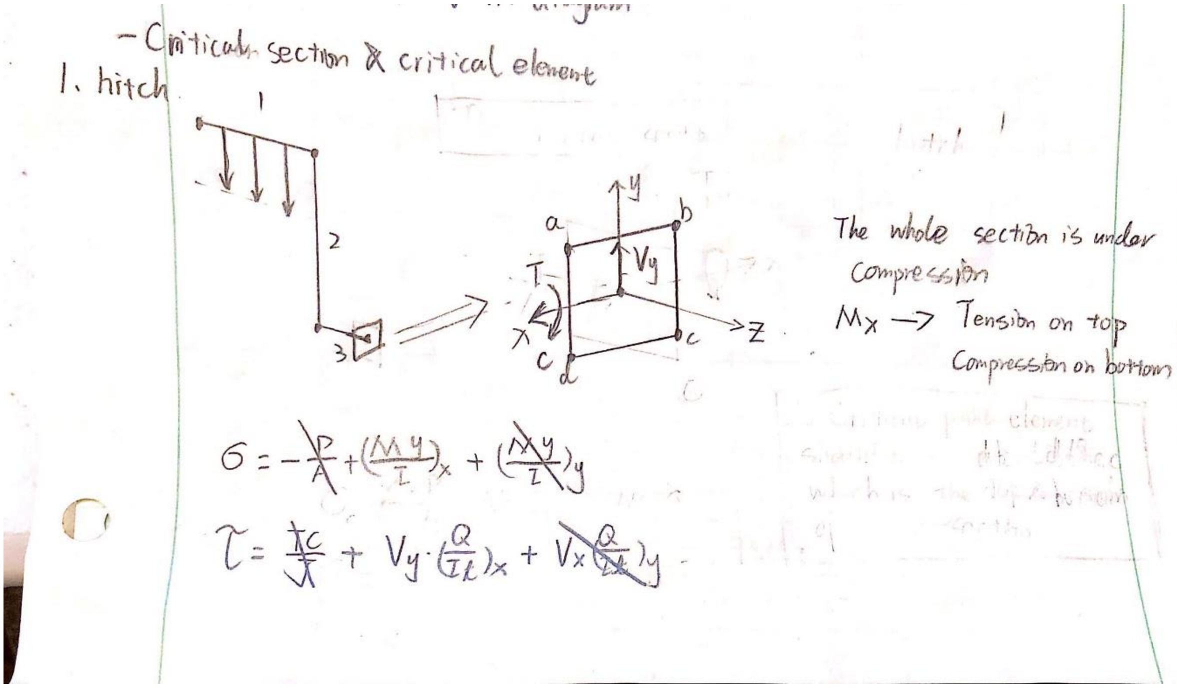
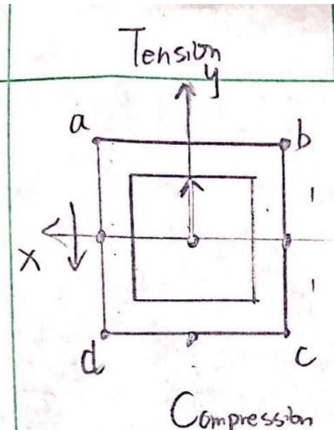
- Appendix C


- Critical section & critical element
1. hitch
1
2
3
a
b
c
d
y
Vy
T
x
z
The whole section is under compression
Mx → Tension on top
Compression on bottom
σ = −P/A + (My/I)x + (My/I)y
τ = Tc/J + Vy·(Q/It)x + Vx(Q/It)y

Page 4



$$\sigma = \left(\frac{MY}{I}\right)_x = \frac{2025 \cdot 1\ in}{I_x} = 2221.72\ psi$$

$$\tau = V_y \cdot \left(\frac{Q}{It}\right)$$

$$Y' = \frac{2 \times 0.25\,(0.75 + 0.125) + 2 \times (0.25 \times 0.75) \cdot \frac{0.75}{2}}{2 \times 0.25 + 2 \times 0.25 \times 0.75}$$

$$= 0.660714\ in$$

$$Q = A' \times Y'$$

$$= (2 \times 0.25 + 2 \times 0.25 \times 0.75)(Y')$$

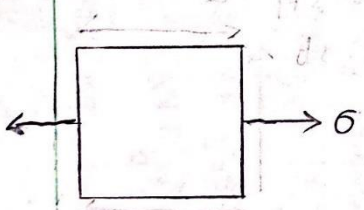
$$= 0.765625\ in^3$$

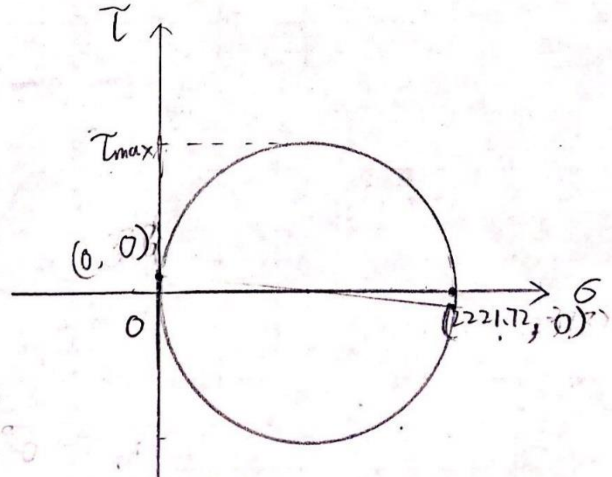
$$\tau = 225 \times \frac{0.765625\ in^3}{0.911458\ in^4 \times 0.25 \times 2} = 378\ lbf/in^2$$

$\sigma = 2221.72$ psi $\tau = 126$ psi

$$\begin{cases} \sigma_x = 2221.72\ psi \\ \tau_{xy} = 0 \end{cases} \qquad \begin{cases} \sigma_y = 0\ psi \\ \tau_{xy} = 0 \end{cases}$$

At the middle point $\tau = 378\ lbf/in^2$, $\sigma = 0$ ∵ $\frac{MY}{I}$ $Y = 0$ ∴ we should consider the larger one and it's at the side where $Y = 1$ and $Q = 0$ ∴ $\tau = 0$





$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} = 2221.72\ psi$$

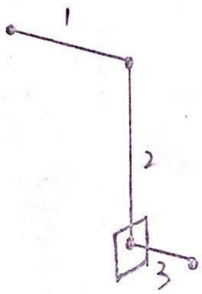
$\sigma_2 = 0$ $\sigma_3 = 0$

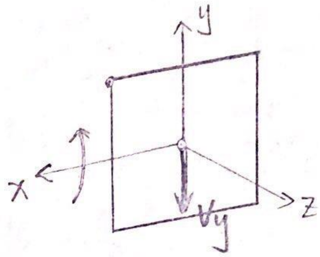
$$\tau_{max} = \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = 1110.86\ psi$$

Page 5

2. Connection of 2 & 3.

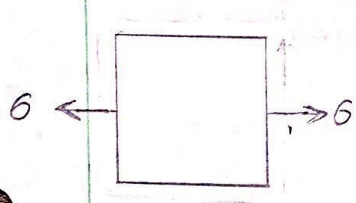
xy-plane

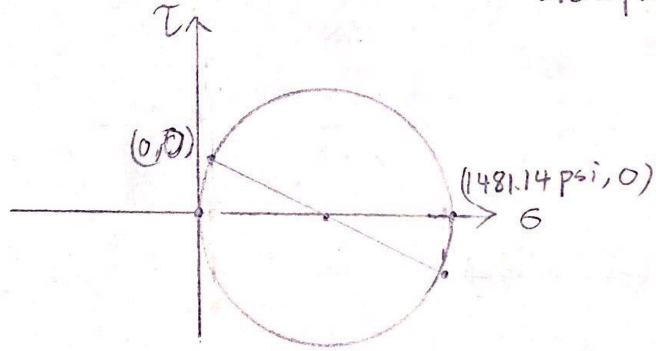




$\sigma = \frac{My}{I} = \frac{1350 \cdot 1}{0.911458} = 1481.14 \text{ psi}$, $\tau = V_y \left(\frac{Q}{It}\right)_x = 225 \cdot \frac{0.76525}{0.911458 \times 0.25 \times 2}$

$= 378 \text{ lbf/in}^2$





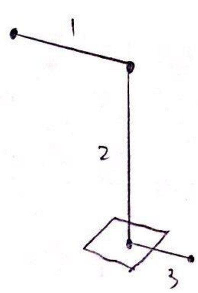
$\sigma_1 = 1481.14 \text{ psi}$

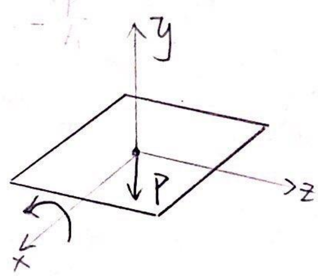
$\sigma_2 = 0$

$\sigma_3 = 0 \text{ psi}$

$\tau_{max} = 740.57 \text{ psi}$

X-Z plane





$\sigma = -\frac{P}{A} + \left(\frac{My}{I}\right)_x = -\frac{75 \times 3}{0.1.75} + \frac{1350 \cdot 1}{0.911458}$

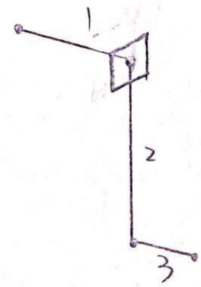
$= 1352.57 \text{ psi}$

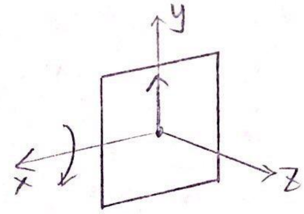
page 6

3、Connection of 1&2.

~~xz-plan~~

xy-plane

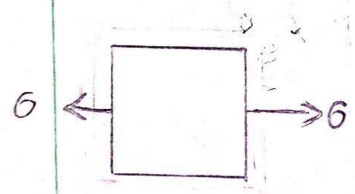




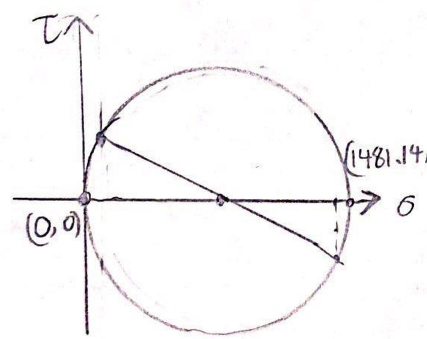
$V_y = 75\times3$

$$\sigma = \frac{My}{I} = \frac{1350\cdot1}{0.911458} \approx 1481.14 \text{ psi}$$

$$\tau = V_y\cdot\left(\frac{Q}{It}\right)_x = 225\text{ lb}\cdot\frac{0.765625\text{ in}^3}{0.911458\cdot0.25\times2} = 378\cdot\text{lbf/in}^2$$



$\begin{cases}\sigma_1 = 1481.14 \text{ psi}\\ \tau = 0\end{cases}$ $\begin{cases}\sigma_2 = 0\\ \tau = 0\end{cases}$



$\sigma_1 = 1481.14$ psi

$\sigma_2 = 0$

$\sigma_3 = 0$

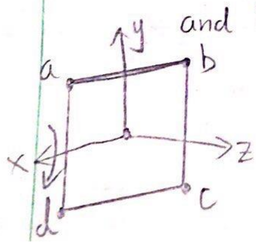
$\tau_{max} = 740.57$ psi

From the calculations above, at section 3 at the hitch,

σ & τ are the largest. $\sigma = 2221.72$ psi $\tau = 1110.86$ psi

∴ critical segment is at the hitch surface

and a, b. is at Tension, c, d is at compression side



These four point are the critical elements.
Critical Location is at the hitch

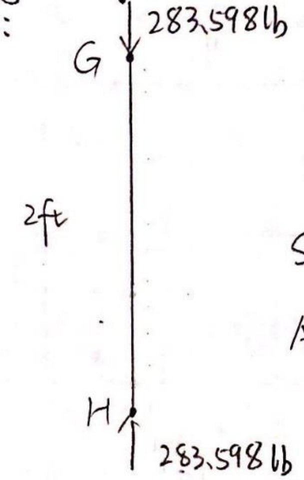
MSS: $n = \frac{S_y}{\sigma_1-\sigma_3} = \frac{34000\text{ psi}}{2221.72\text{ psi} - 0} = \boxed{15.3035}$

- Appendix D

Page 7

- Buckling Analysis, we should use the $F_{max} = 283.598$ lb

Part 2:



$I = 0.911458 \text{ in}^4$

$A = 2^2 - 1.5^2 = 1.75 \text{ in}^2$

$K = \sqrt{\frac{I}{A}} = 0.545545 \text{ in}$

$S_r = \frac{L}{K} = \frac{2 \times 12 \text{ in}}{0.545545 \text{ in}} = 43.9927$

Assume G, H are fixed.

$\Rightarrow C = 1.2$

$S_y = 34000 \text{ psi}$ $\quad E = 27.6 \text{ Mpsi} = 2.76 \times 10^7 \text{ psi}$

$(S_r)_1 = \pi \sqrt{\frac{2CE}{S_y}} = 138.666 \quad \because (S_r)_1 >> S_r$

$\Rightarrow$ Johnson's columns.

$P_{cr} = A\left[S_y - \frac{1}{CE}\left(\frac{S_y \cdot S_r}{2\pi}\right)^2\right] =$

$P_{cr} = 1.75 \text{ in}^2 \left[34000 \text{ psi} - \frac{1}{1.2 \times 2.76 \times 10^7 \text{ psi}}\left(\frac{34000 \cdot 43.9927}{2\pi}\right)^2\right]$

$= 56505.6$ lb.

$\therefore n = \frac{P_{cr}}{F_{max}} = 199.246 > 1$

since n is way higher than 1, the part 2 will not fail for buckling

- Appendix E

page 8

- Fatigue failure

∵ My material is ductile $S_{ut} = 85\,ksi < 212\,ksi$.

∴ $S_e' = 0.5\,S_{ut} = 0.5 \times 85000\,psi = 42500\,psi$

$S'_{10^3} = f \cdot S_{ut}$ $\quad f = \frac{\sigma'_F}{S_{ut}}(2\times10^3)^b$ $\quad \sigma_F' = S_{ut} + 50\,ksi = 135\,ksi$

$f = \frac{\sigma'_F}{S_{ut}}(2\times10^3)^b$ $\quad b = -\frac{\log\frac{\sigma_F'}{S_e'}}{\log(2N_e)}$ $\quad 2N_e = 2\times10^6$.

$\Rightarrow b = -\frac{\log(\frac{\sigma_F'}{S_e'})}{\log(2N_e)} = -0.079661$

$f = \frac{\sigma'_F}{S_{ut}}(2\times10^3)^b = 0.866867$. $\quad S'_{10^3} = f \cdot S_{ut} = 73.6837\,ksi$.

- $S_e = k_a \cdot k_b \cdot k_c \cdot k_d \cdot k_e \cdot k_f \cdot S_e'$

$k_a = a \cdot S_{ut}^b$ $\quad S_{ut} = 85\,ksi$. $\quad$ From table 6-2

$a = 1.34\,kpsi$

$b = -0.085$

$k_a = 0.918553$

k_b: $d_e = 0.808\sqrt{hb} = 1.616$

$k_b = 0.879\,d^{-0.107}$ $(0.11 \le d \le 2\text{ inch})$

$= 0.834998$

$k_c = 1$ for combined bending / torsion.

$k_d = \frac{S_T}{S_{RT}}$ choose $70°F$, $k_d = 1$. table 6-4

$k_e = 1$.

$k_f = 1 + q(k_t - 1)$

q: from Fig 6-20. 6-21 $\quad q \approx 1$

$k_t = 1$ because we are not considering the hitch connection

∴ $k_f = 1 + 0 = 1$

$\Rightarrow S_e = ~~32547~~\ 32597.1\ psi$

Page 9.

$\sigma_{max} = 2221.72$ psi $\quad \sigma_{min} = 740.573$ psi

$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = 740.573$ psi

$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 1481.15$ psi

→ Safety factor for fatigue yielding. $n_y = \frac{S_y}{\sigma_{max}} = \frac{34000 \text{ psi}}{2221.72 \text{ psi}}$

$\boxed{= 15.3035}$

→ Safety factor for fatigue fracture

$$n_f = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} = \frac{1}{\frac{740.573 \text{ psi}}{32597.1 \text{ psi}} + \frac{1481.15 \text{ psi}}{85000 \text{ psi}}} = \boxed{24.9102}$$

- Appendix F

⊟ Static Analysis:1

General objective and settings:

Design Objective	Single Point
Study Type	Static Analysis
Last Modification Date	2018/11/29, 15:06
Detect and Eliminate Rigid Body Modes	No

Mesh settings:

Avg. Element Size (fraction of model diameter)	0.1
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

⊟ Material(s)

Name	Stainless Steel	
General	Mass Density	0.289018 lbmass/in^3
	Yield Strength	34000 psi
	Ultimate Tensile Strength	85000 psi
Stress	Young's Modulus	27600 ksi
	Poisson's Ratio	0.3 ul
	Shear Modulus	10615.4 ksi
Part Name(s)	ME2614_project.ipt	

⊟ Operating conditions

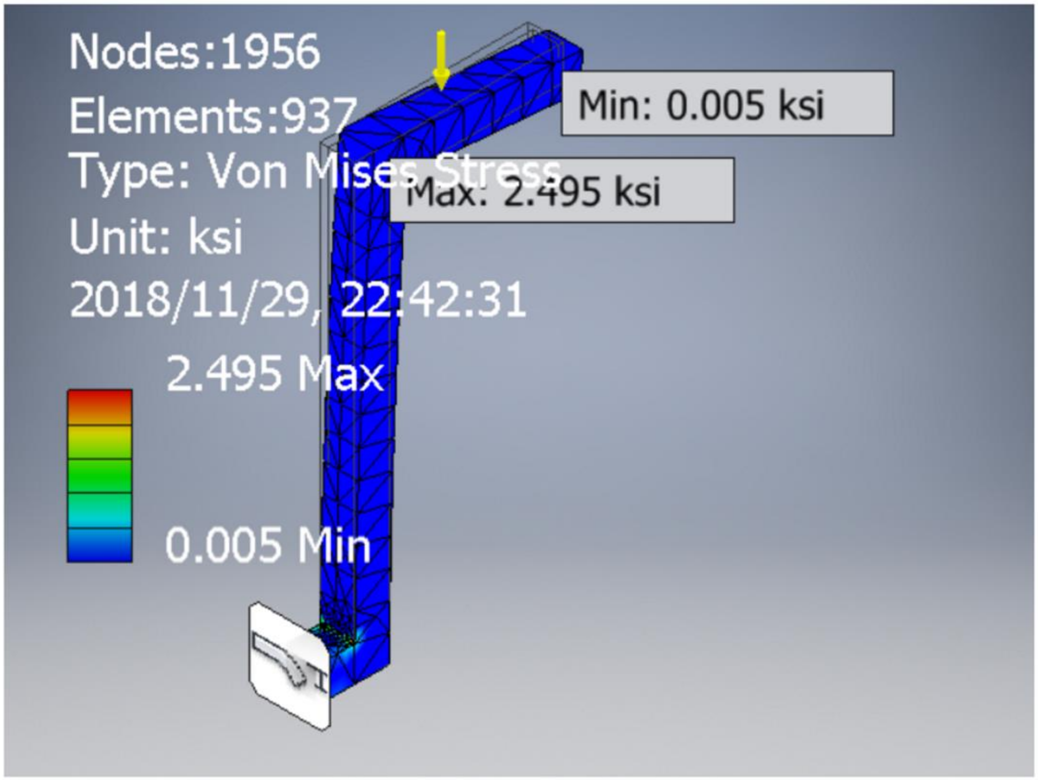
⊟ Force:1

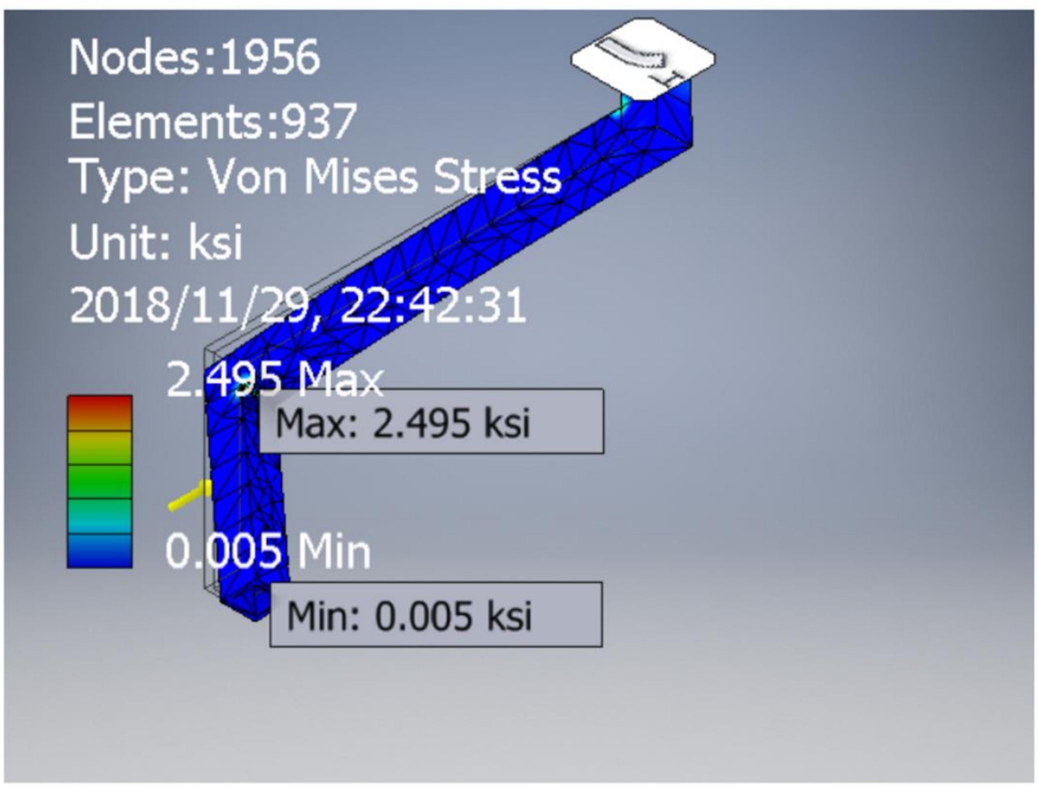
Load Type	Force
Magnitude	75.000 lbforce
Vector X	0.000 lbforce
Vector Y	-75.000 lbforce
Vector Z	0.000 lbforce

⊟ Fixed Constraint:1

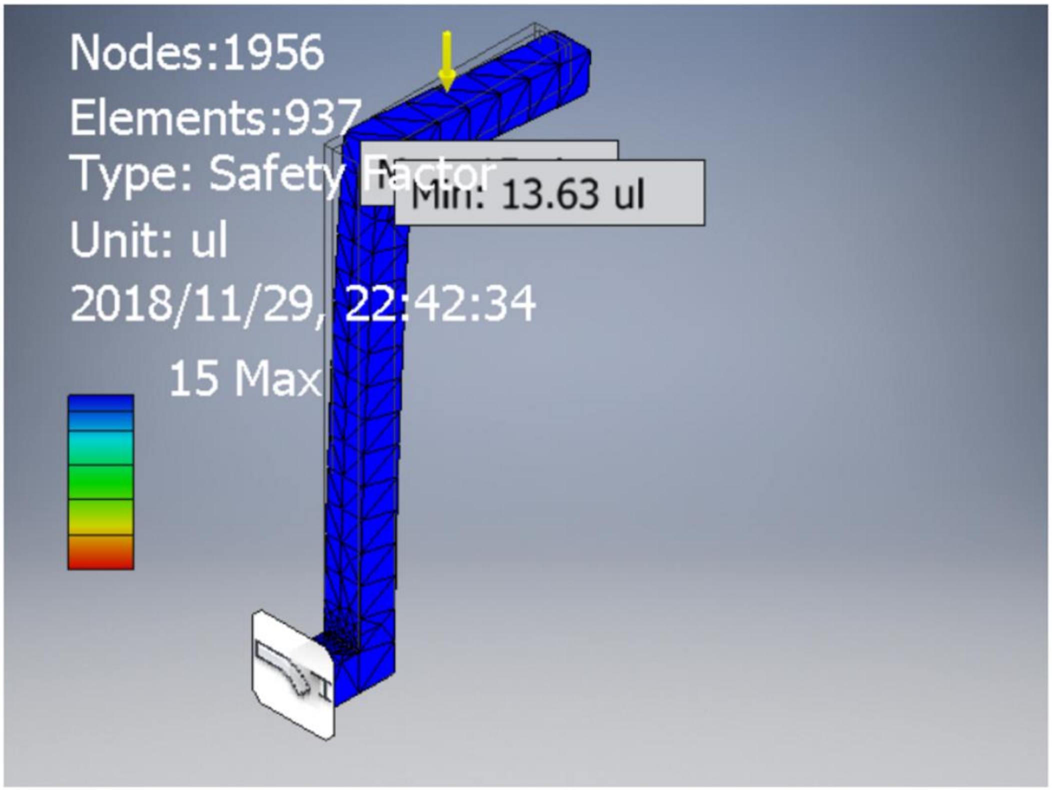
Constraint Type	Fixed Constraint

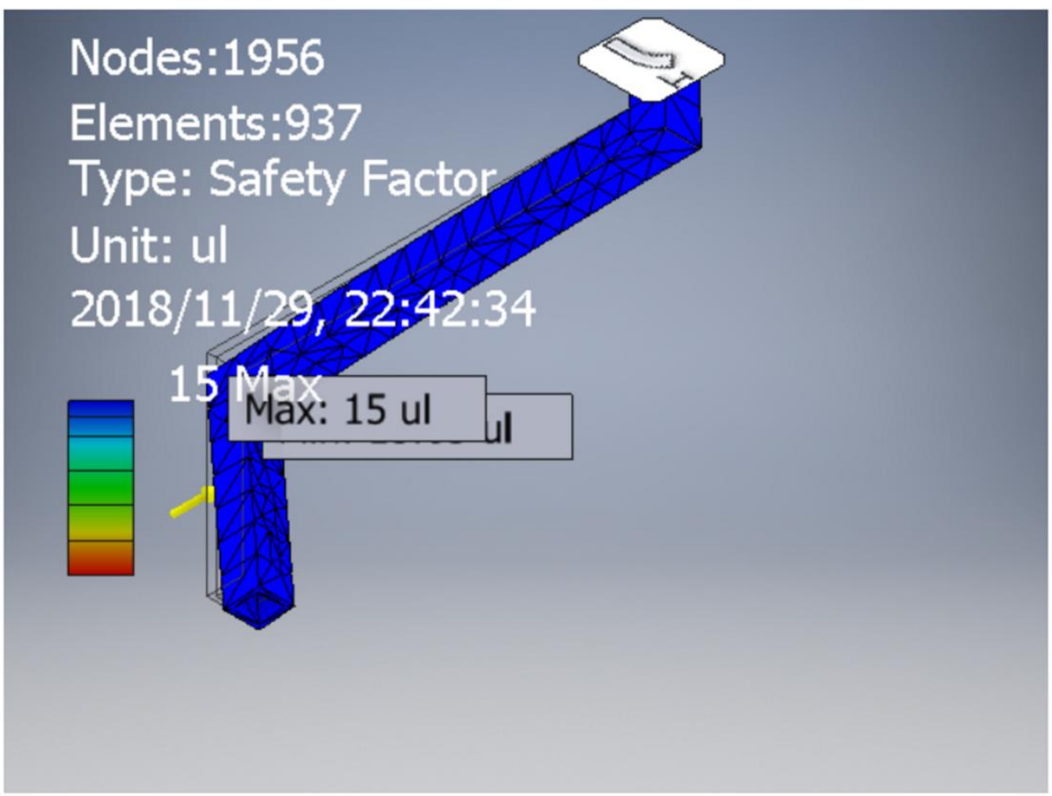
⊟ **Von Mises Stress**



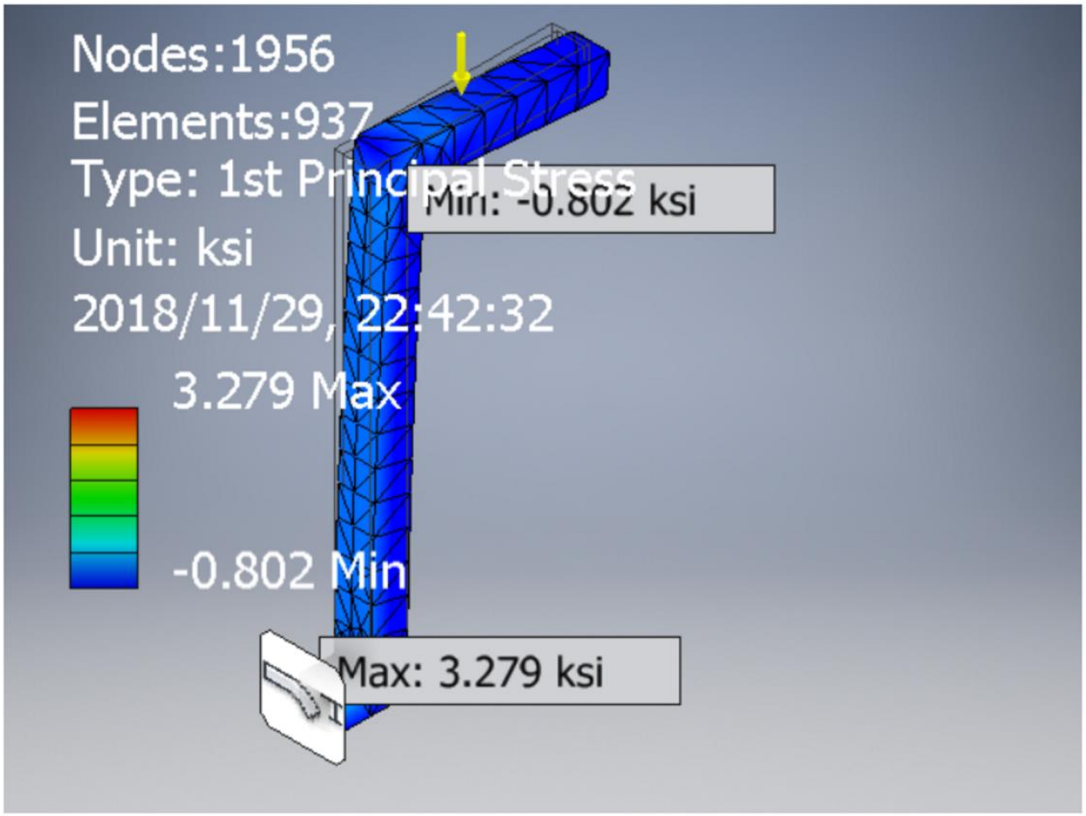


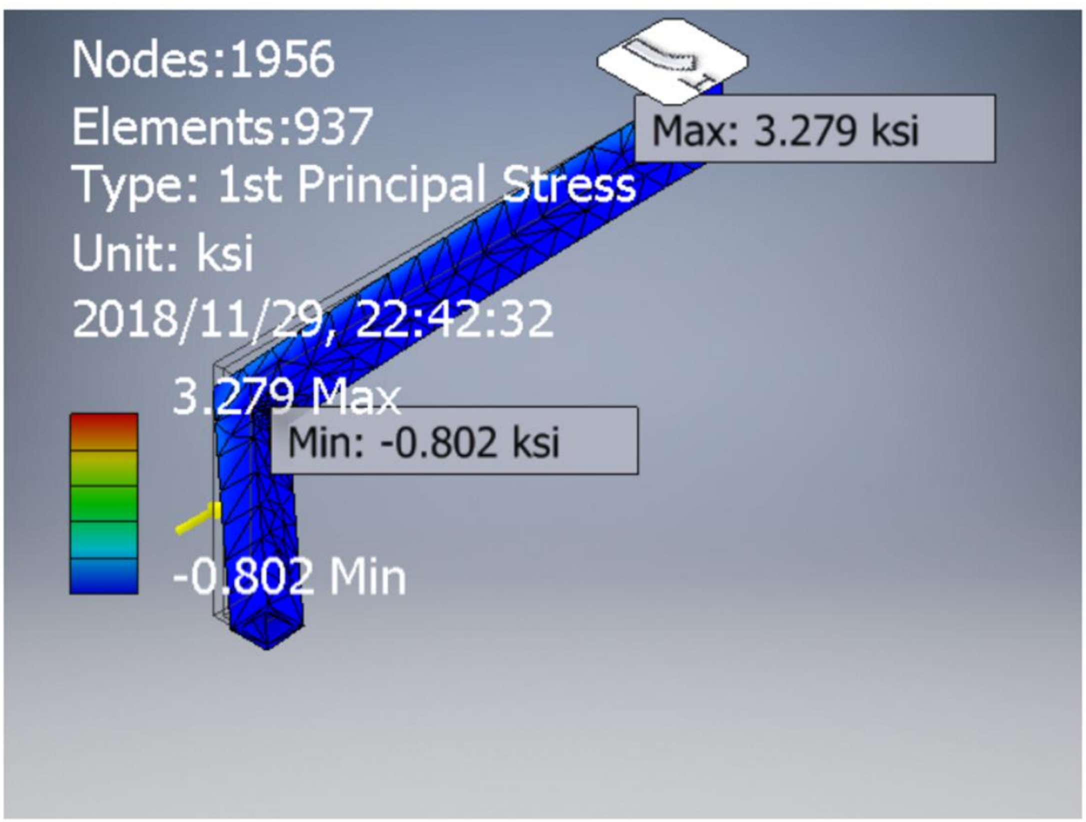
⊟ Safety Factor



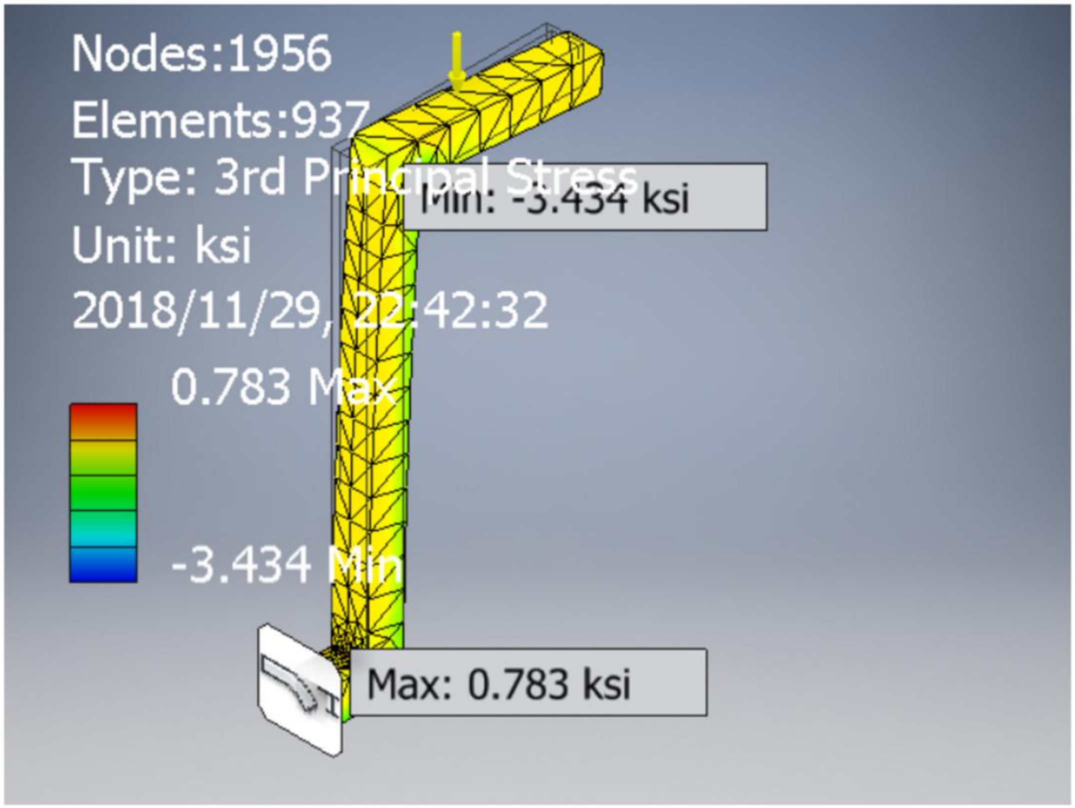


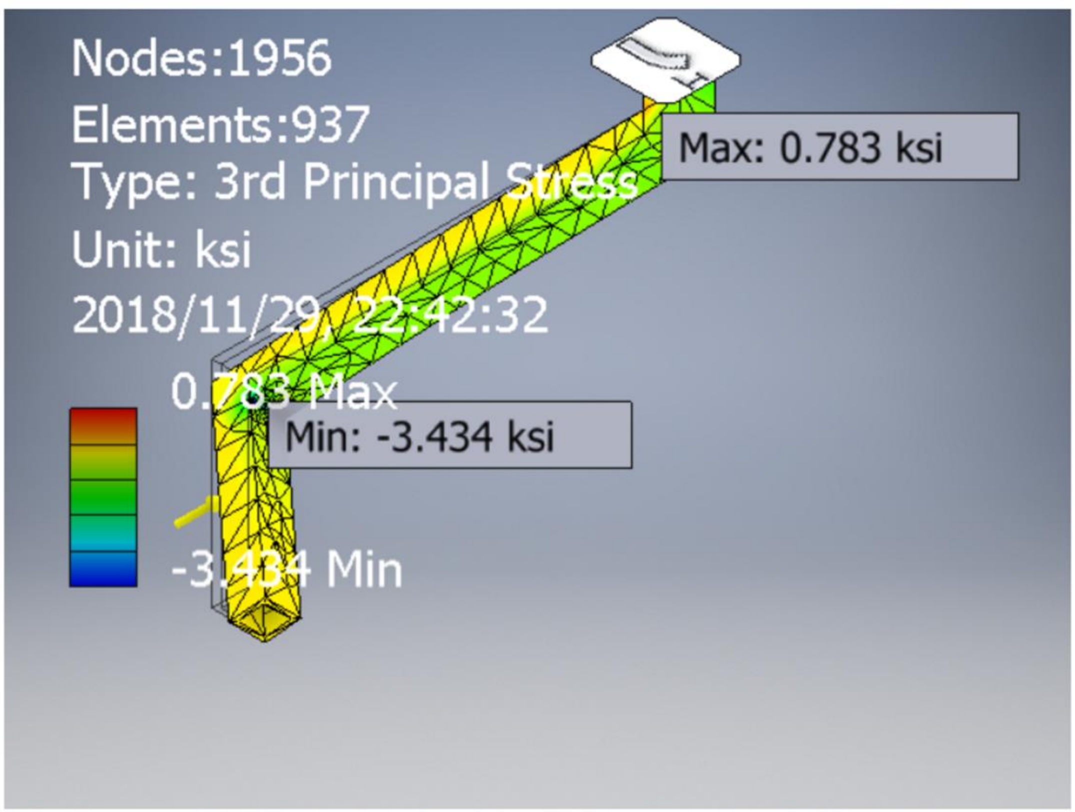
⊟ 1st Principal Stress





⊟ 3rd Principal Stress

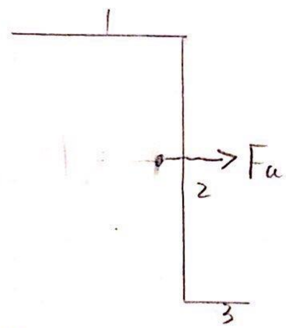




-Appendix G

page 10

- Extra credit



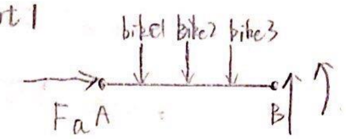
$F_a = 0.5 \times W_{total}$

$= 47.2663\ lbf$

-Acceleration.

Static F_a pointing to the right.

Part 1



$\Sigma M_B = 0$

$\Rightarrow 75 \cdot 3 + 75 \times 6 + 75 \times 9 - M_1 = 0$

$M_1 = -1350\ lb \cdot in$

$\sigma_x = \pm \frac{P}{A} \pm \left(\frac{MY}{I}\right) = \frac{47.2663\ lbf}{A} + \frac{MY}{I} = 1508.15\ psi\ (C)$

$\sigma_y = 0 \quad \tau_{xy} = 0$ (reason included in previous calculations)

$\therefore \sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} = 1508.15\ psi$

$\sigma_2 = 0 \quad , \quad \sigma_3 = 0$

$\Rightarrow$ MSS. $n = \frac{S_y}{\sigma_1 - \sigma_3} = \boxed{22.5441}$

Part 2:

$M = 45\ lb \cdot 24\ in = 1080\ lb \cdot in$

$\sigma = 0 \frac{P}{A} + \frac{MY}{I} = ~~1313.49~~ + (\sigma_1)_1 = 2821.64\ psi$

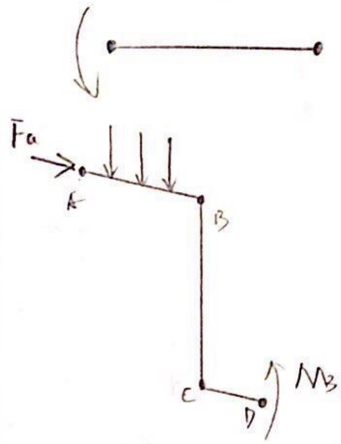
$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} = 2821.64\ psi$

$\sigma_2 = 0 \quad \sigma_3 = 0$

$\Rightarrow$ MSS: $n = \frac{S_y}{\sigma_1 - \sigma_3} = \boxed{12.0497}$

page 11

Part 3:



$$\Sigma M_C = 0$$

$$\rightarrow -F_a \cdot 24in + 75\times3 + 75\times6 + 75\times9 + M_B = 0$$

$$M_B = -215.609\ lb\cdot in$$

$$\sigma = \frac{My}{I} = 3058.19$$

$$\sigma_1 = 3058.19\ psi. \qquad \sigma_2 = 0,\ \sigma_3 = 0$$

$$NSS: n = \frac{S_y}{\sigma_1 - \sigma_3} = \boxed{11.1177}$$

∴ Due to all the calculations, the part is safe.

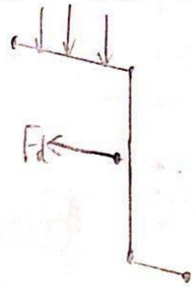
Fatigue calculation

$$\sigma_{max} = 3058.19\ psi \qquad \sigma_{min} = 1019.4\ psi$$

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = 2038.8\ psi \qquad n_y = \frac{S_y}{\sigma_{max}} = \boxed{11.1177}$$

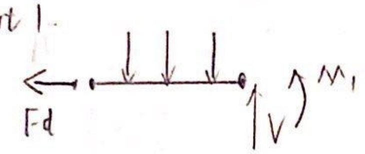
$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 4077.59\ psi \qquad n_f = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} = \boxed{9.04837}$$

-Decelerating: $F_d = 0.8 \times W_{total} = 75.626\ lbf$



page 12

part 1.

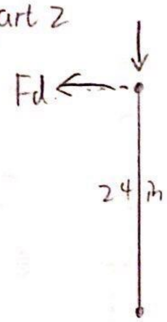


$$\sigma = \frac{P}{A} + \frac{MY}{I}$$
$$= 1524.36\ psi$$

$\sigma_1 = 1524.36\ psi \qquad \sigma_2 = 0,\ \sigma_3 = 0$

$\Rightarrow$ MSS: $n = \frac{S_y}{\sigma_1 - \sigma_3} = \boxed{22.3045}$

part 2



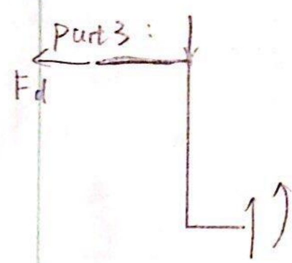
$$\sigma = \frac{P}{A} + \frac{MY}{I} + \frac{MY}{I}$$
$$= \frac{75.626\,lb}{A} + \frac{1350\,lb\cdot in \cdot 1\,in}{I} + \frac{72 \times 12 \cdot in}{I}$$
$$= 2557.65\ psi$$

$\sigma_B = \sigma + \sigma_A = 4082.01\ psi$

$\sigma_1 = 4082.01\ psi,\quad \sigma_2 = 0,\quad \sigma_3 = 0$

MSS: $n = \frac{S_y}{\sigma_1 - \sigma_3} = \boxed{8.32924}$

Part 3:



$$\sigma = \frac{P}{A} + \frac{MY}{I} + \frac{MY}{I}$$
$$= \frac{75.626}{A} + \frac{2025 \cdot 1}{I} + \frac{75.626 \times 24\,in \times 1}{I}$$
$$= 4256.27\ psi$$

$\sigma_C = \sigma + \sigma_B = 8338.28\ psi$

$\sigma_1 = 8338.28\ psi \qquad \sigma_2 = 0 \qquad \sigma_3 = 0$

$\Rightarrow$ MSS: $n = \frac{S_y}{\sigma_1 - \sigma_3} = \boxed{4.07758}$

Fatigue:

$\sigma_{max} = 8338.28\ psi \qquad \sigma_{min} = 2779.43\ psi$

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = 2779.43\ psi$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 5558.86\ psi$$

$$n_f = \frac{S_y}{\sigma_{max}} = \boxed{4.07758} \qquad n_y = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} = \boxed{6.63726}$$

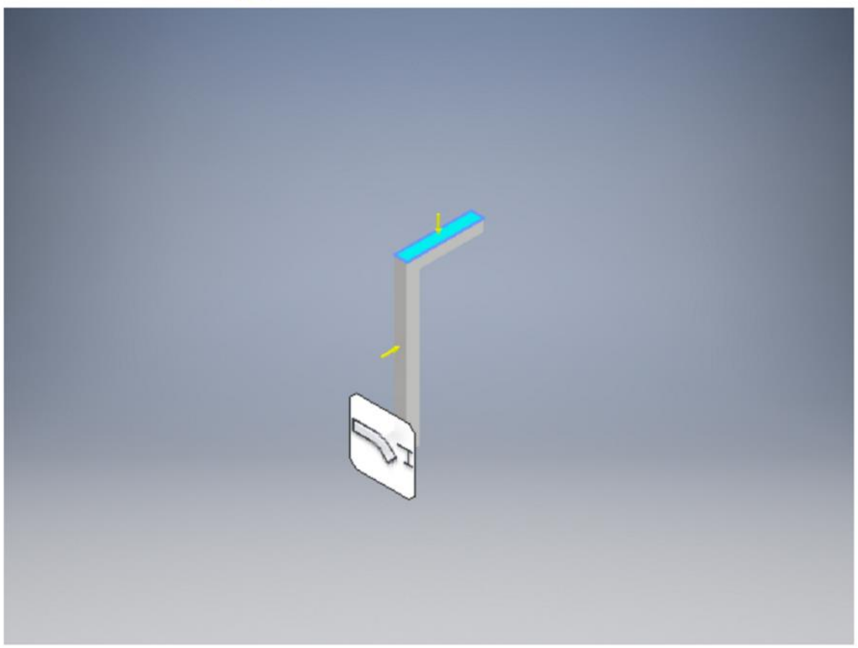
-Appendix H

deceleration

⊟ Force:1

Load Type	Force
Magnitude	75.000 lbforce
Vector X	0.000 lbforce
Vector Y	-75.000 lbforce
Vector Z	0.000 lbforce

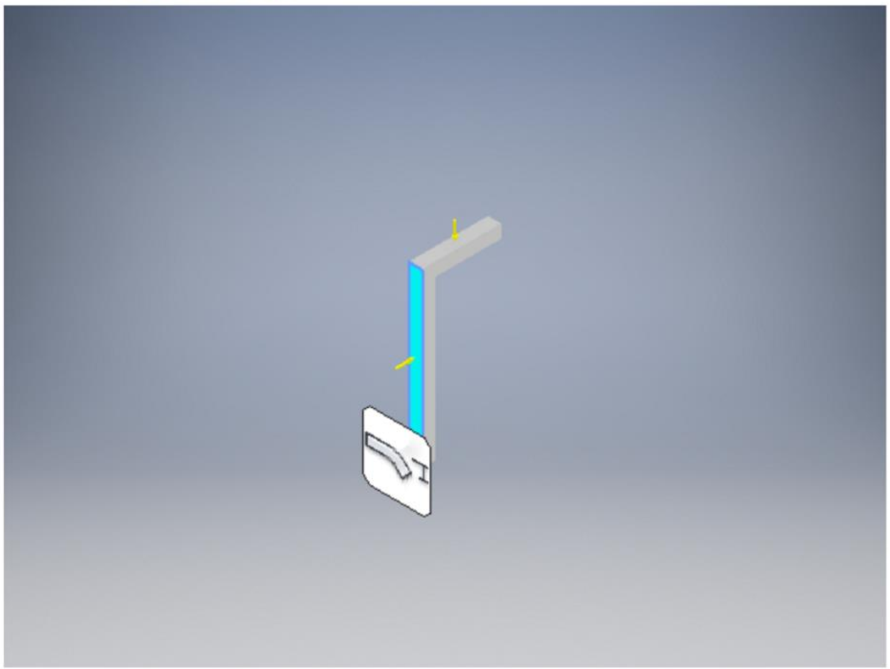
⊟ Selected Face(s)



⊟ Force:2

Load Type	Force
Magnitude	75.626 lbforce
Vector X	75.626 lbforce
Vector Y	0.000 lbforce
Vector Z	0.000 lbforce

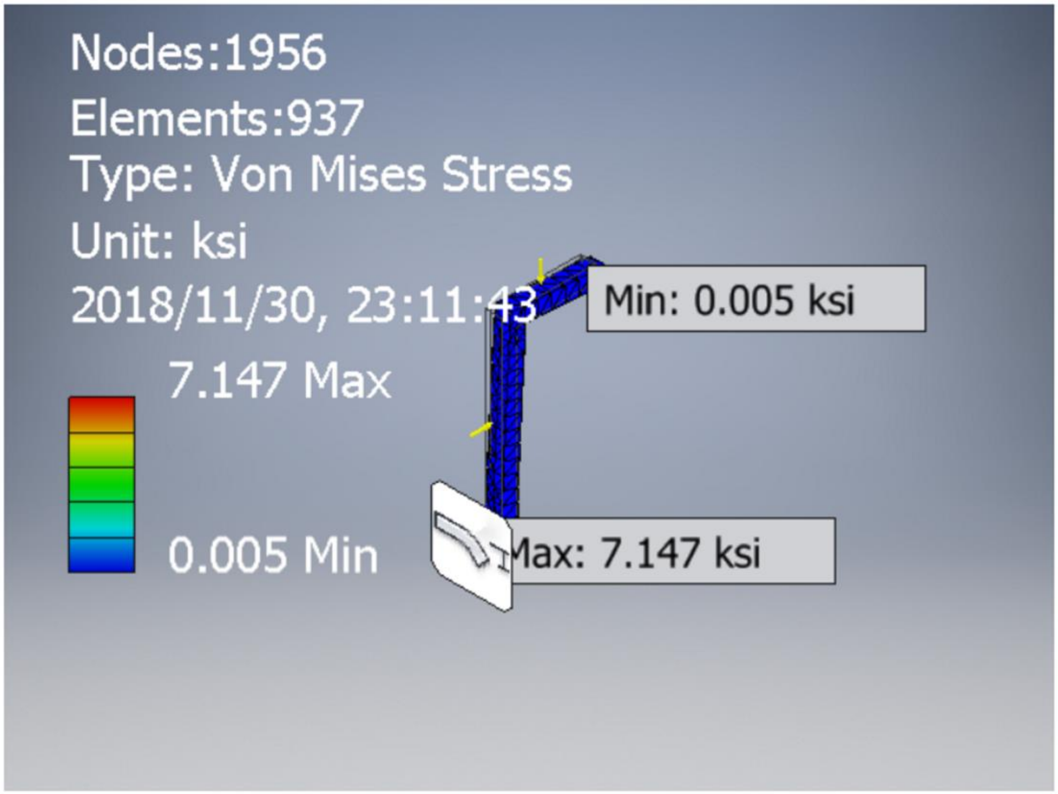
⊟ Selected Face(s)

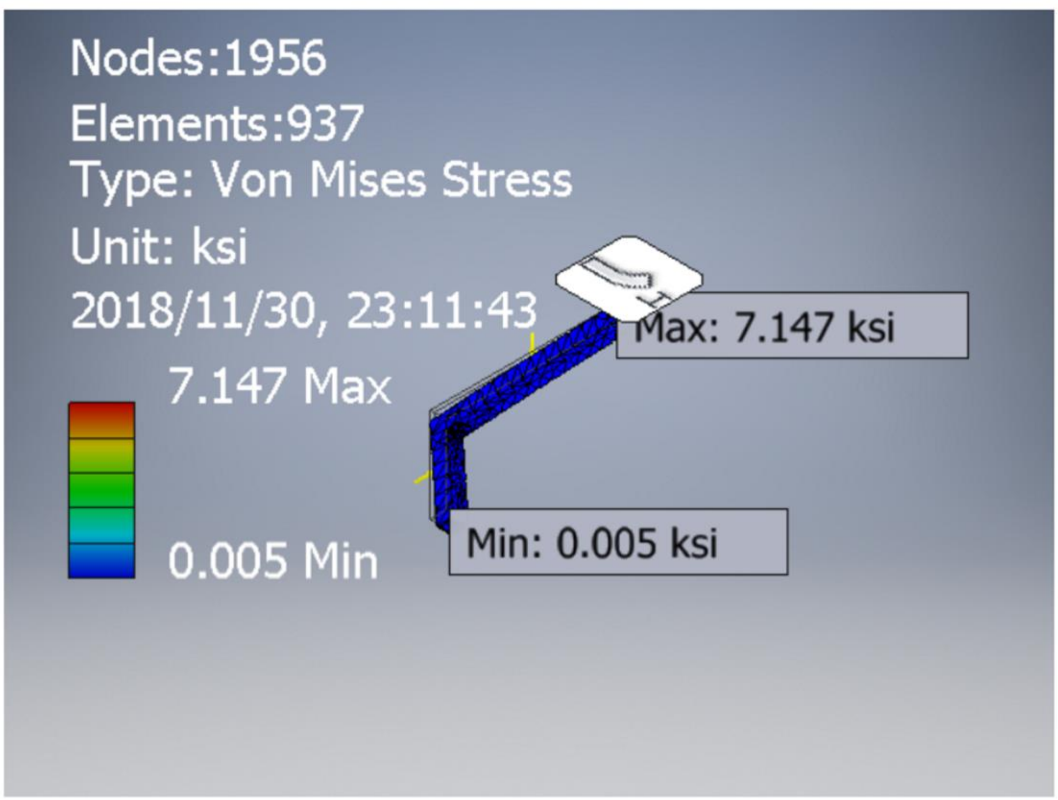


⊟ Fixed Constraint:1

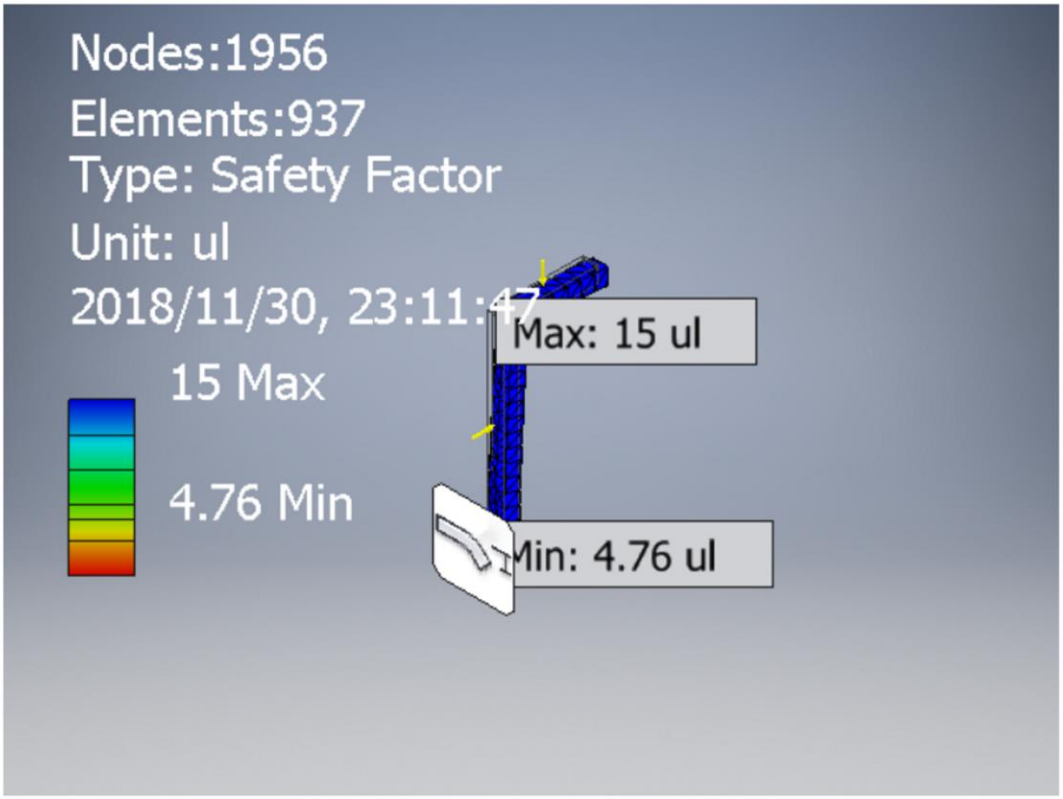
Constraint Type	Fixed Constraint

⊟ Von Mises Stress





⊟ **Safety Factor**

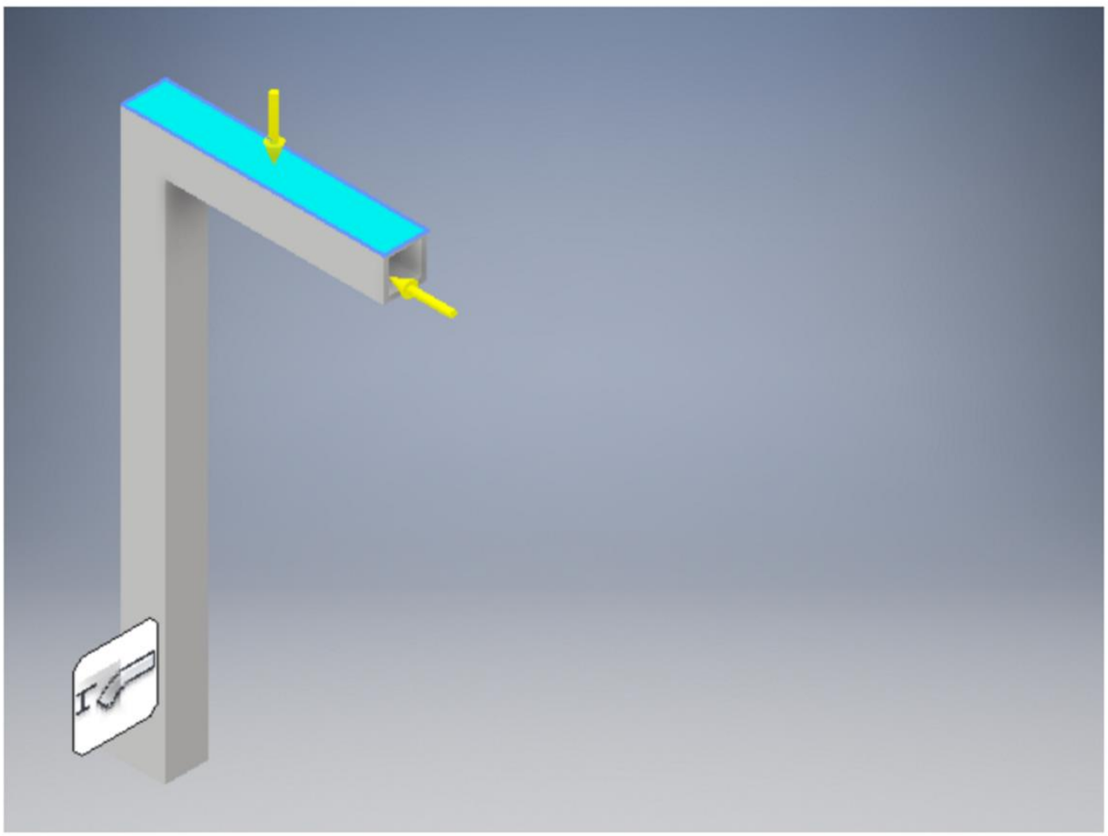


Acceleration

⊟ Force:1

Load Type	Force
Magnitude	75.000 lbforce
Vector X	0.000 lbforce
Vector Y	-75.000 lbforce
Vector Z	0.000 lbforce

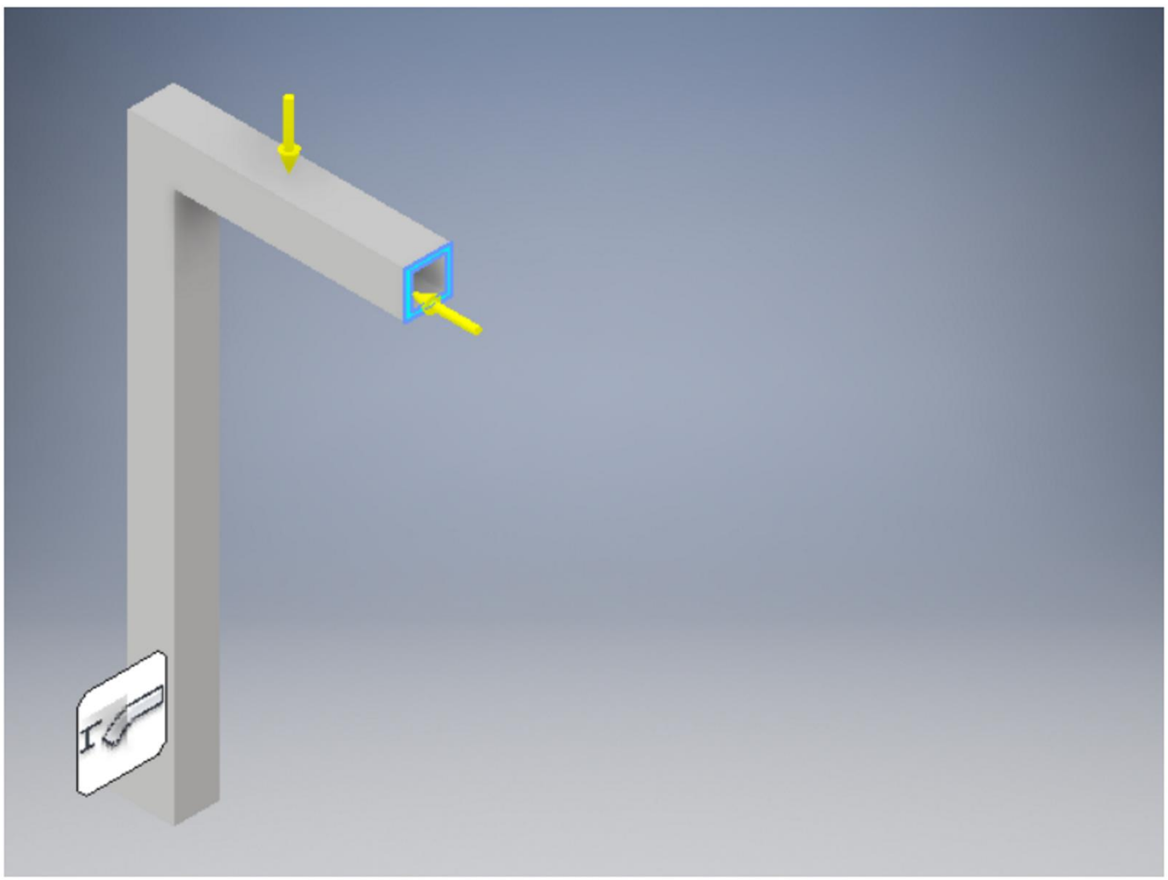
⊟ Selected Face(s)



⊟ Force:2

Load Type	Force
Magnitude	47.266 lbforce
Vector X	-47.266 lbforce
Vector Y	0.000 lbforce
Vector Z	0.000 lbforce

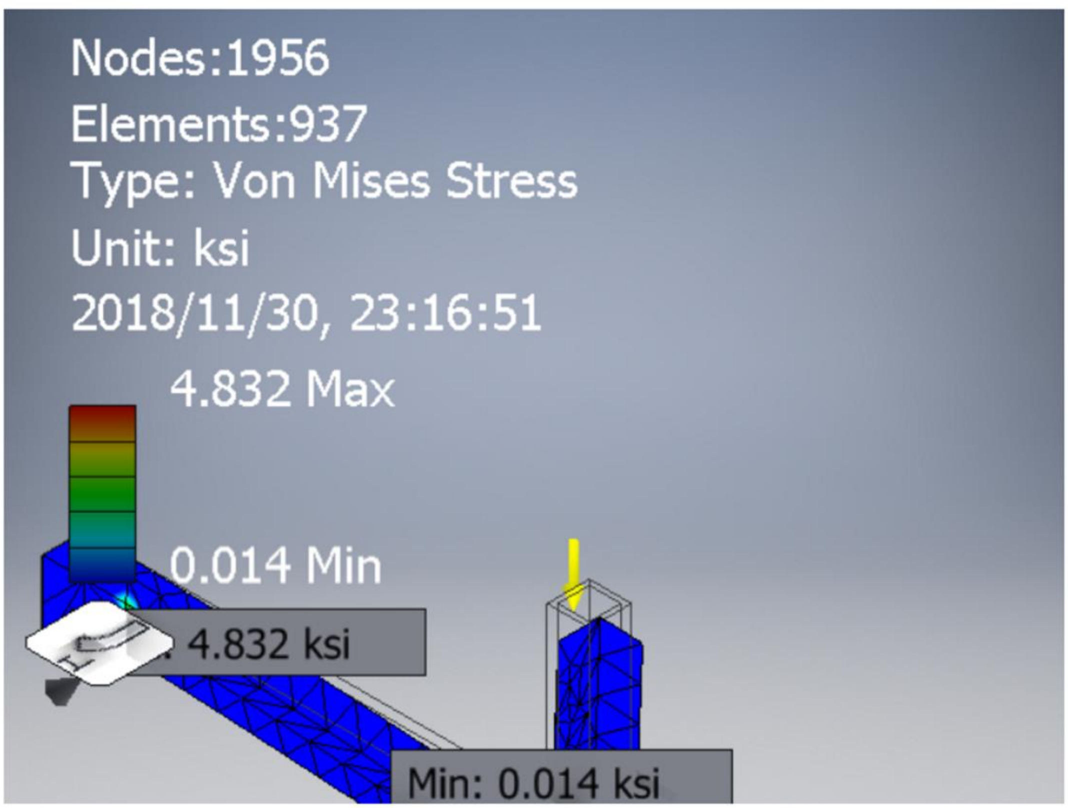
⊟ Selected Face(s)



⊟ Fixed Constraint:1

Constraint Type	Fixed Constraint

⊟ Von Mises Stress



⊟ Safety Factor