Checking the Validity of the Current Bracket Design that holds the Kill Switch

Kill switch, also known as brake overtravel switch, is an additional safety component that is required by the F-SAE competition. The brake over travel switch, BOT, functions as a power-kill switch in an event of brake failure, and it's an ordinary normal open switch such that it does not let current flow in its normal state. The switch is fitted right behind the brake paddle in a closed-circuit manner (pulled up condition) and placed in a way that brake paddle does not touch the switch even under full braking situation. The BOT switch is activated in case of braking failure or because of the excessive travel of the brake pedal in which the pedal directly hits the switch and let it go to its normal condition. Once the kill switch is pushed back inward, the engine will turn off, and the current supply from crucial dynamic components, such as ECU and fuel pump, will be cut. The concern of this crucial safety part is not in its functionality state as it operates very well, but in the effectiveness of the bracket that the switch is mounted into. This concern arose after a visual inspection of the bracket which questioned if the bracket and the fasteners used would meet the requirements and pass the important failure modes.

The analysis process started by taking pictures of the current mounted bracket and the BOT switch and then proceeded by untightening the fasteners and the kill switch to take the necessary measurements of the bracket as well as the fasteners used. After taking the necessary measurements, the boundary conditions and the critical load points on the bracket were determined such that there are two sets of the structural analysis that must be run to test how competent the bracket and its joints regions are. The first set of structural analysis will be on the welded region of the bracket (Section 1), and the second analysis set will be done for the screws featured to mount the bracket (Section 1). For the welded region, the analysis will test if the current weldments are satisfactory for the maximum possible foot pressure applied, 1200 psi, and according to American Welding Society code which includes a 1.6 design factor for the allowable shear stress in the weldments: $\tau_{All} = \frac{(0.577 s_y)}{1.6}$

The second analysis check (Section 2) will be conducted for the screws which are loaded on shear such that it will be on determining the minimum safe shear load that could be applied with a factor safety of 2 for the different failure modes. For the two analysis sets, suggested redesigns will be shown if needed.

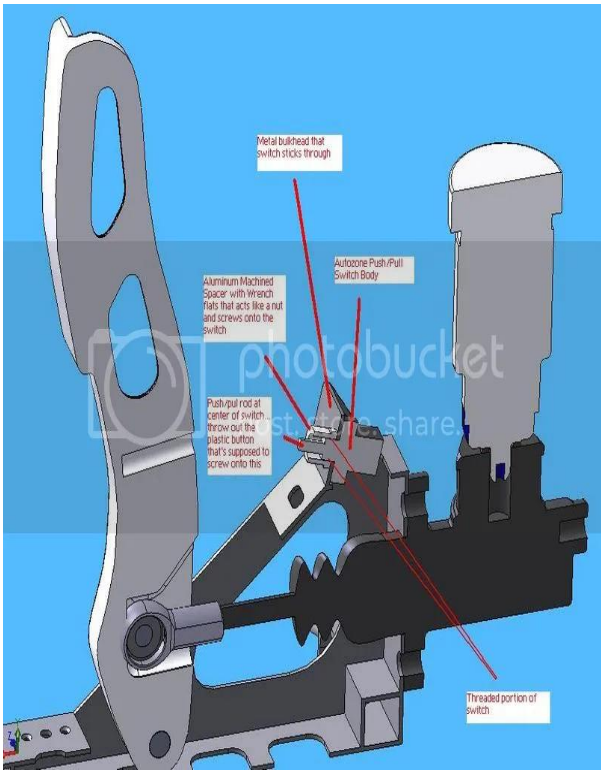
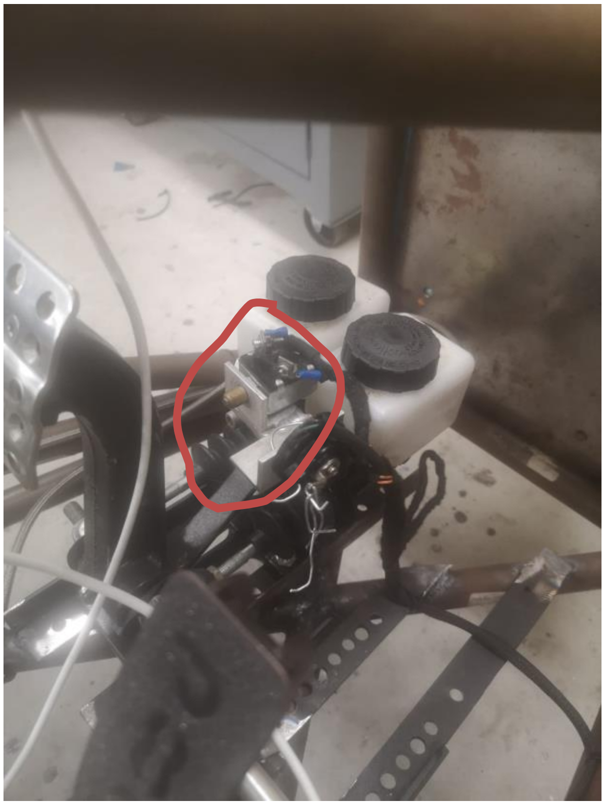
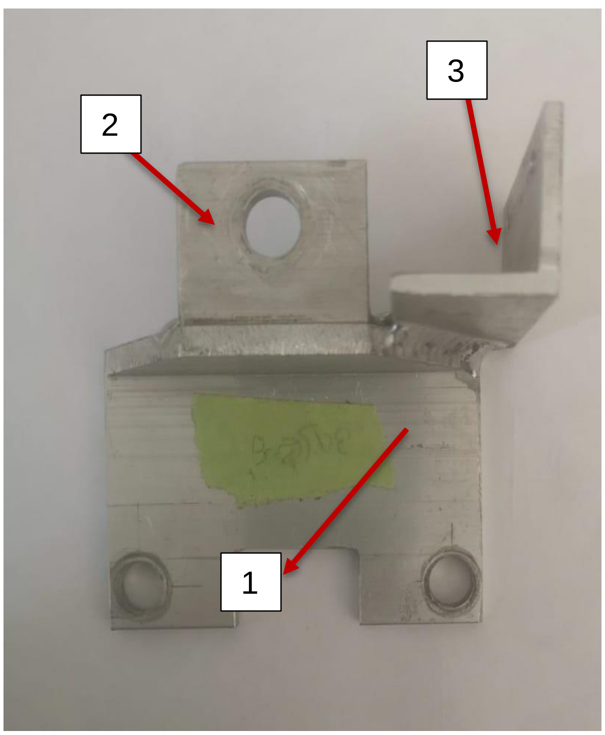
<table>
<tr>
<td>
</td>
<td>Pros:
- Adhesive part of the braking system that is designed with braking full assembly. A metal bulkhead hosing the switch body is side welded into the braking system structure
- Flexible to adjust for a cheap switch that could bought from Auto-Zone
Cones:
- If the bulkhead gets damaged by the load caused by panic braking, it’s hard to replace as it’s welded into the chassis
- May not work well with our current braking system as it’s already assembled for specific dimensions.
Source:
http://www.fsae.com/forums/showthread.php?7962-Brake-Pedal-Over-Travel-Switch</td>
</tr>
</table>

Table 1: Researched designs with pros and cons for each



Current kill switch mount setup is red circled in the left. The bracket into which the BOT switch is mounted into is made of 6061 Aluminum which is a popular choice alloy for welding applications, and it features a good strength to weight ratio.



The part of interest: the bracket consists of three pieces welded together. The bracket is held vertically using two fasteners. The joint points of these two fasteners can be seen down at the bottom of piece (1). The joint point seen at the center of piece (2) is not holding the weight of the bracket; it's just in which the kill switch will be fixed. Also, Piece (2) is welded on piece (1). Piece (3) is used to mount the pedal travel sensor and it's excluded from the analysis.

Dimensions of piece (1):

- Base length(w) = 76.5 mm
- Length from the circle central bottom to the base (a) = 2 mm
- Diameter of the hole = 9 mm
- Height = 30.73 mm

	Dimensions of piece (2) Looking from the top: -Length(b) = 33.6 mm -Side length (at which the weld is) = 25.5 mm - Bead weld length per side (d) = 10 mm Looking from front: -Base length (b) = 33.6 mm - height = 30.25 mm -Hole Diameter = 10 mm - Length from the center of the hole to the base (L) = 15.125mm
	The bolt used in piece (1) joint points: -M8-1 class 10.9 -Major d = 8 mm - pitch = 1mm - fine-pitch -class 10.9 -A_t (tensile area) = 39.2 mm^2 -A_r(root area)= 36.0 mm ^2

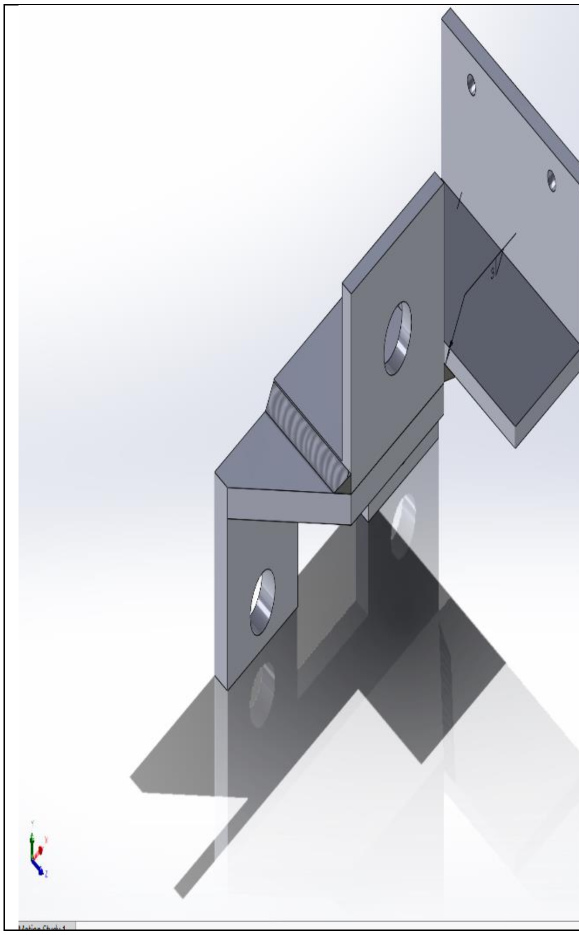
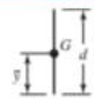
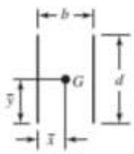
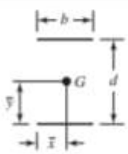
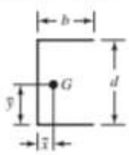
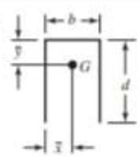
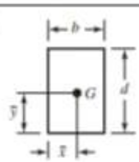
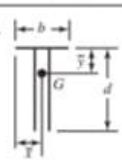
	➢ 3D CAD model of the part built to the specifications above. The part material is Aluminum 6061. The two upper pieces are welded onto the bottom one. ➢ Fixed supports are attached to the bottom plate (piece 1) while a normal force of 650N is applied to the top front face (piece 2). ➢ A static structural analysis is carried out to determine to maximum shear stress on the weld and the factor of safety. ➢ Check out the appendix for this CAD part drawing

Table 2: Current setup and design parameters

Table 9–2

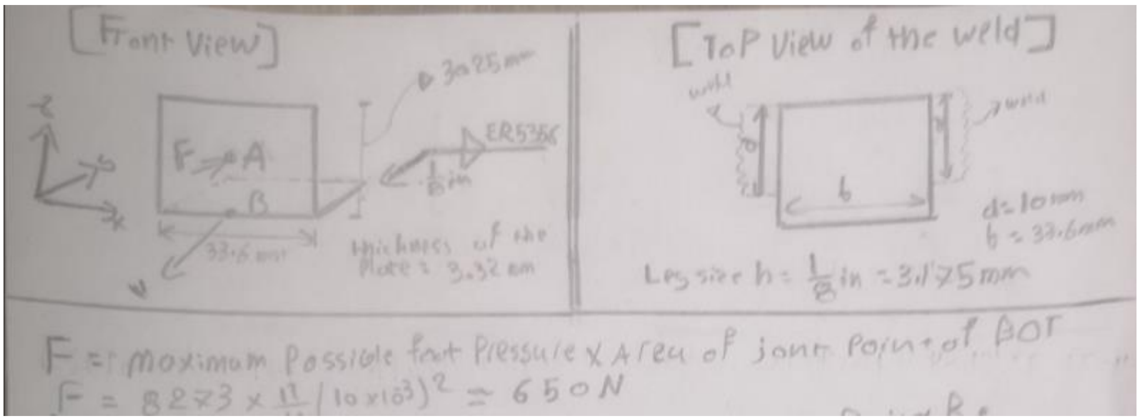
Bending Properties of Fillet Welds*

Weld	Throat Area	Location of G	Unit Second Moment of Area
1. 	$A = 0.707hd$	$\bar{x} = 0$ $\bar{y} = d/2$	$I_u = \dfrac{d^3}{12}$
2. 	$A = 1.414hd$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \dfrac{d^3}{6}$
3. 	$A = 1.414hb$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \dfrac{bd^2}{2}$
4. 	$A = 0.707h(2b + d)$	$\bar{x} = \dfrac{b^2}{2b + d}$ $\bar{y} = d/2$	$I_u = \dfrac{d^2}{12}(6b + d)$
5. 	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \dfrac{d^2}{b + 2d}$	$I_u = \dfrac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$
6. 	$A = 1.414h(b + d)$	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_u = \dfrac{d^2}{6}(3b + d)$
7. 	$A = 0.707h(b + 2d)$	$\bar{x} = b/2$ $\bar{y} = \dfrac{d^2}{b + 2d}$	$I_u = \dfrac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$

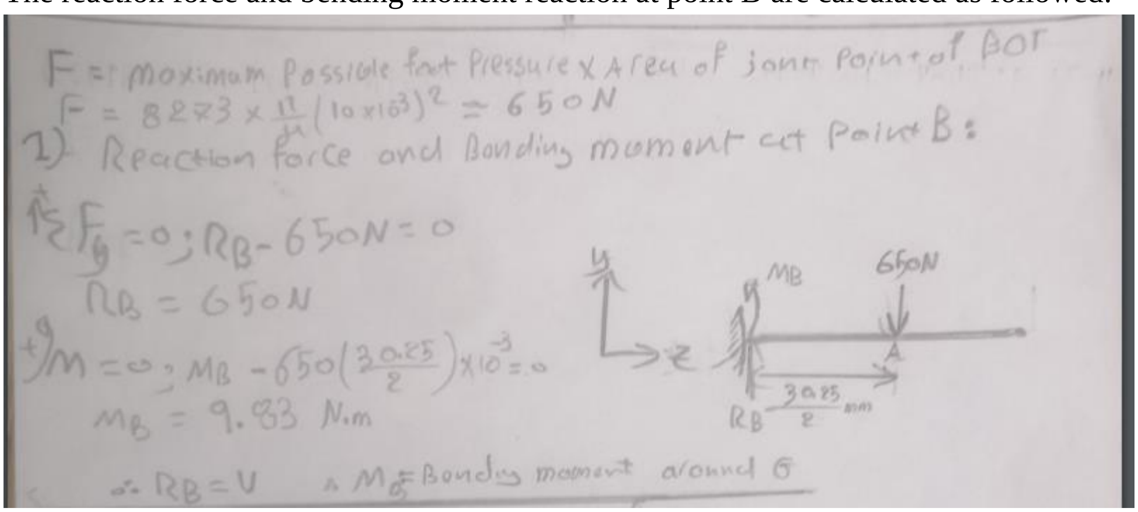
Section (1): Is the current weldment attachment in piece (2) satisfactory?

- ER5356 welding wire with leg size of 1/8 in (3.175 mm) is used. Two fillets weld in both sides each weld length is, d = 10mm

- In case of braking failure, the maximum foot pressure is approximated to be 1200 psi (8273 kPa); thus, the force acting on point A which represents the center of BOT switch joint, and it is found to be 650 N.

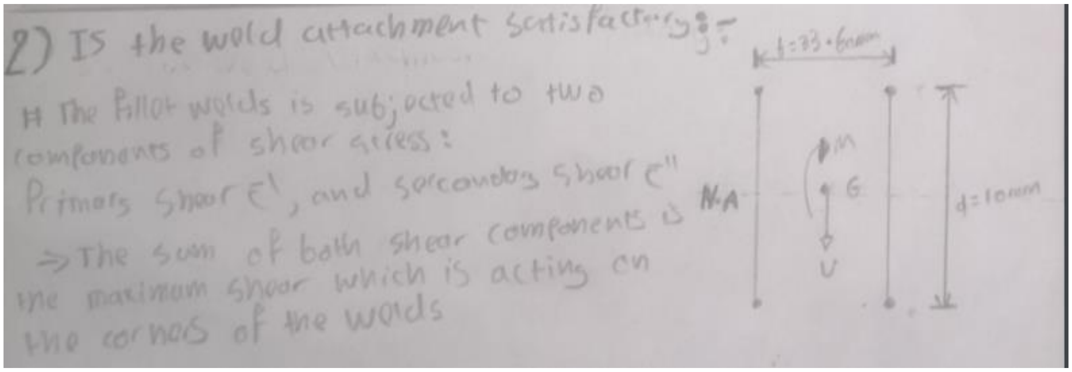


- The reaction force and bending moment reaction at point B are calculated as followed:



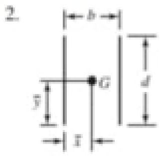
- The reaction force (V = 650 N) and bending moment (M =9.83N-m) at point B

- The reaction force V and bending moment at point B will make the fillet welds be subjected to two components of shear stress, Primary shear, $\bar{\tau}$ (due to shear force) and secondary shear, $\bar{\bar{\tau}}$ (due to the normal force produced by the bending moment) as shown below:



- From table 9-2, case (2) represents this weldment attachment, the neutral axis at point G is at($\bar{x}$, $\bar{y}$) where, $\bar{y} = \frac{d}{2}$ and $\bar{x}$ = b/2. The maximum shear stress will be the sum of two shear components and will be acting at the corners of the welds. The following calculations are performed to obtain the maximum shear stress:

2.



$A = 1.414hd$ | $\bar{x} = b/2$, $\bar{y} = d/2$ | $I_u = \frac{d^3}{6}$

2-1: Primary shear: τ'

$\tau' = \frac{V}{A}$; $V = 650N$; A: Total throat area of all the welds;

from Table 9-2:

$A = 1.414\,bd = 1.414 \times 3.175 \times 10$

$A = 36.2\ mm^2$

$\tau' = \frac{650}{36.2} = \boxed{18.0\ MPa}$

2-2: Secondary shear (due to Normal force produced by the bending moment)

$\tau'' = \frac{Mc}{I}$; $M = 9.83\ N.m$

; $c = \frac{d}{2} = \frac{10}{2} = 5\ mm$

$I = 0.707\,h\,I_u$, $I_u = \frac{d^3}{6}$ (from table 9-2)

$I_u = \frac{10^3}{6} = 166.67\ mm^3$

$I = 0.707 \times 3.175 \times 166.67 = 374\ mm^4$

$\tau'' = \frac{Mc}{I} = \frac{9.83 \times 5 \times 10^3}{374} = 131\ MPa$

2-3: Maximum shear stress:

$\tau_{max} = [\tau'^2 + \tau''^2]^{1/2} = [18.0^2 + 131^2]^{1/2} = \boxed{132\ MPa}$

- Notes: definition of important parameters used in the above calculations

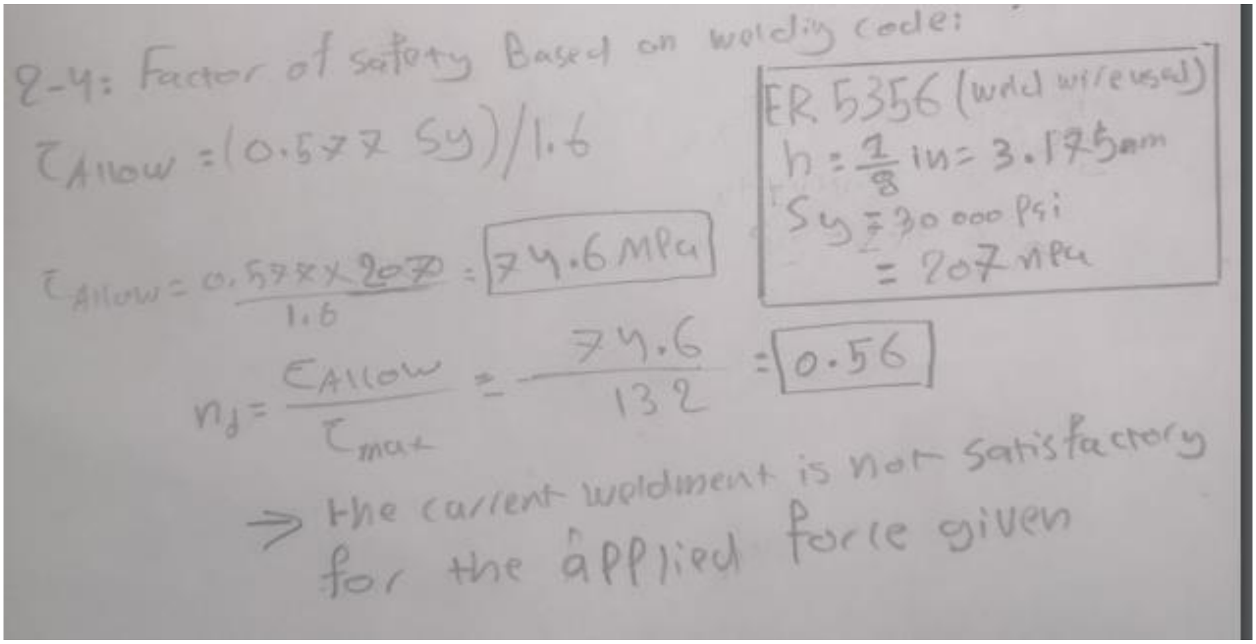
A = Total throat area

C = the distance from the neutral axis of the weld group to the point of the interest

I = moment of inertia of the weld group (based on throat area)

I_u = Unit moment of inertia for designated weld shapes given in table 9-2

- The shear stress allowable based on the welding code is equal to $\tau_{All} = \frac{(0.577 s_y)}{1.6}$, where s_y is the tensile yielding strength of ER 5356.



9-4: Factor of safety Based on welding code:

$\tau_{Allow} = (0.577\ S_y)/1.6$

ER 5356 (weld wire used)
$h = \frac{1}{8}$ in $= 3.175$ mm
$S_y = 30\,000$ psi
$= 207$ MPa

$\tau_{Allow} = \frac{0.577 \times 207}{1.6} = \boxed{74.6\ \text{MPa}}$

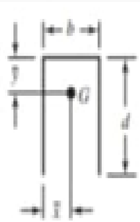
$n_d = \frac{\tau_{Allow}}{\tau_{max}} = \frac{74.6}{132} = \boxed{0.56}$

⇒ the current weldment is not satisfactory for the applied force given

- The design factor of safety of the current weld attachment is found to be 0.56 which is not satisfactory for the applied load

- Alternative design will be approached by reinforcing the weld attachment. Increasing the throat area of the weld attachment will decrease the net shear stress in the welds' corners. The following analysis set shows the new suggested weld attachment. Knowing that the new weldment attachment is represented by case (5) in table 9-2:

5.



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

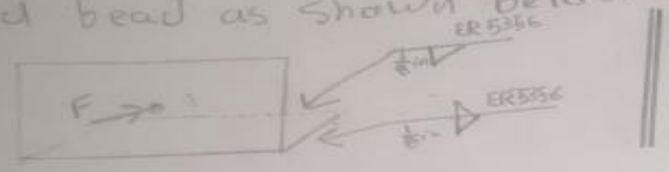
$\bar{x} = b/2$

$\bar{y} = \frac{d^2}{b + 2d}$

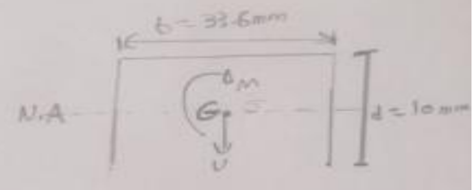
$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2$

Improvement:

Increase the throat area, A, by adding additional weld bead as shown below:



From Table 9-2; consider Case 5



$\Rightarrow \bar{y} = \frac{d^2}{b+2d} = \frac{10^2}{33.6+2\times10} = \boxed{1.87\ mm}$

$\Rightarrow$ c (Point of critical load) = $d - \bar{y}$

$c = 10 - 1.87 = \boxed{8.13\ mm}$

$\Rightarrow$ Throat area, $A = 0.707h(b+2d)$

$A = 0.707\times 3.175\times(33.6+2\times10) = \boxed{120\ mm^2}$

$\Rightarrow$ Primary shear; τ'

$\tau' = \frac{V}{A} = \frac{650}{120} = 5.42$ MPa

$\Rightarrow$ Secondary Shear τ''

$\tau'' = \frac{Mc}{I}$; $M = 9.83$ N.m, $c = 8.13$ mm, $I = 0.707\,h\,I_u$

$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b+2d)\bar{y}^2 = \left[\frac{2\times10^3}{3}\right] - 2\times10^2\times1.87 + (33.6-2\times10)(1.87^2)$

$I_u = 480\ mm^3$

$I = (0.707)(480)\times(3.175) = 1177.5\ mm^4$

$\tau' = \frac{Mc}{I} = \frac{9.83\times8.13\times10^3}{1177.5} = 67.9$ MPa

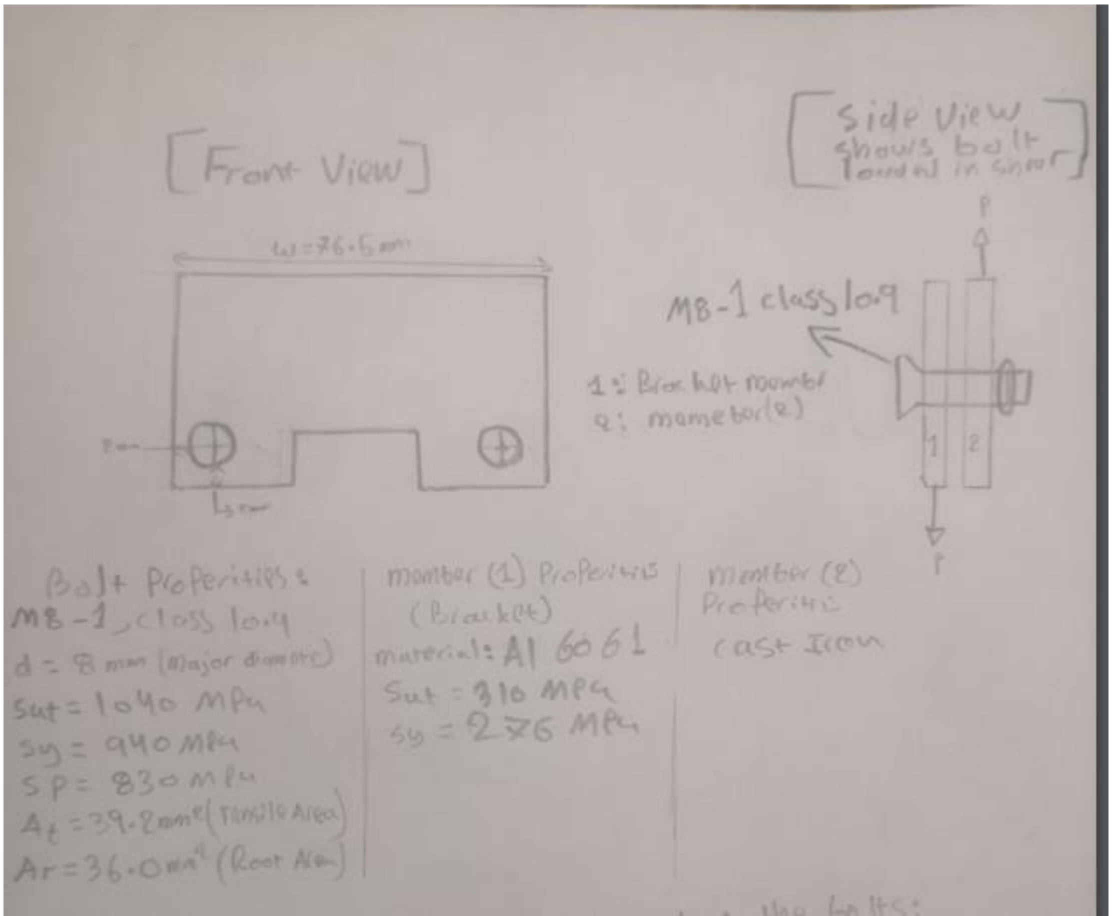
$\tau_{max} = \sqrt{\tau'^2+\tau''^2} = [5.42^2+67.9^2]^{1/2} = 68.1$ MPa

$n_d = \frac{\tau_{allow}}{\tau_{max}} = \frac{74.6}{68.1} = \boxed{1.10}$ satisfactory

- The suggested weld attachment shape will result in having a design factor above than 1 (n =1.10), which is satisfactory based on AWS design safety code.

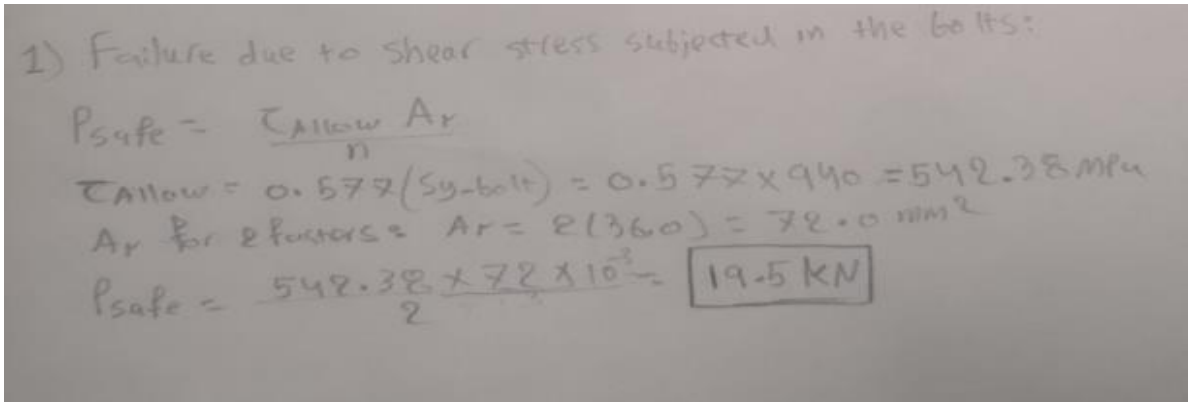
Section (2): Finding the safe tensile shear load "P" that can be applied to the connection in piece (1) to provide a minimum factor of safety of 2 for different failure modes.

M8-1 class 10.9 bolts are used. The properties of the bolt material as well as the clamped materials are shown below:



- First failure mode: failure due to shear stress subjected in the two bolts

Notes: the shear area used is the root diameter area (A_r) because the threaded portion of the fastener passes through the shear interface. The allowable shear force is 0.577 (s_y) according to Von Mises criteria, where s_y is the tensile yielding strength of bolt.



1) Failure due to shear stress subjected in the bolts:

$P_{safe} = \frac{\tau_{Allow} A_r}{n}$

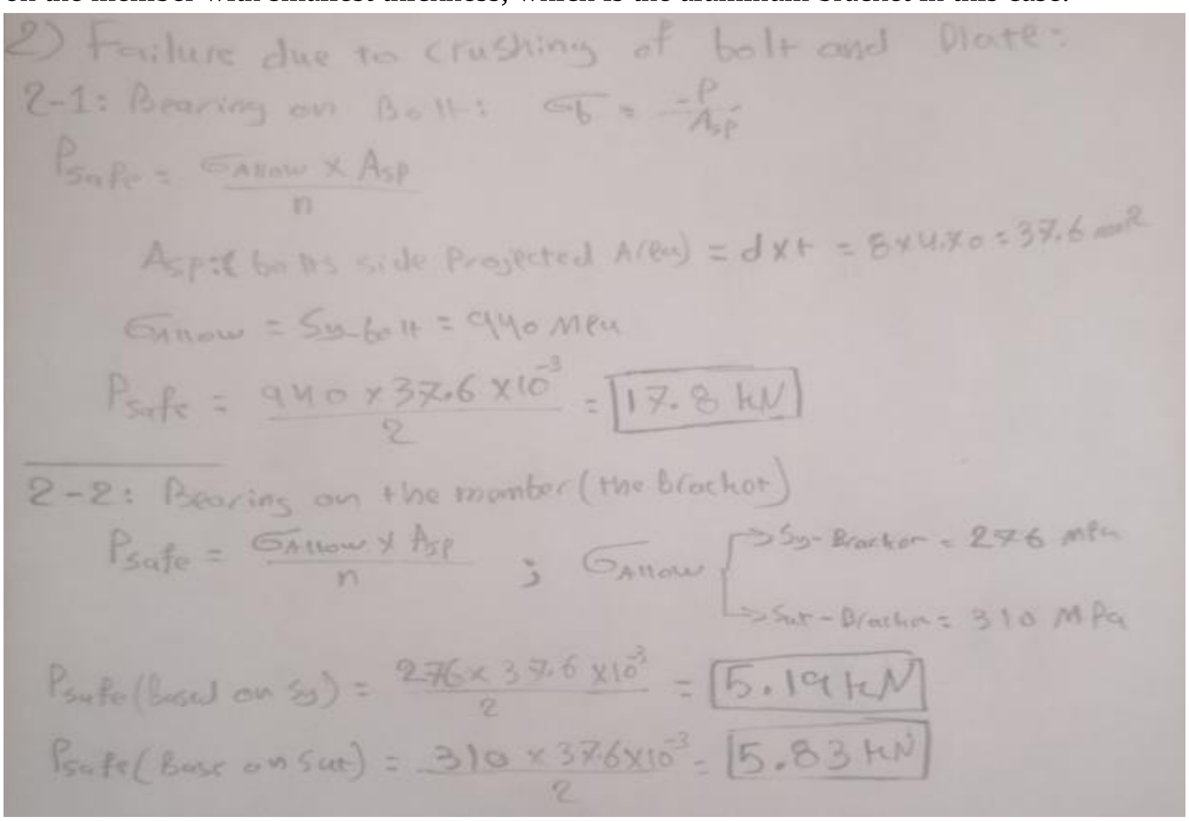
$\tau_{Allow} = 0.577(S_{y\text{-}bolt}) = 0.577 \times 940 = 542.38\ MPa$

A_r for 2 fasteners: $A_r = 2(36.0) = 72.0\ mm^2$

$P_{safe} = \frac{542.38 \times 72 \times 10^{-3}}{2} = \boxed{19.5\ kN}$

- Second failure mode: failure due to crushing of bolt and the bracket

Notes: the safe load is obtained for the bearing on the bolt also obtained for the bearing stress on the member with smallest thickness, which is the aluminum bracket in this case.



2) Failure due to crushing of bolt and plate:

2-1: Bearing on Bolt: $\sigma_b = \frac{-P}{A_{sp}}$

$P_{safe} = \frac{\sigma_{Allow} \times A_{sp}}{n}$

A_{sp}: (bolts side Projected Area) $= d \times t = 8 \times 4.70 = 37.6\ mm^2$

$\sigma_{Allow} = S_{y\text{-}bolt} = 940\ MPa$

$P_{safe} = \frac{940 \times 37.6 \times 10^{-3}}{2} = \boxed{17.8\ kN}$

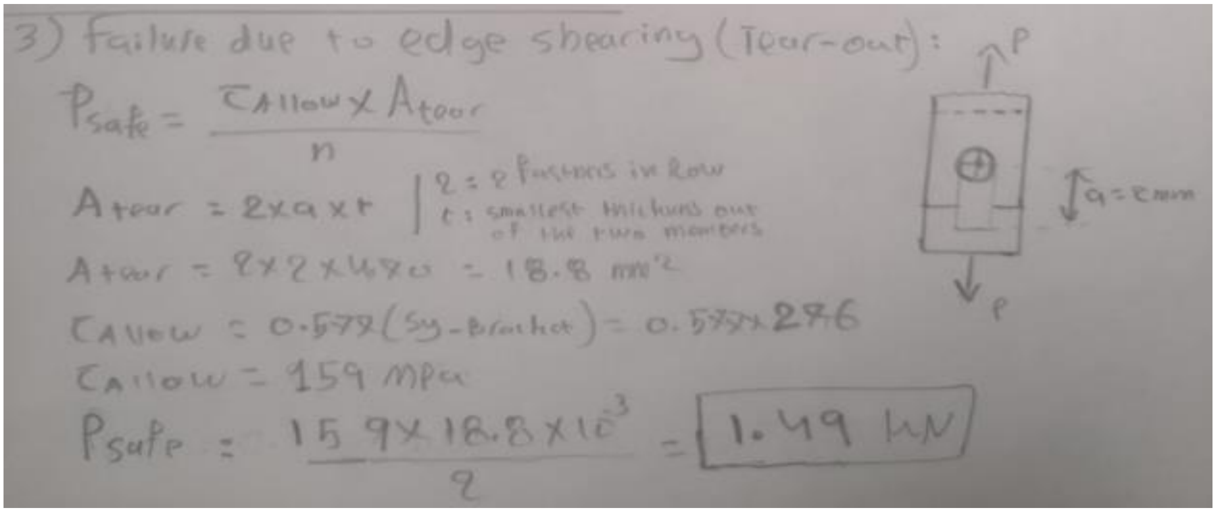
2-2: Bearing on the member (the bracket)

$P_{safe} = \frac{\sigma_{Allow} \times A_{sp}}{n}$; $\sigma_{Allow} \begin{cases} \rightarrow S_{y\text{-}Bracket} = 276\ MPa \\ \rightarrow S_{ut\text{-}Bracket} = 310\ MPa \end{cases}$

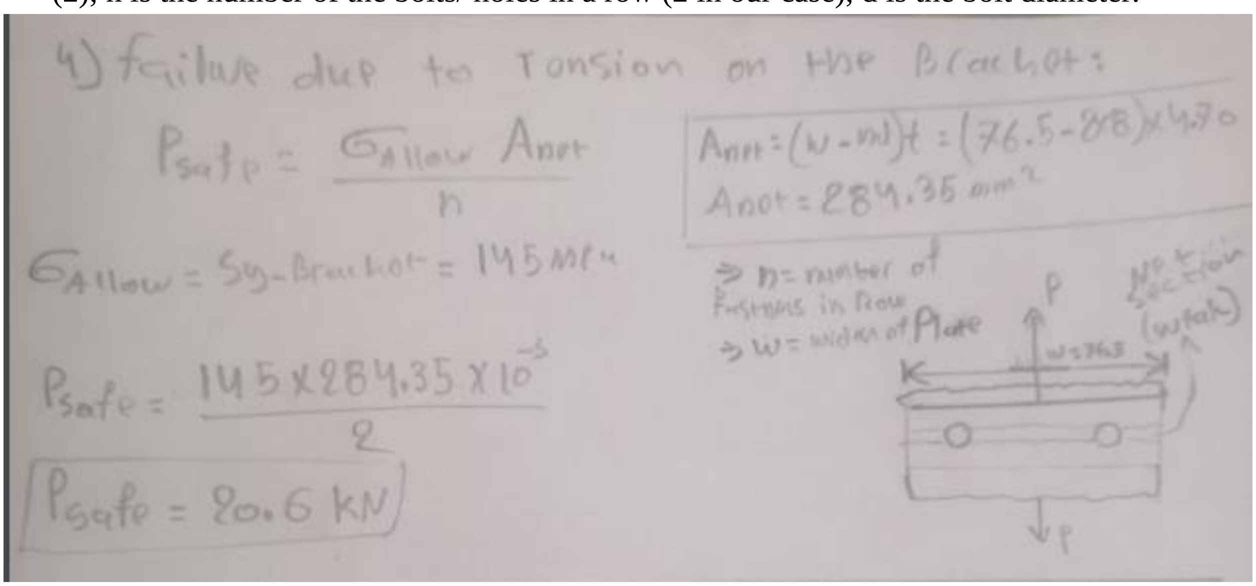
$P_{safe}(\text{Based on } S_y) = \frac{276 \times 37.6 \times 10^{-3}}{2} = \boxed{5.19\ kN}$

$P_{safe}(\text{Base on } S_{ut}) = \frac{310 \times 37.6 \times 10^{-3}}{2} = \boxed{5.83\ kN}$

- Third failure mode: failure due to edge shearing.

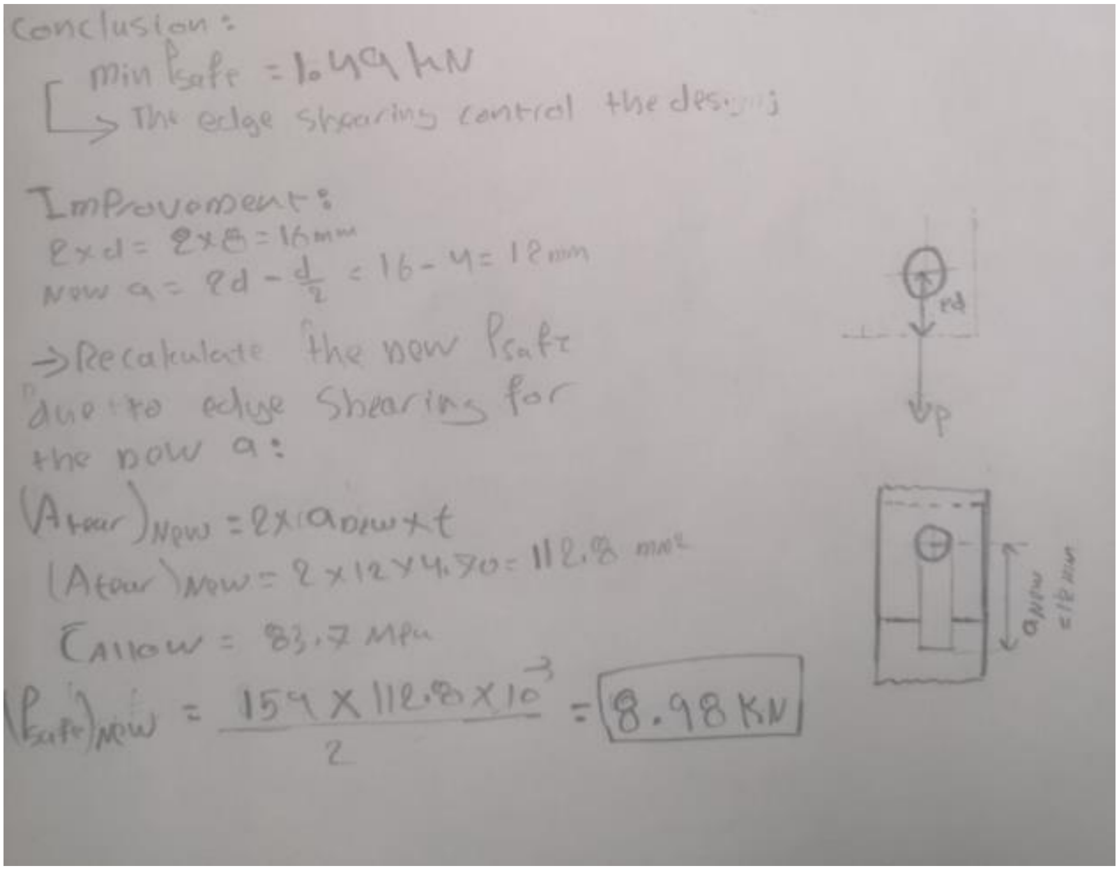


- Forth failure mode: failure due to yielding of the bracket's net cross-sectional area due to tension.
  Notes: $A_{net} = (w - nd)t$ = the net area of the bracket; w is the width of the bracket piece (2); n is the number of the bolts/ holes in a row (2 in our case), d is the bolt diameter.



- The minimum safe tensile shear load "P" is obtained to be 1.49 kN due to the edge shearing. Therefore, the edge shearing failure mode will control any redesign improvement.

Suggested redesign: The best way to minimize the shear stress due to edge shearing is increasing A_{tear}. It's recommended that the distance from the center of the bolt joint to the bottom edge to be 2d, where d is the nominal diameter of the bolt. This will increase the A_{tear} and, therefore, decrease the edge shearing stress and eventually will increase the safe load margin. The new safe load based on the suggested improvement is recalculated as follows:


Conclusion:

min $P_{safe} = 1.49$ kN

→ The edge shearing control the design

Improvement:

$2 \times d = 2 \times 8 = 16$ mm

New $a = 2d - \frac{d}{2} = 16 - 4 = 12$ mm

→ Recalculate the new P_{safe} due to edge shearing for the new a:

$(A_{tear})_{New} = 2 \times (a_{new}) \times t$

$(A_{tear})_{New} = 2 \times 12 \times 4.70 = 112.8\ mm^2$

$\tau_{allow} = 83.7$ MPa

$(P_{safe})_{New} = \frac{159 \times 112.8 \times 10^{-3}}{2} = \boxed{8.98\ kN}$

➢ Results of failure due to edge shearing for the current design and the suggested improvement:

Failure Mode: Edge Shearing	Current Design	Suggested Improvemnet
A_{tear} (mm^2)	18.8	112.8
Safe Load "P" (kN)	1.49	8.98

Conclusion

The goal of this CDR part is to check the current validity of the Kill switch mount and whether it can withstand the foot pressure when the brake fails. Two stress regions were checked. The first region is the weld attachment on piece two onto piece one. The current weld attachment was found to be unsatisfactory according to the American Welding Society design factor code (0.560). An improvement suggested which is increasing the throat area by adding one more weld bead at same leg size. The improvement paid off as the obtained design factor of safety was above 1. Another region of concern was the two fasteners holding the main piece in the bracket (Piece 1). Different failures mode was checked, and the safe shear load was obtained for each of which. The leading failure mode was due to edge shearing as it resulted in having the minimum safe load out of the different modes. An enhancement suggested which was increasing the distance from the bolt center to the bottom edge to be double the diameter value of the bolt. The later would increase the tear Area and, thus, increasing the margin of safe shear load. Nevertheless, this improvement will be implemented because minimum safe load found was 1.49 kN which is still a comfortable load margin.

Appendix