To: Professor Younis

From: Mason Averill

Subject: Design Problem 2

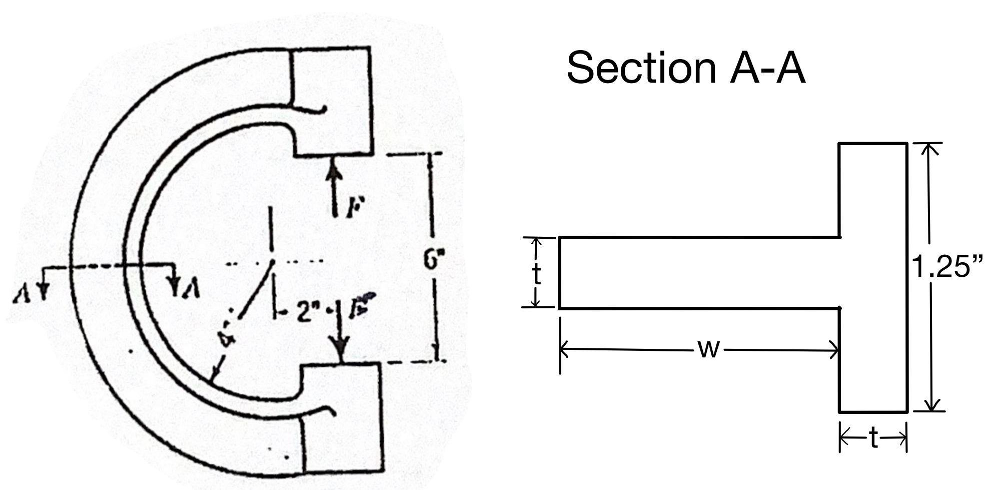
Date: 19 November 2020

Purpose:

The purpose of this memo is to communicate the methodology and results of Design Problem 2 for ME-550: Advanced Stress Analysis, completed November 19th 2020.

Purpose and Scope of Assignment:

The purpose of this assignment was to determine the optimum cross section properties for a C-clamp with a T-style cross section. Particularly, by reviewing Figure 1, the objective was to determine the ideal ‘w’ (width) and ‘t’ (thickness) such that the stress developed in the clamp was greater than -60 ksi but less than 20 ksi when the loading situation is as shown in Figure 1 (a) with F=1200lbf. In addition, the minimum allowable value for ‘t’ was given as 3/16 in. The undetermined dimensions were also constrained to being an increment of 1/16” due to manufacturing capabilities.




(a) (b)

*Figure 1: Loading Situation of C-Clamp and General Cross Section Properties*

Method of Analysis:

In order to select the optimum width and thickness, some constraints had to be determined for the possible values they could take. In addition, an objective had to be established in order to determine what exactly is meant by the 'optimum cross section'. The following choices were made in regard to these parameters:

1. The maximum allowable dimension for the thickness was set to 1”
2. The minimum allowable dimension for the width was set to 1”
3. The maximum allowable dimension for the width was set to 2”
4. The maximum allowable tensile stress was set to 20 ksi
5. The maximum allowable compressive stress was set to 60 ksi or
6. The objective consisted of minimizing both the deflection and mass of the clamp. Minimizing the deflection was weighted as being two times more important than minimizing the mass

The clamp was then modeled in SOLIDWORKS and a static analysis was performed with the fixture and loading conditions as shown by Figure 2. By exploiting symmetry, the clamp can be modeled as a half-clamp with the section at A-A fixed, a point load at the free end with a magnitude of 1200lbf, and an equivalent moment acting at the free end due to the offset distance of 2” shown in Figure 1 (a).

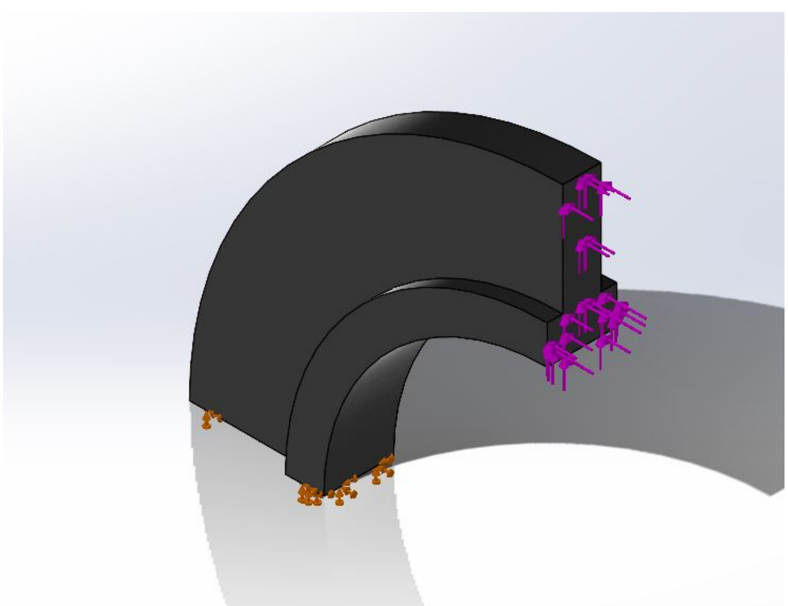


*Figure 2: Fixture and Loading Conditions*

With a static analysis completed in SOLIDWORKS, an optimization study could then be run. The first iteration of the optimization study considered all possible allowable combinations of the dimensions for the width and thickness. However, this results in 238 different scenarios to evaluate, so the 'FAST' solution method was utilized. This solution method considers only enough cases required to draw accurate estimations for all other possible cases. The outcome of this first optimization study resulted in a width of 2" and a thickness of 0.1875". These results, as well as the parameters used to determine them, can be seen by viewing Figures 3 and 4. Some further experimentation showed that the optimum results always occurred with a maximum allowable value for the width.

The stresses utilized for the optimization constraint consisted of the maximum principal stress at the inner radius of the clamp and the minimum principal stress at the outer radius of the clamp.

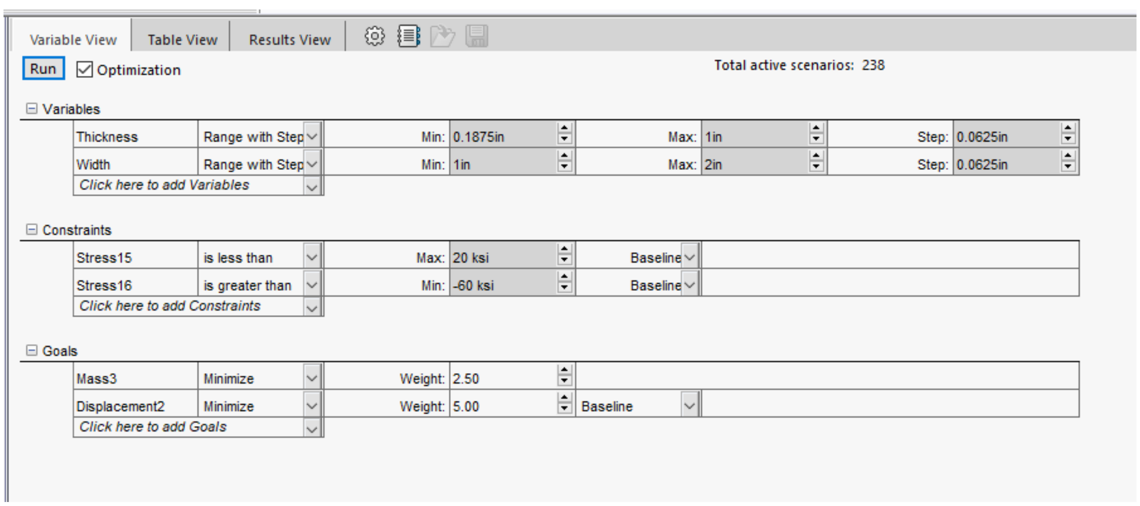
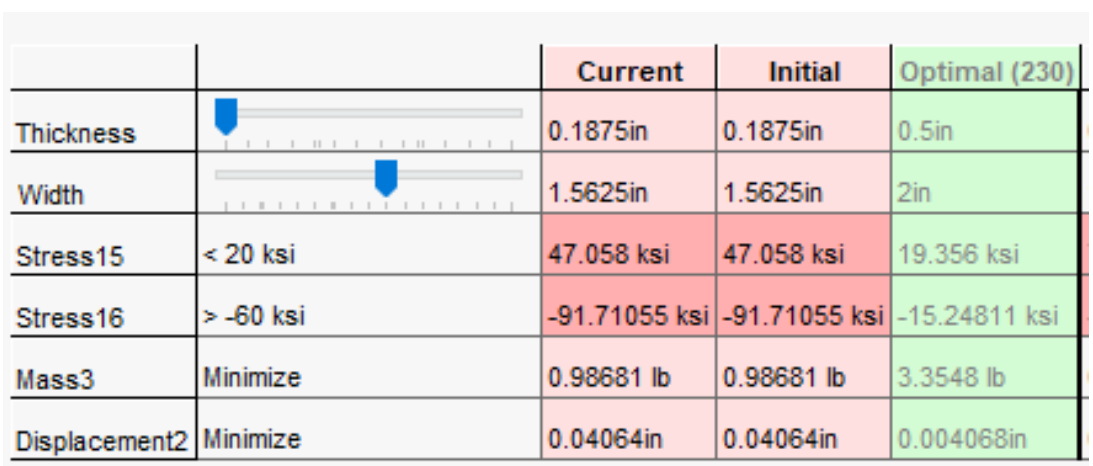



*Figure 3: Parameters Considered for First Optimization Iteration*



| | | Current | Initial | Optimal (230) |
|---|---|---|---|---|
| Thickness | | 0.1875in | 0.1875in | 0.5in |
| Width | | 1.5625in | 1.5625in | 2in |
| Stress15 | < 20 ksi | 47.058 ksi | 47.058 ksi | 19.356 ksi |
| Stress16 | > -60 ksi | -91.71055 ksi | -91.71055 ksi | -15.24811 ksi |
| Mass3 | Minimize | 0.98681 lb | 0.98681 lb | 3.3548 lb |
| Displacement2 | Minimize | 0.04064in | 0.04064in | 0.004068in |

*Figure 4: Results of First Optimization Iteration*

Next, a “High Quality” optimization study was performed. A factor of safety of 1.25 was considered for the maximum tensile and compressive stress developed in the section at A-A using the same methodology as before. The width was held constant at 2” and the thickness was allowed to vary from 3/16” up to 1”. These parameters, as well as the results of this study can be seen by viewing Figures 5 and 6.

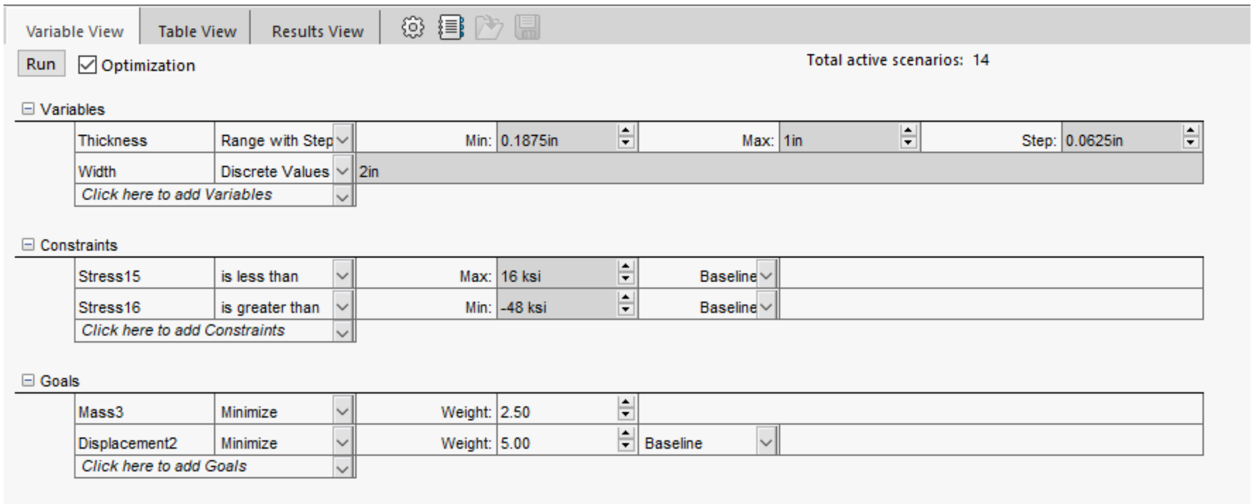



*Figure 5: Parameters for High Quality Optimization Study*

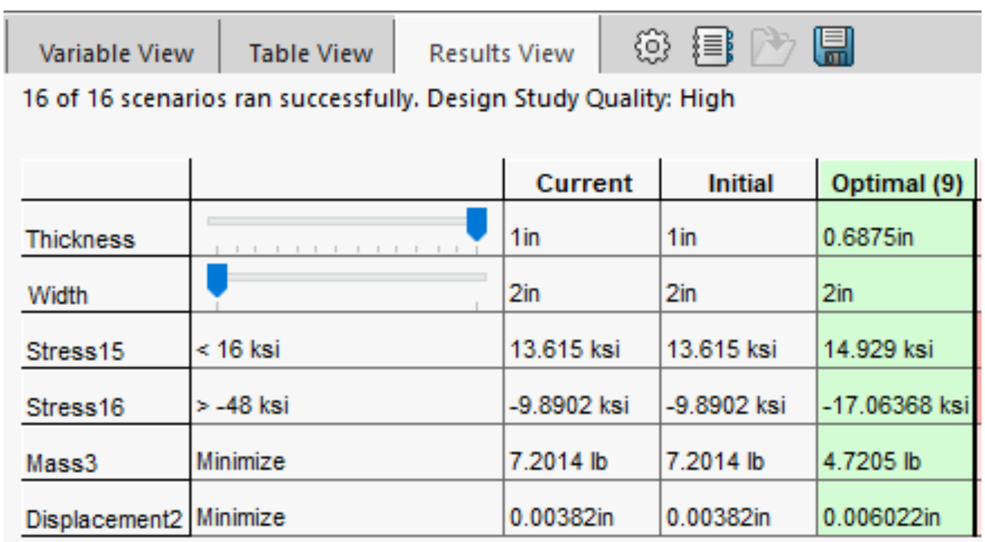



*Figure 6: Results of High Quality Optimization Study*

The optimum cross-sectional properties had now been determined. The results are shown by Figure 7.

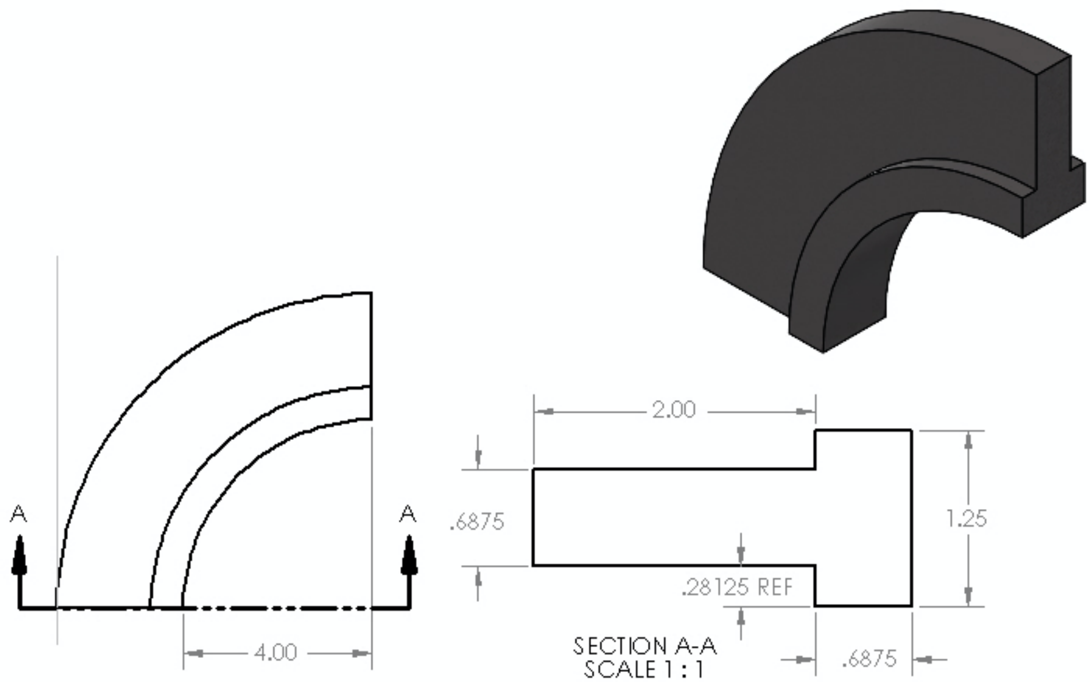



*Figure 7: Optimum Cross Sectional Properties*

Results:

Figures 8 and 9 show the magnitude of the maximum principal stress on the clamp and over the section at A-A, respectively.

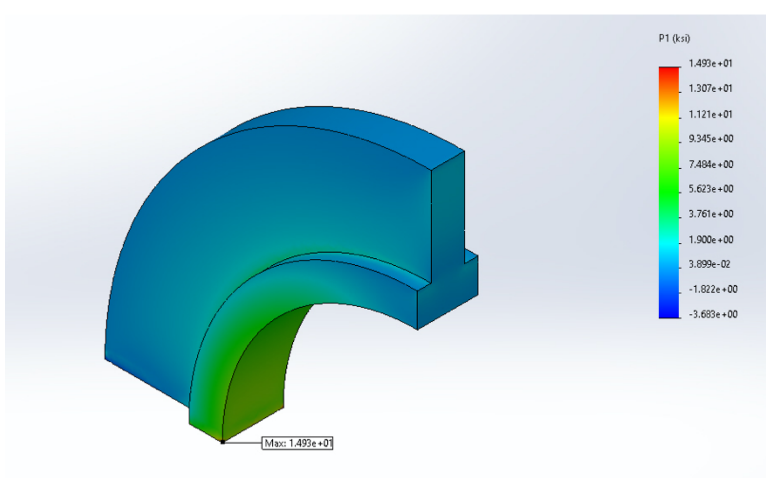



*Figure 8: Maximum Principal Stress Distribution on the Clamp*

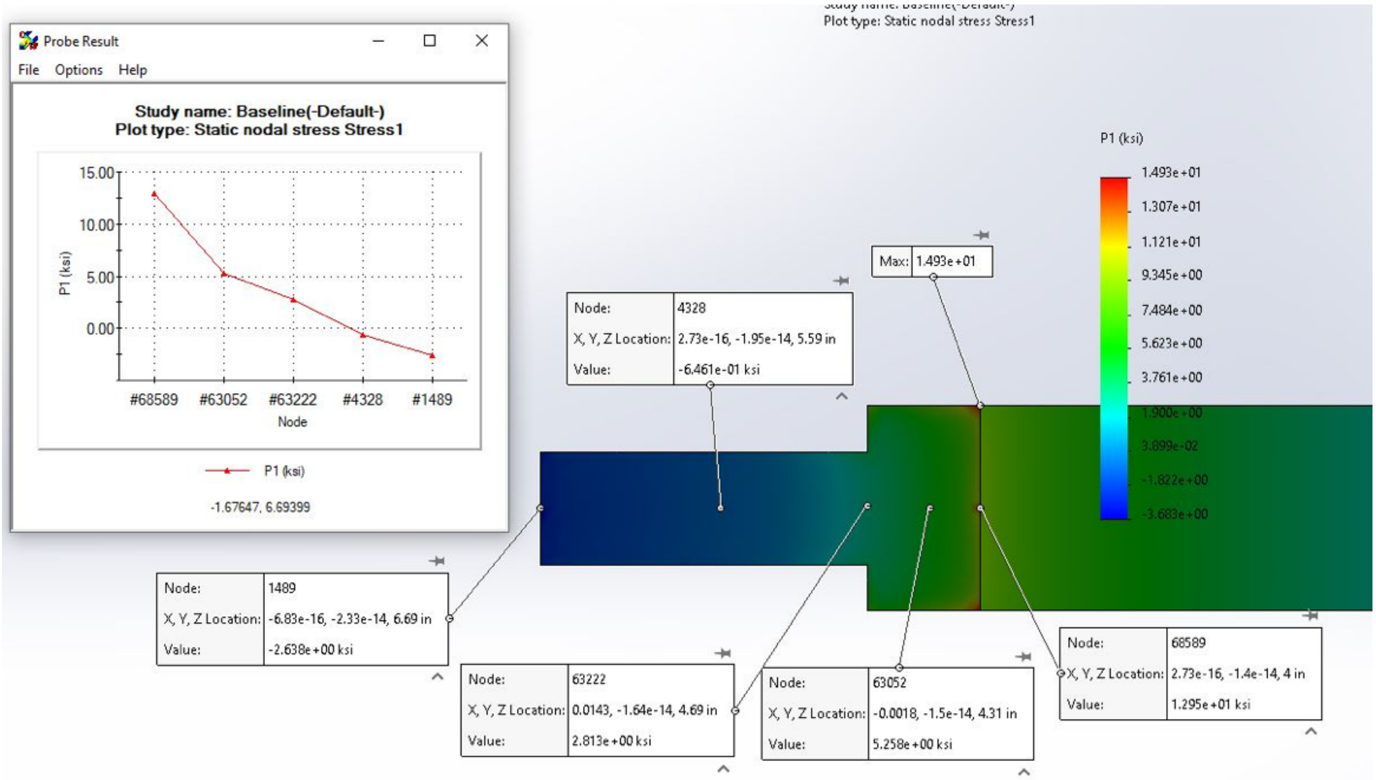



*Figure 9: Maximum Principal Stress Distribution at Section A-A*

Note that the plot shown in the upper left side of Figure 9 is the stress distribution in the section from the inner radius towards the outer radius. As would be expected, the maximum value of the first principal stress occurs at the inner radius.

Figures 10 and 11 show the magnitude of the minimum principal stress on the clamp and over the section at A-A, respectively.

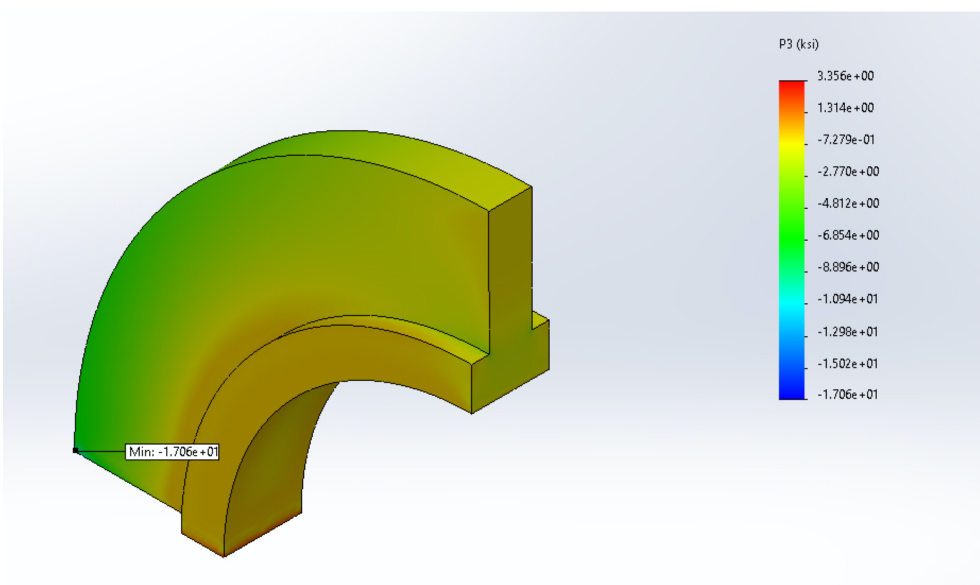



*Figure 10: Minimum Principal Stress Distribution on the Clamp*

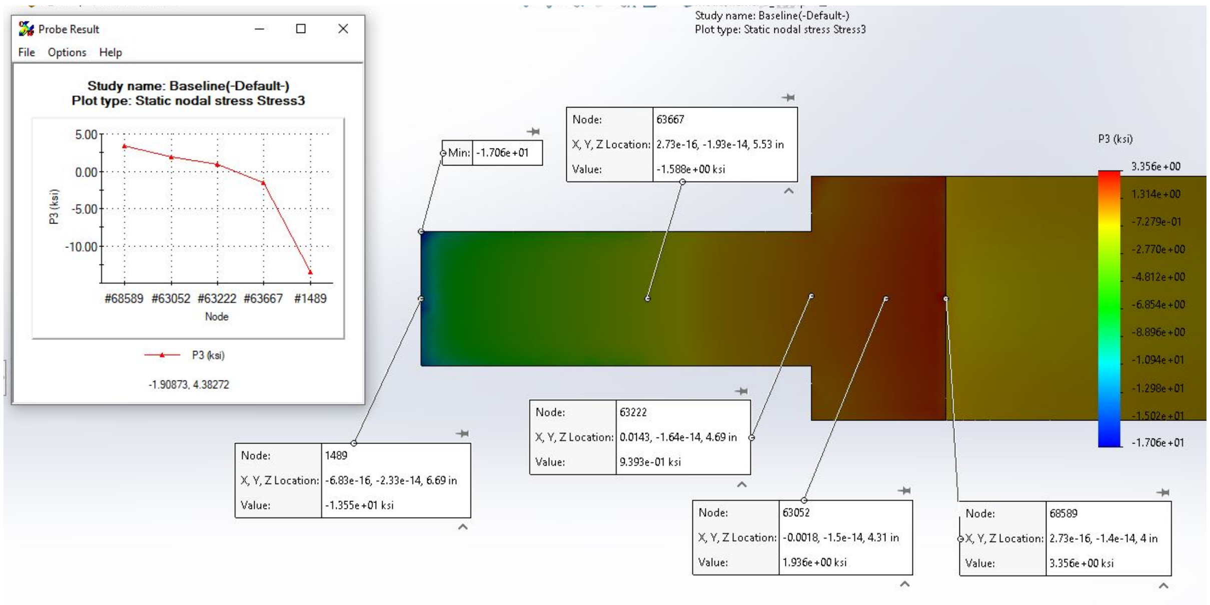



*Figure 11: Minimum Principal Stress Distribution at Section A-A*

Again, note that the plot shown in the upper left side of Figure 11 is the stress distribution in the section from the inner radius towards the outer radius. As would be expected, the maximum compressive stress is developed at the outer radius.

Figure 12 shows the deflection of the clamp due to the applied loads.

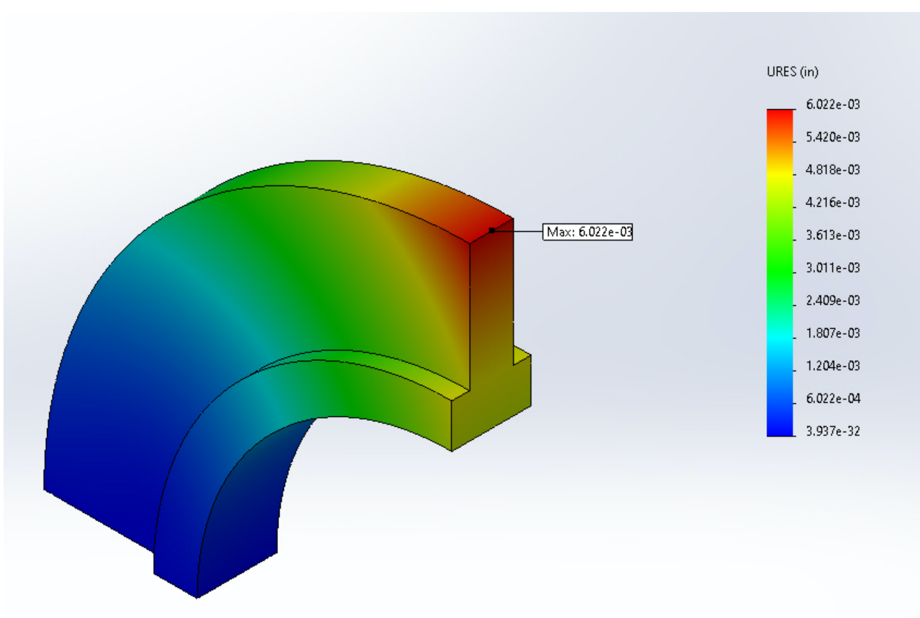



*Figure 12: Deflection Distribution on the Clamp*

Figures 13 and 14 show the factor of safety distribution on the clamp and over the section at A-A, respectively. The failure criterion selected for the clamp was Coulomb-Mohr, as this is the typically the most accurate failure theory for cast iron, which is a brittle material.

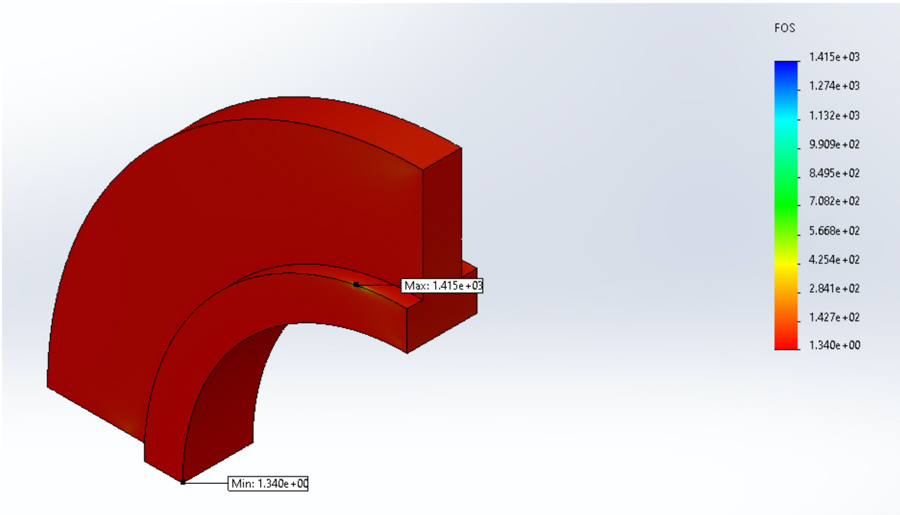



*Figure 13: Factor of Safety Distribution on the Clamp*

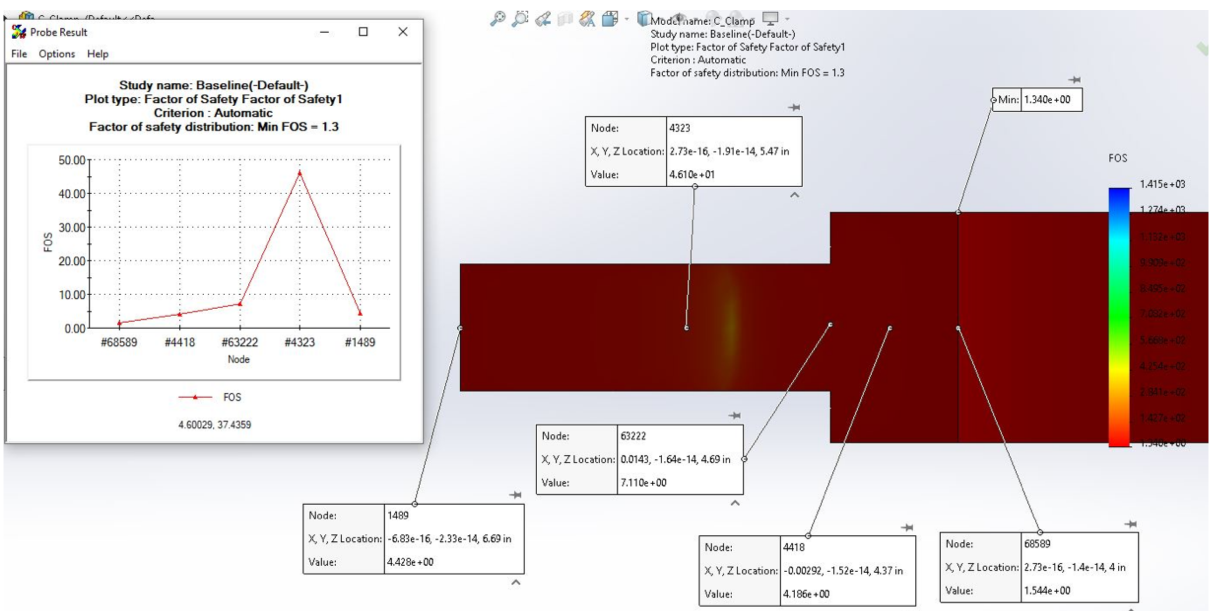



*Figure 14: Factor of Safety Distribution at Section A-A*

Again, note that the plot shown in the upper left side of Figure 14 is from the inner radius towards the outer radius. As would be expected the factor of safety becomes very large at a location relatively close to the neutral axis.

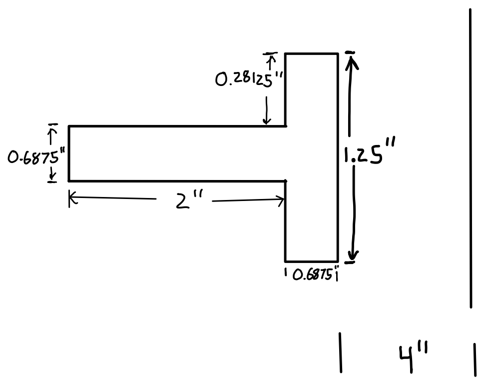
Conclusion and Discussion:

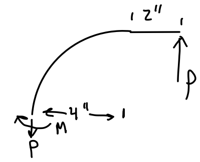
The optimum profile for the T-section C-clamp was determined and is as shown by Figure 7. The stress distribution in the clamp, the stress distribution at section A-A, the deflection of the clamp, and the factor of safety against failure can be seen in Figures 8-14.

Rationale for Solution Method:

Note that hand calculations for the tangential and radial stresses are shown in the Appendix for the optimum cross section. I decided to solve this problem in SOLIDWORKS rather than coding it in MATLAB or an equivalent because prior to this project I had not used the SOLIDWORKS simulation package. This is an important skill I wanted to develop this semester and this seemed like a great opportunity to do so. In addition, this solution method allowed me to much better visualize what the stress distribution looks like in curved beams, as well as along the section at which the stresses become a maximum. It was also interesting to see the effects that sharp edged corners have on the maximum stress intensity. I did some exploration with a fillet radius across the entire profile with varying radii and observed the maximum stress developed. I learned a great deal from completing the project this way and can now easily transfer the skills learned while doing so to other problems and loading situations that do not have analytical solutions.

# Appendix



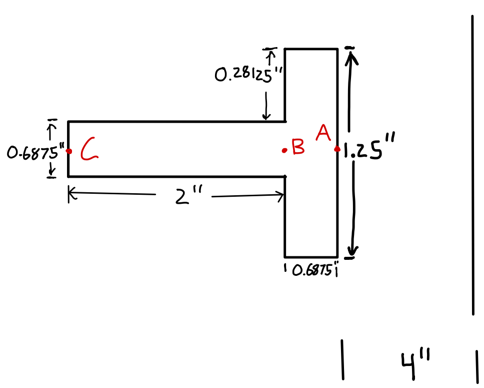

$b_p = 0.28125''$

$\bar{r} = 4 + \frac{0.6875}{2} = 4.34375'' = \bar{r}$

$t_f = 0.6875''$

$$\frac{b_p^2}{\bar{r}\, t_f} = \frac{0.28125^2}{4.34375 \cdot 0.6875} = 0.026488 \Rightarrow \alpha = 1$$

no correction factor needed




$A_{total} = 1.25 \cdot 0.6875 + 2 \cdot 0.6875$

$A_{total} = 2.23438$

$$R_c = \frac{(1.25 \cdot 0.6875) \cdot \left(\frac{4 + 4.6875}{2}\right) + (2 \cdot 0.6875) \cdot \left(\frac{4.6875 + 6.6875}{2}\right)}{A}$$

$R_c = 5.17067''$

$A_m = 1.25 \cdot \ln\left(\frac{4.6875}{4}\right) + 0.6875 \cdot \ln\left(\frac{6.6875}{4.6875}\right) = 0.442553$

$R = \frac{A}{A_m} = 5.04883$

$\bar{y} = R_c - R = 0.121843$

$M = (2 + R_c) \cdot 1200 = -8604.81 \text{ in·lbf} = M$ (opening beam)

$\sigma_x = \frac{M_z (\rho - R)}{\rho \bar{y} A} + \frac{P}{A}$

$\sigma_r = -\frac{M}{\bar{y} + \rho A}\left[R A_m|_\rho - A|_\rho\right]$

A: $\sigma_x|_{\rho = 4''} = 8824.67$ Psi

B: $\sigma_x|_{\rho = 4.6875''} = 2973.45$ Psi

C: $\sigma_x|_{\rho = 6.6875''} = -7207.76$ Psi

A: $\sigma_r|_{\rho = 4''} = 0$

B-: $\sigma_r|_{flange} = +\frac{+8604.81}{0.121843 \cdot 1.25 \cdot 4.6875 \cdot 2.234} \cdot \left[4.6875 \cdot 1.25 \cdot \ln\left(\frac{4.6875}{4}\right) - 0.6875 \cdot 1.25\right] = 763.889$

B+: $\sigma_r|_{web} = +\frac{+8604.81}{0.121843 \cdot 0.6875 \cdot 4.6875 \cdot 2.234} \cdot \left[4.6875 \cdot 1.25 \cdot \ln\left(\frac{4.6875}{4}\right) - 0.6875 \cdot 1.25\right] = 1388.89$ Psi

C: $\sigma_r|_{\rho = 6.6875''} = 0$