MECH 4450 Term Project Report

Project 2 (Static structure)

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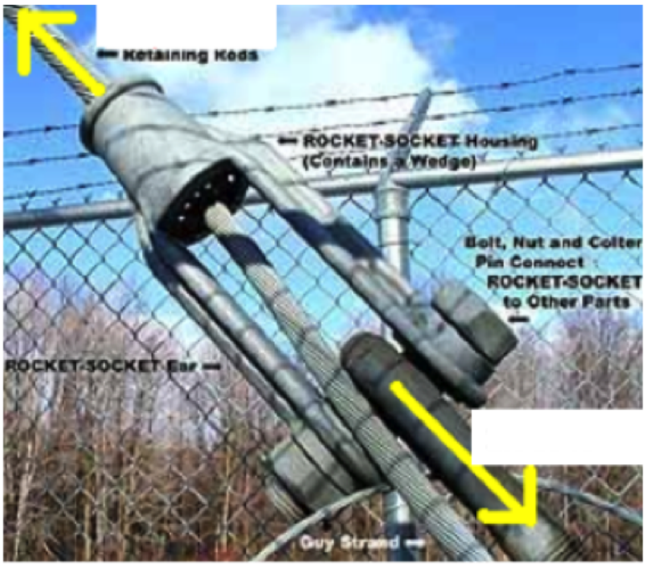
1 Introduction

1.1 Description of the problem

The cable anchor is a component at the end of the guy wire that helps to anchor the guyed tower as the picture below shows. It is widely used in engineering structures, such as broadcast transmission towers, bridges and so on. The problem is to analyze the load of the anchor, and to optimize the design.



In the analysis part, it is need to find out the points where failure is most possible to happen. In other words, the place where maximum local stress occurs. The design part will be discussed below.

Commercial finite element analysis software suite ANSYS will be used.

1.2 Design objectives

- The safety factor is required to be at least 2.
- The weight of the structure should be minimized.

- Dimensions should be adjusted in a way that other components (the guy wire and the bolt) will also have a good safefy factor, and the connection between the anchor and other components are safe enough. For example, decrease $D2$ may increase the safety factor and reduce the weight of the anchor itself, but it will reduce the safety factor of the bolt significantly.

1.3 Conditions

The material used to build the cable anchor will be structural steel.

Some dimensions are fixed. $H9 = 25cm$, $V7 = 6cm$, $D1 = 6cm$.

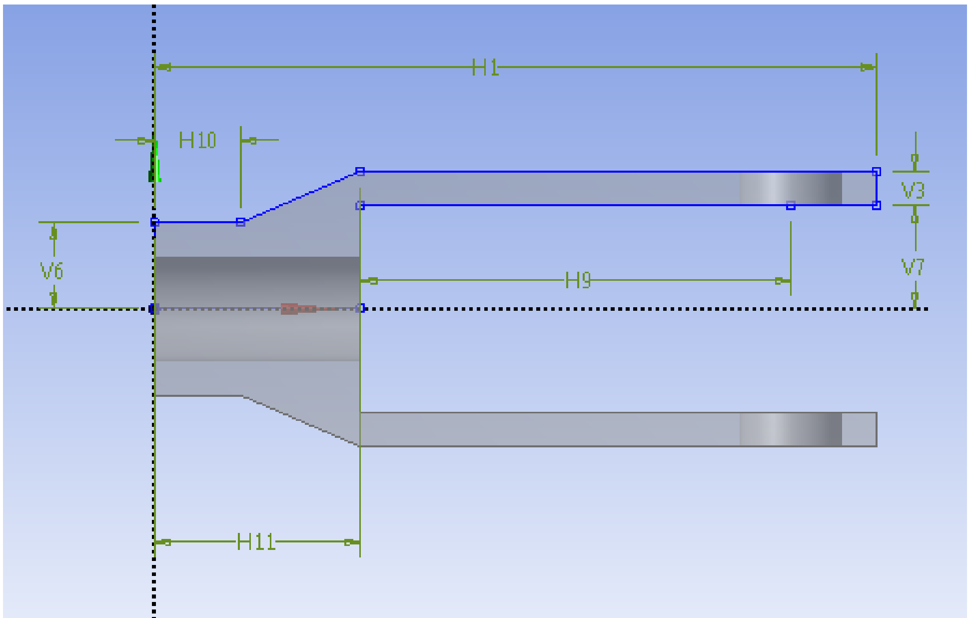
The cable anchor will be loaded with a axial force of $2 \times 10^5 N$. On one side, the force will be exerted on the guy wire via a cylindrical surface in a form of frictional force. It can be treated as fixed support. One the other hand, the force is balanced using a bolt put through two holes. Bearing load can be assumed for the situation.

Symmetrical model can be assumed.

2 Program modelling

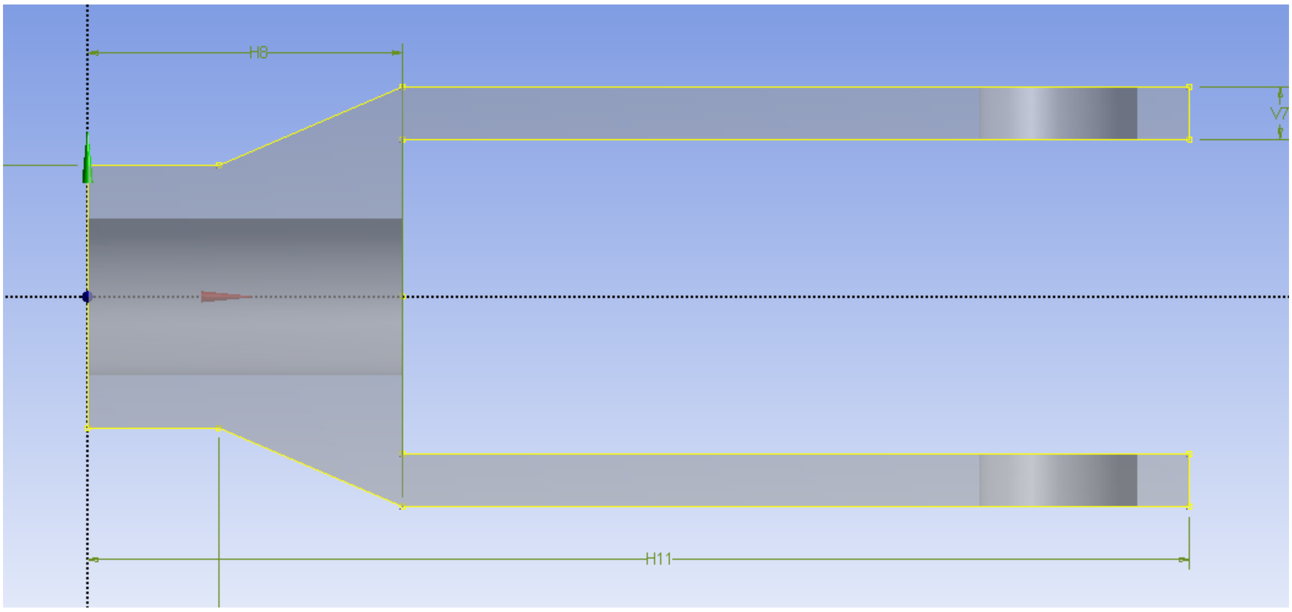
2.1 Geometry

The top view of original design is shown below:

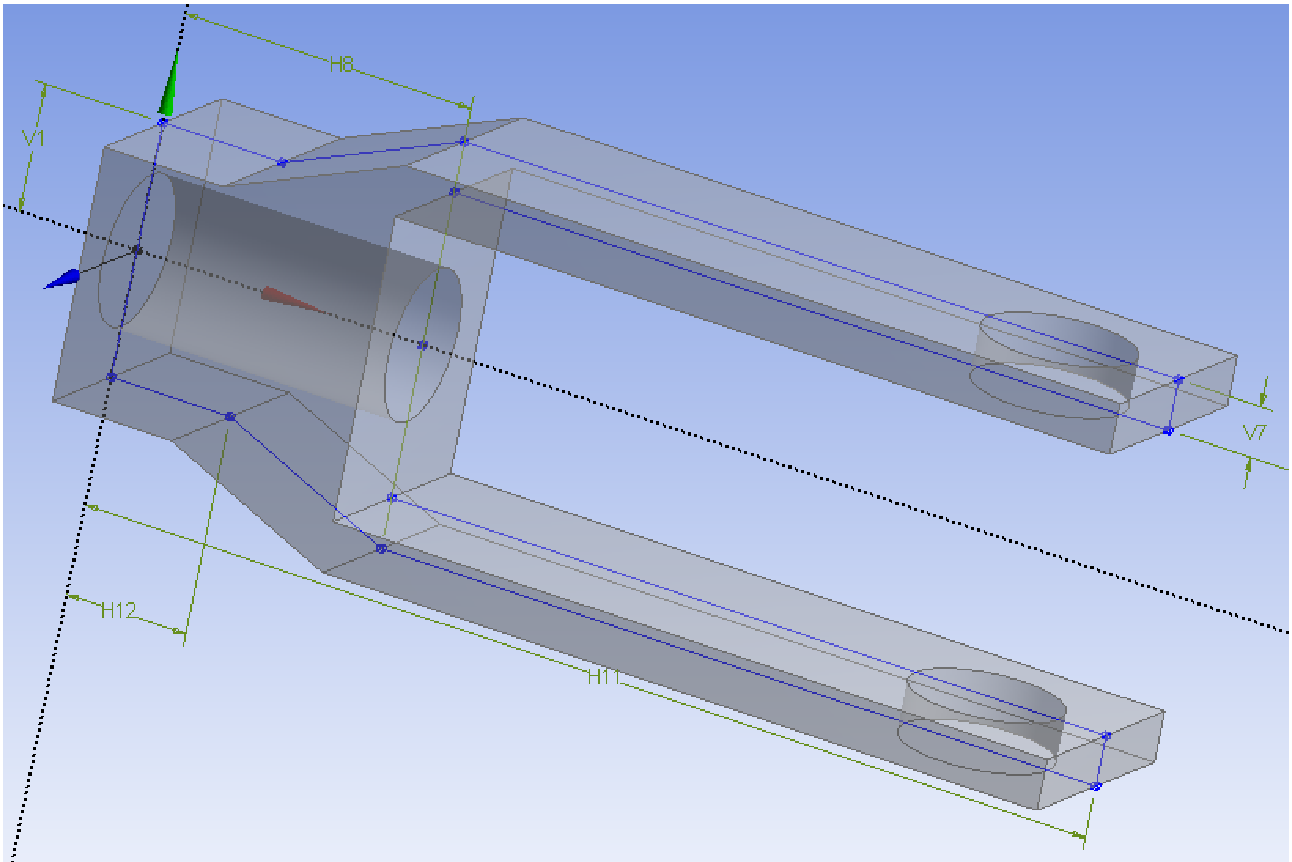


Where $H1 = 42cm$, $H10 = 5cm$, $H11 = 12cm$, $H9 = 25cm$, $V3 = 2cm$, $V6 = 5cm$, $V7 = 6cm$, diameters of all holes are $6cm$.

It is resembled as below:



The 3D model built is then as below, where the height of the component is assumed to be $10cm$:



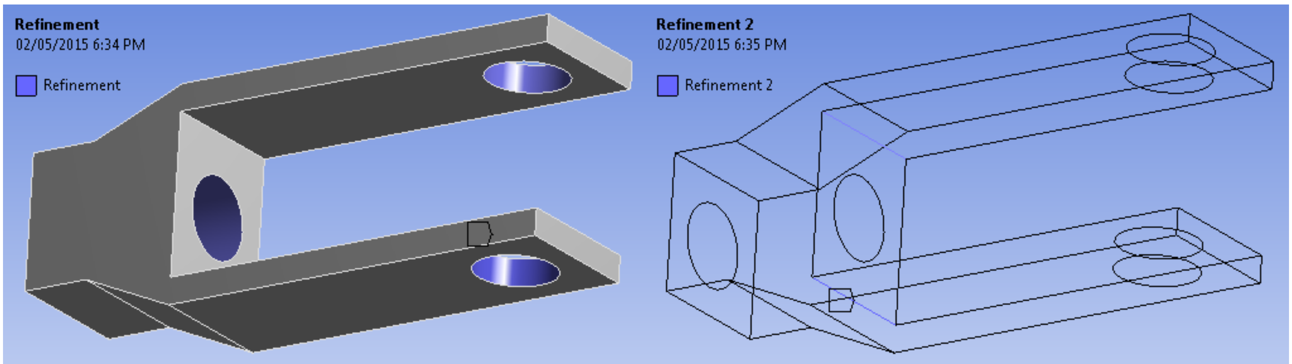
The boundary conditions are the loads, where symmetric properties on both axis can be assumed.

3 FEM analysis

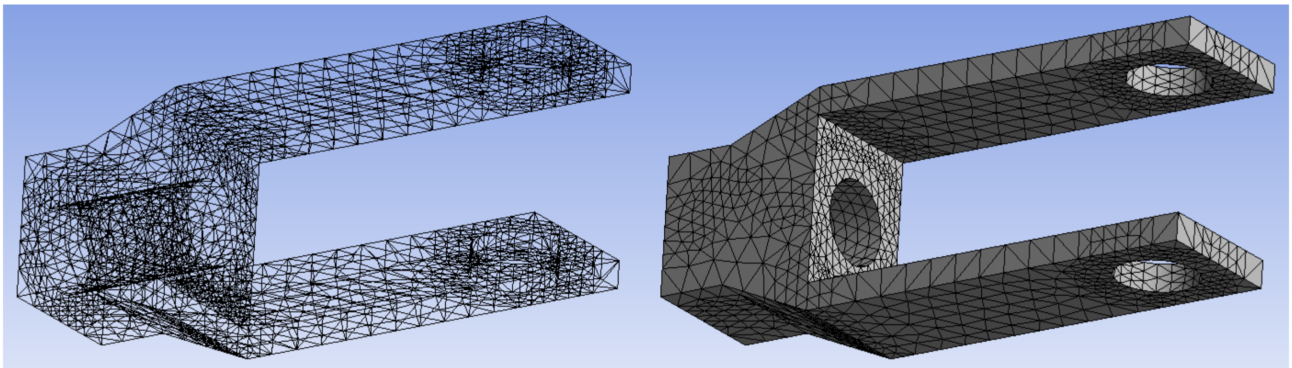
3.1 Mesh setup

As this is a 3D model, tetrahedron shape of elements will be used.

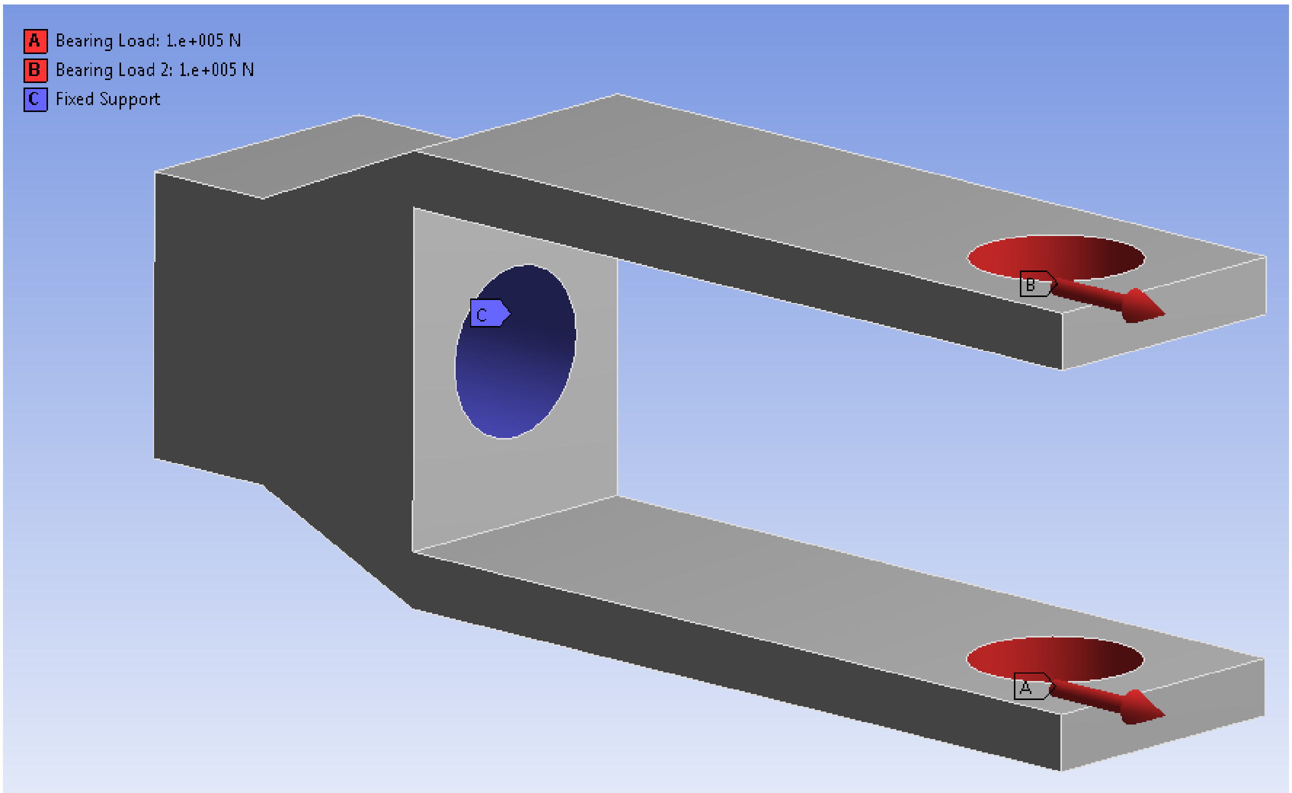
For the mesh, two refinements are added as below, where the first one (*Refinement*) is for the cylindrical surface of loading, and the second one (*Refinement 2*) is for the sharp edges of 90 degree where stress concentration might occur.



The overall mesh with a size of $2cm$ is shown below:

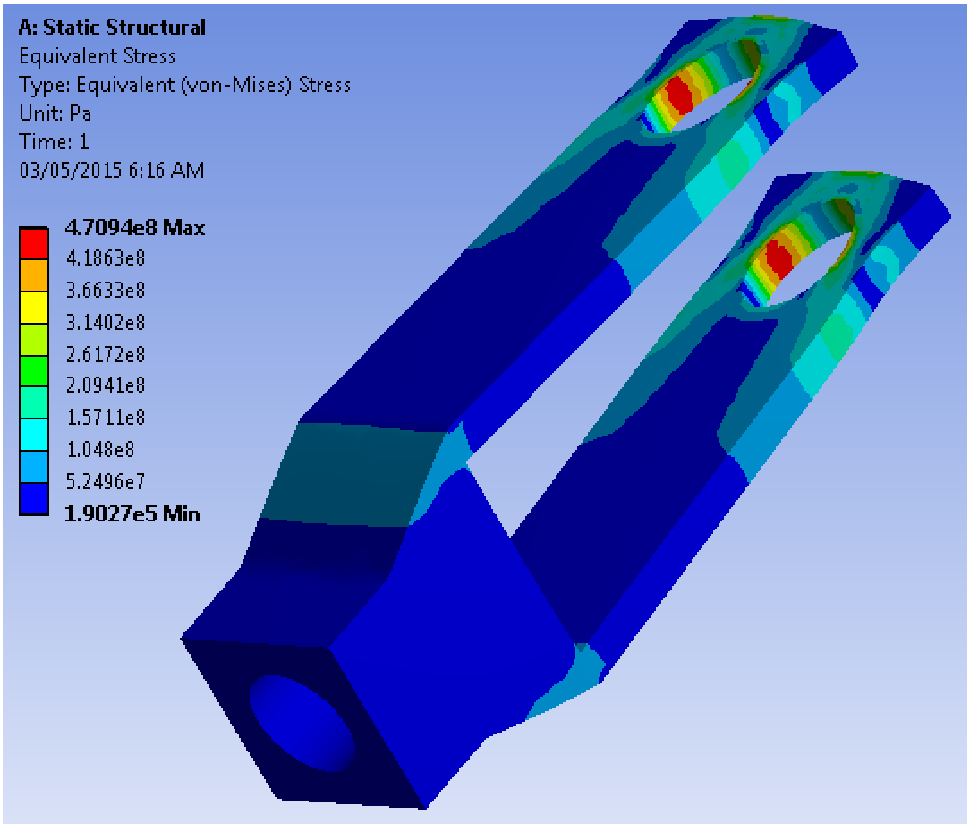


3.2 Boundary conditions setup

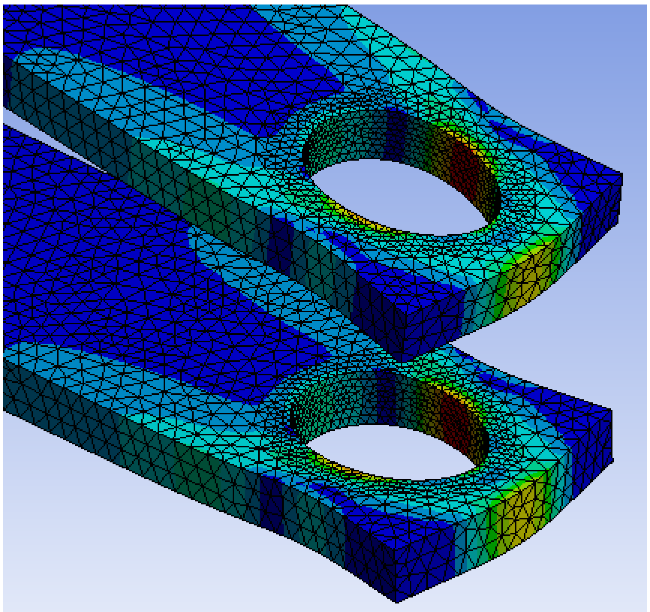


3.3 Results

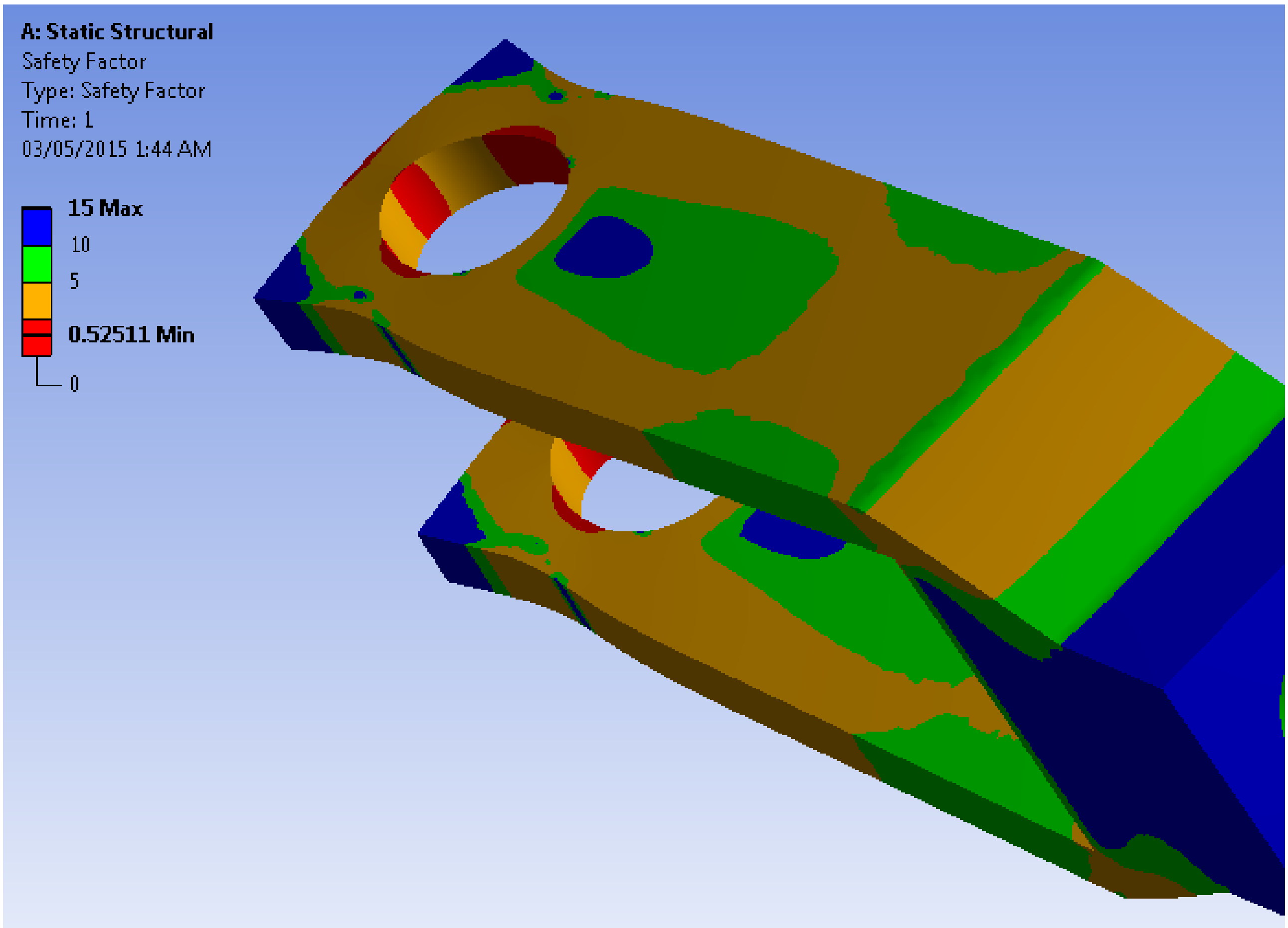
As uniform material is assumed, the local safety factor would be proportional to the local principle stress.

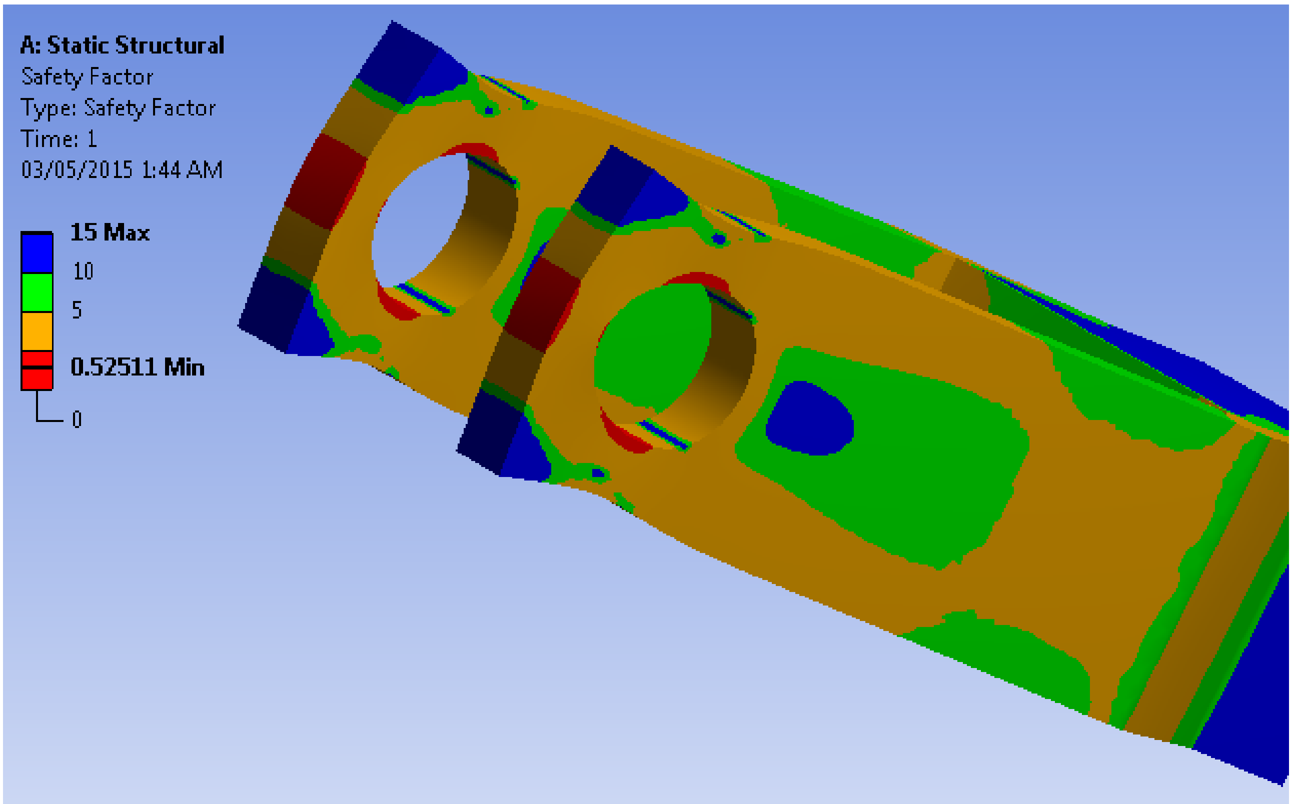


We can clear see that the maximum stress is at the four symmetric points: the side end of the wholes. They are exactly the points where failure is most possible to happen. An enlarged figure below shows it better:



The local safety factors are shown below:

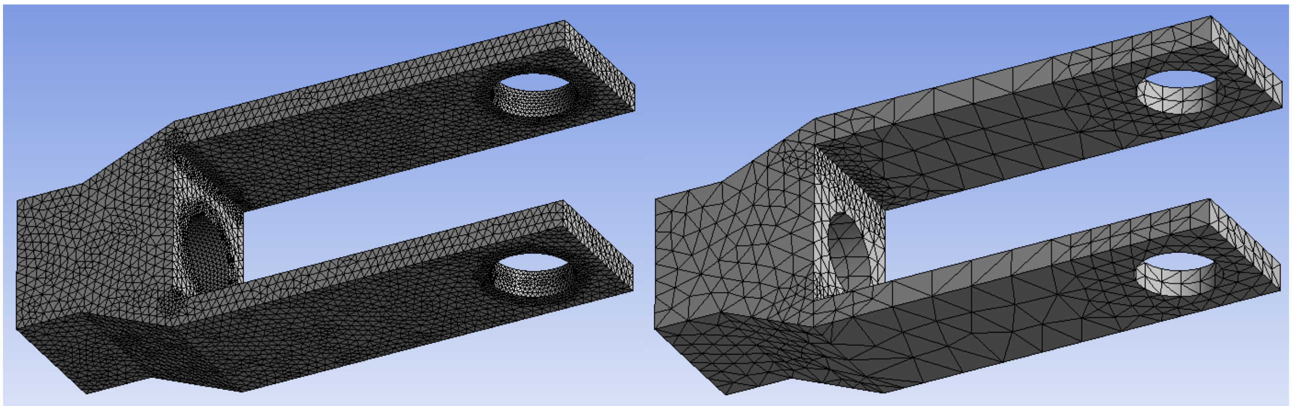




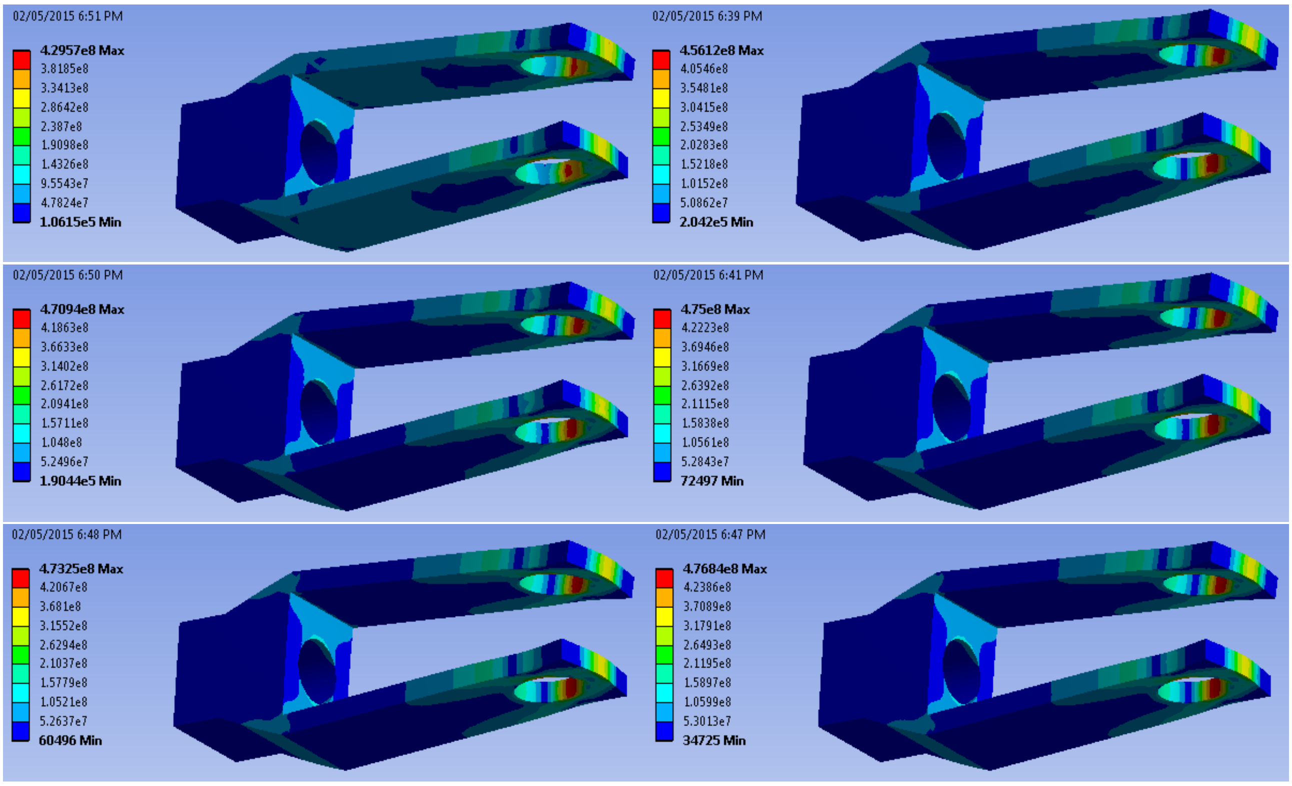
Clearly, as the minimum safety factor is around 0.5, the original design does not meet the requirements.

3.4 Convergence study

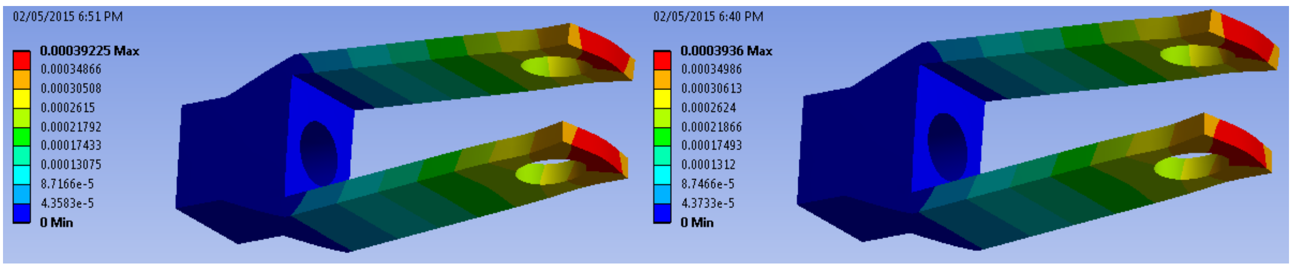
For convergence study, mesh sizes of $3cm$, $2cm$, $1.5cmm$ $1cm$, $0.8cm$ and $0.65cm$ are used. The mesh of minimum ($0.65cm$) and maximum ($3cm$) mesh size are shown below:

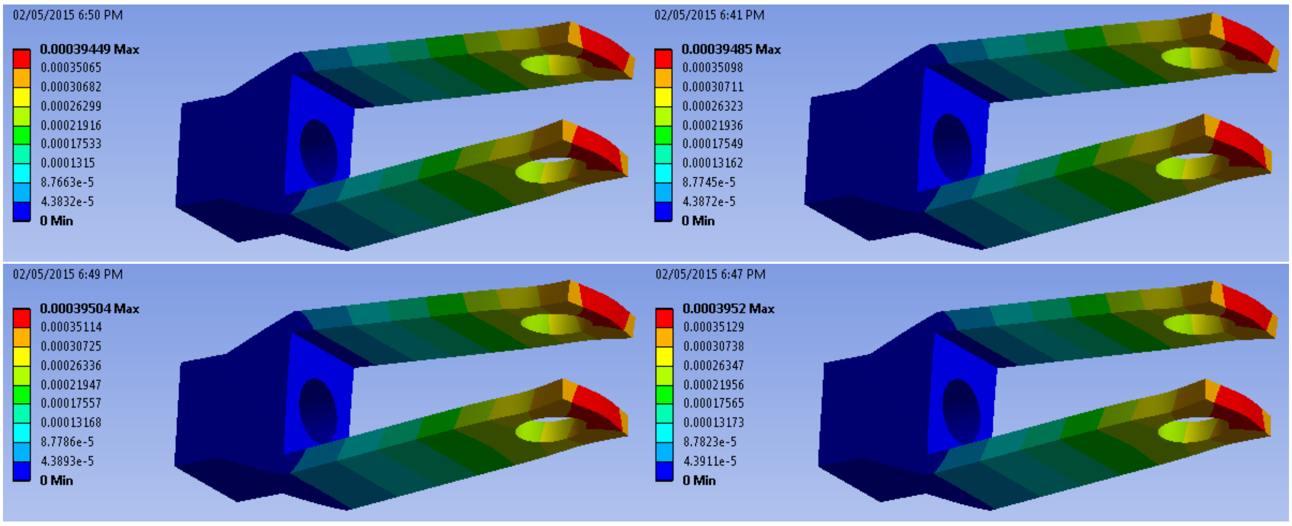


The results for principle stresses are below, listed in size-decreasing order.

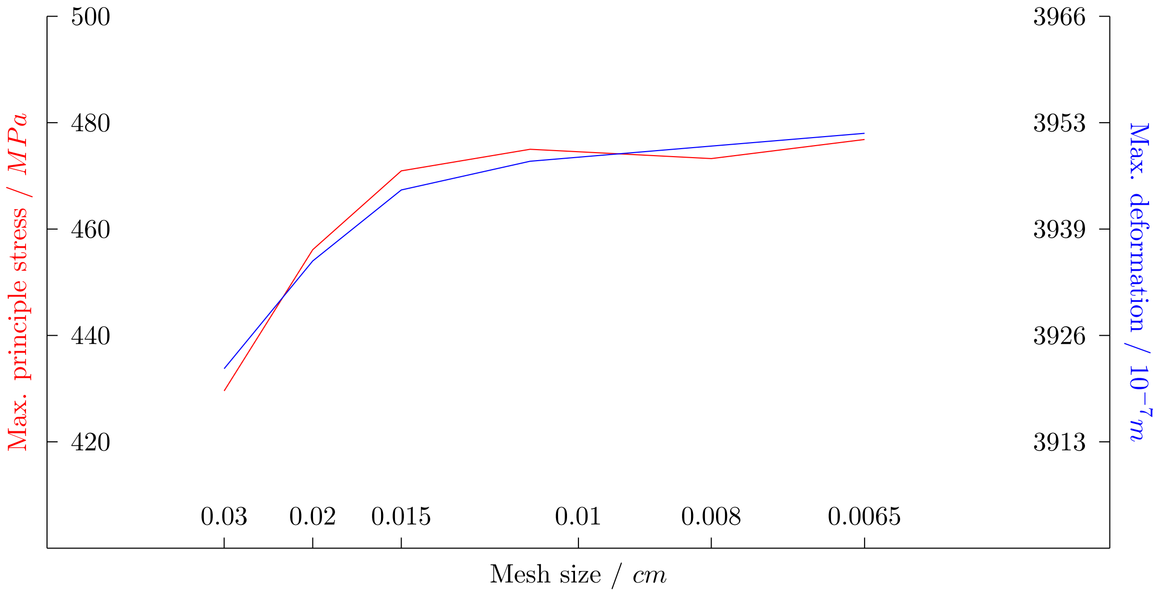


The results for deformations are below, listed in size-decreasing order.





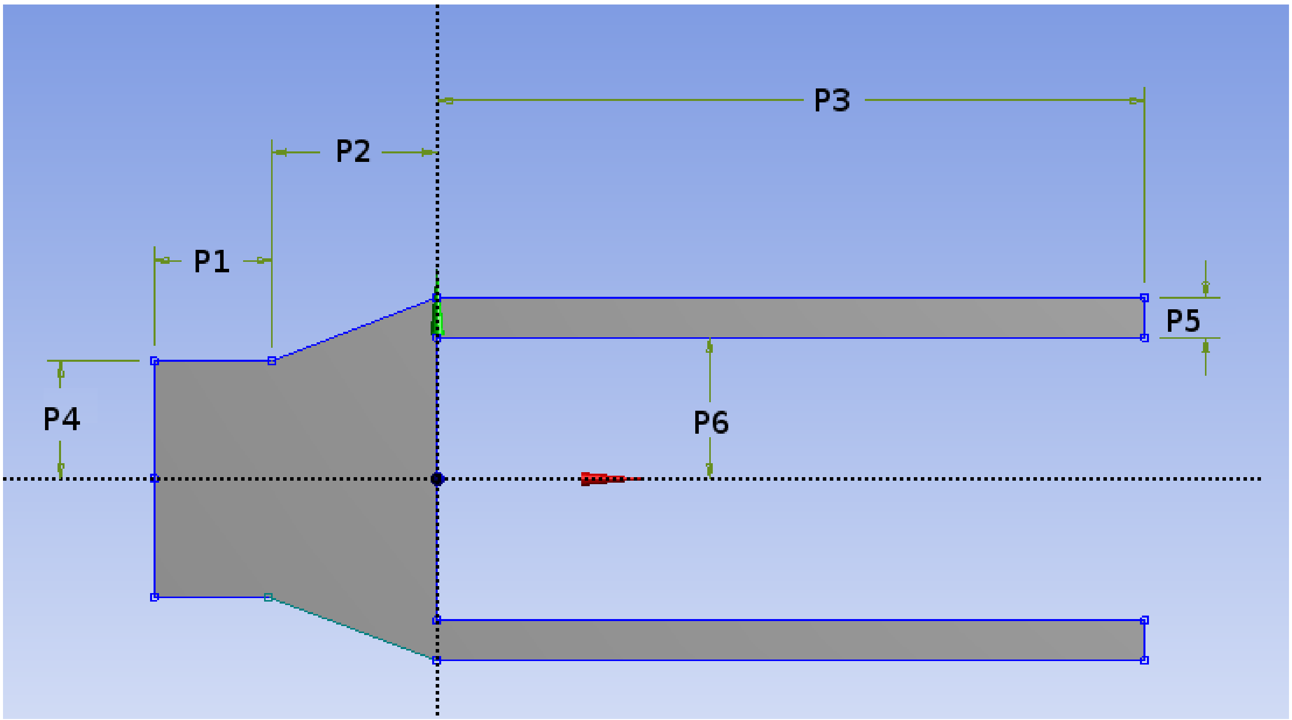
The change of both results with mesh sizes can be plotted below (x-axis in reciprocal scale):



We can see it converges. Therefore using a mesh size of $0.65cm$ in the following study will be reasonable.

4 Optimization

To make optimization easier, another set of parameters will be used (note that P6 is not used as the dimension is fixed):



$$P1 = H10$$
$$P2 = H11 - H10$$
$$P3 = H1 - H11$$
$$P4 = V6$$
$$P5 = V3$$
$$P7 = HEIGHT/2$$
$$P8 = D2$$

4.1 Manual optimization for individual parameters

4.1.1 Iteration 1

Change one parameter at a time, while keeping other parameters the same as original design:

P1 $= H10$

Table of Design Points

	A	B	C	D	E	F	G	H	I	J	K
1	Name	P1 - H10								P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	1.5	7	30	5	2	6	5	6	0.52684	14.985
4	DP 1	2	7	30	5	2	6	5	6	0.52749	15.266
5	DP 2	2.5	7	30	5	2	6	5	6	0.52487	15.548
6	DP 3	3	7	30	5	2	6	5	6	0.52703	15.829
7	DP 4	3.5	7	30	5	2	6	5	6	0.52715	16.111
8	DP 5	4	7	30	5	2	6	5	6	0.52639	16.392
9	DP 6	4.5	7	30	5	2	6	5	6	0.52718	16.674
10	DP 7	5	7	30	5	2	6	5	6	0.52502	16.955
11	DP 8	5.5	7	30	5	2	6	5	6	0.52565	17.237
12	DP 9	6	7	30	5	2	6	5	6	0.52617	17.518
13	DP 10	6.5	7	30	5	2	6	5	6	0.52718	17.8

It can be seen that $H10$ can be reduced to save weight without decreasing safety factor greatly.

P2 $= H11 - H10$

Table of Design Points

	A	B	C	D	E	F	G	H	I	J	K
1	Name		P2 - H11_MINUS_H10							P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	5	4	30	5	2	6	5	6	0.52542	14.913
4	DP 1	5	4.5	30	5	2	6	5	6	0.5281	15.253
5	DP 2	5	5	30	5	2	6	5	6	0.52711	15.594
6	DP 3	5	5.5	30	5	2	6	5	6	0.52604	15.934
7	DP 4	5	6	30	5	2	6	5	6	0.52718	16.275
8	DP 5	5	6.5	30	5	2	6	5	6	0.5263	16.615
9	DP 6	5	7	30	5	2	6	5	6	0.52573	16.955
10	DP 7	5	7.5	30	5	2	6	5	6	0.52623	17.296
11	DP 8	5	8	30	5	2	6	5	6	0.52653	17.636
12	DP 9	5	8.5	30	5	2	6	5	6	0.52607	17.977
13	DP 10	5	9	30	5	2	6	5	6	0.52626	18.317

It can be seen that $H11$ can be reduced to save weight without decreasing safety factor greatly. Combined with the previous entry, we can seen that $H11$ can be reduced without decreasing safety factor greatly.

P3 $= H1 - H11$

	A	B	C	D	E	F	G	H	I	J	K
1	Name			P3 - H1_MINUS_H_11						P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	5	7	28.5	5	2	6	5	6	0.23485	16.484
4	DP 1	5	7	29	5	2	6	5	6	0.41948	16.641
5	DP 2	5	7	29.5	5	2	6	5	6	0.46876	16.798
6	DP 3	5	7	30	5	2	6	5	6	0.52573	16.955
7	DP 4	5	7	30.5	5	2	6	5	6	0.58544	17.112
8	DP 5	5	7	31	5	2	6	5	6	0.63799	17.269
9	DP 6	5	7	31.5	5	2	6	5	6	0.67988	17.426
10	DP 7	5	7	32	5	2	6	5	6	0.71533	17.583
11	DP 8	5	7	32.5	5	2	6	5	6	0.73318	17.74
12	DP 9	5	7	33	5	2	6	5	6	0.75157	17.897
13	DP 10	5	7	33.5	5	2	6	5	6	0.76701	18.054

It can be seen that reducing $H1 - H11 - H9$, which is the part outer than the bearings, will reduce the safety factor greatly. That value should be increased instead.

P4 $= V6$

	A	B	C	D	E	F	G	H	I	J	K
1	Name				P4 - V6					P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	5	7	30	3.5	2	6	5	6	0.52796	14.963
4	DP 1	5	7	30	3.75	2	6	5	6	0.52699	15.295
5	DP 2	5	7	30	4	2	6	5	6	0.5274	15.627
6	DP 3	5	7	30	4.25	2	6	5	6	0.52665	15.959
7	DP 4	5	7	30	4.5	2	6	5	6	0.52713	16.291
8	DP 5	5	7	30	4.75	2	6	5	6	0.52621	16.623
9	DP 6	5	7	30	5	2	6	5	6	0.52573	16.955
10	DP 7	5	7	30	5.25	2	6	5	6	0.52717	17.287
11	DP 8	5	7	30	5.5	2	6	5	6	0.52592	17.62
12	DP 9	5	7	30	5.75	2	6	5	6	0.52592	17.952
13	DP 10	5	7	30	6	2	6	5	6	0.52729	18.284

It can be seen that $V6$ can be reduced to save weight, and safety factor will not be influenced.

P5 $= V3$

Table of Design Points											
	A	B	C	D	E	F	G	H	I	J	K
1	Name					P5 - V3				P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	5	7	30	5	1.7	6	5	6	0.44522	15.509
4	DP 1	5	7	30	5	1.85	6	5	6	0.48499	16.232
5	DP 2	5	7	30	5	2	6	5	6	0.52573	16.955
6	DP 3	5	7	30	5	2.15	6	5	6	0.56695	17.679
7	DP 4	5	7	30	5	2.3	6	5	6	0.60401	18.402
8	DP 5	5	7	30	5	2.45	6	5	6	0.64471	19.125
9	DP 6	5	7	30	5	2.6	6	5	6	0.68663	19.848
10	DP 7	5	7	30	5	2.75	6	5	6	0.72751	20.572
11	DP 8	5	7	30	5	2.9	6	5	6	0.76949	21.295
12	DP 9	5	7	30	5	3.05	6	5	6	0.81136	22.018
13	DP 10	5	7	30	5	3.2	6	5	6	0.85533	22.741

It can be seen that increasing $V3$ can increase the safety factor greatly.

P7 $= HEIGHT/2$

Table of Design Points											
	A	B	C	D	E	F	G	H	I	J	K
1	Name							P7 - HALF_HEIGHT		P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	5	7	30	5	2	6	3.5	6	0.21677	10.803
4	DP 1	5	7	30	5	2	6	3.8	6	0.30414	12.034
5	DP 2	5	7	30	5	2	6	4.1	6	0.37432	13.264
6	DP 3	5	7	30	5	2	6	4.4	6	0.43051	14.495
7	DP 4	5	7	30	5	2	6	4.7	6	0.47958	15.725
8	DP 5	5	7	30	5	2	6	5	6	0.52502	16.955
9	DP 6	5	7	30	5	2	6	5.3	6	0.56828	18.186
10	DP 7	5	7	30	5	2	6	5.6	6	0.61022	19.416
11	DP 8	5	7	30	5	2	6	5.9	6	0.64732	20.647
12	DP 9	5	7	30	5	2	6	6.2	6	0.68422	21.877
13	DP 10	5	7	30	5	2	6	6.5	6	0.71556	23.107

It can be seen that increasing the height will increase safety factor greatly. However, the weight will also be increased greatly.

P8 $= D2$

Table of Design Points

	A	B	C	D	E	F	G	H	I	J	K
1	Name								P8 - D2	P9 - Safety Factor Minimum	P10 - Solid Mass
2	Units										kg
3	Current	5	7	30	5	2	6	5	4.5	0.68234	17.344
4	DP 1	5	7	30	5	2	6	5	4.8	0.65681	17.275
5	DP 2	5	7	30	5	2	6	5	5.1	0.63515	17.202
6	DP 3	5	7	30	5	2	6	5	5.4	0.60119	17.124
7	DP 4	5	7	30	5	2	6	5	5.7	0.56603	17.042
8	DP 5	5	7	30	5	2	6	5	6	0.52573	16.955
9	DP 6	5	7	30	5	2	6	5	6.3	0.48234	16.864
10	DP 7	5	7	30	5	2	6	5	6.6	0.44086	16.769
11	DP 8	5	7	30	5	2	6	5	6.9	0.39447	16.669
12	DP 9	5	7	30	5	2	6	5	7.2	0.34768	16.565
13	DP 10	5	7	30	5	2	6	5	7.5	0.30253	16.456

It can be seen that reducing $D2$ will increase the safety factor, and reduce the weight slightly. However, as reducing $D2$ will decrease the safety of the bolt significantly, it's preferred that $D2$ is kept at $6cm$ and not changed.

4.1.2 Iteration 2

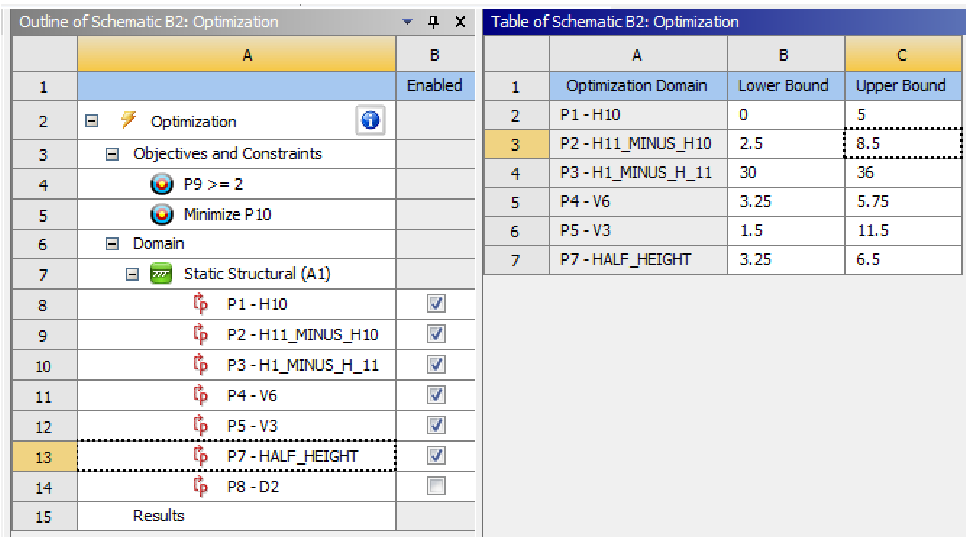
As P5($V3$) is the most important factor, this time we only change P5.

According to the result of iteration 1, the following values will be used for other parameters:

$$P1 = 1.5$$
$$P2 = 4$$
$$P3 = 33.5$$
$$P4 = 3.5$$
$$P7 = 4.7$$
$$P8 = 6$$

4.2 Automatic optimization

The following settings will be used:



Outline of Schematic B2: Optimization

	A	B
1		Enabled
2	Optimization	
3	Objectives and Constraints	
4	P9 >= 2	
5	Minimize P10	
6	Domain	
7	Static Structural (A1)	
8	P1 - H10	☑
9	P2 - H11_MINUS_H10	☑
10	P3 - H1_MINUS_H_11	☑
11	P4 - V6	☑
12	P5 - V3	☑
13	P7 - HALF_HEIGHT	☑
14	P8 - D2	☐
15	Results	

Table of Schematic B2: Optimization

	A	B	C
1	Optimization Domain	Lower Bound	Upper Bound
2	P1 - H10	0	5
3	P2 - H11_MINUS_H10	2.5	8.5
4	P3 - H1_MINUS_H_11	30	36
5	P4 - V6	3.25	5.75
6	P5 - V3	1.5	11.5
7	P7 - HALF_HEIGHT	3.25	6.5

5 Conclusion

In this design project, the dimension of an anchor is optimized using ANSYS finite element analysis tool.