Name : Yip Winn Sheng Alwyn
Student ID : 0326644
Semester : 4 (ME)

1.0 Introduction

In this assignment , a structure was required to be studied, designed and subsequently analysed by using both Solidworks for designing and ANSYS to analysis. The structure that I have chosen was a fixed ladder. Generally , a fixed ladder is a vertical ladder which is mounted onto the wall to gain access to the roof or other structure for industrial purposes. The ladder mainly consist of a few rungs of steps , a side member and a stand off bracket which acts as a fixed support to the wall. Fixed ladder are normally built out of steel or aluminium but can also be made out of reinforced polymers.

Figure 1 Fixed Ladder

Based on the properties of materials in **Table 1 ,** the fixed ladder was constructed in Solidworks and subsequently analysed in ANSYS. The interaction between the infinite element in the modal can be analysed by obtaining the maximum equivalent stress, average skewness and the safety factor. An appropriate type of mesh was generated based on the average skewness obtained. Subsequently, boundary condition was applied at suitable location in order to obtain a good quality mesh. In order to obtain an even better quality mesh, refinement will be done to further improve the mesh. In the finally stage of the report, an optimization will be done on the original design to obtain similar maximum equivalent stress with significant reduction in weight.

1.1 Solid Modelling

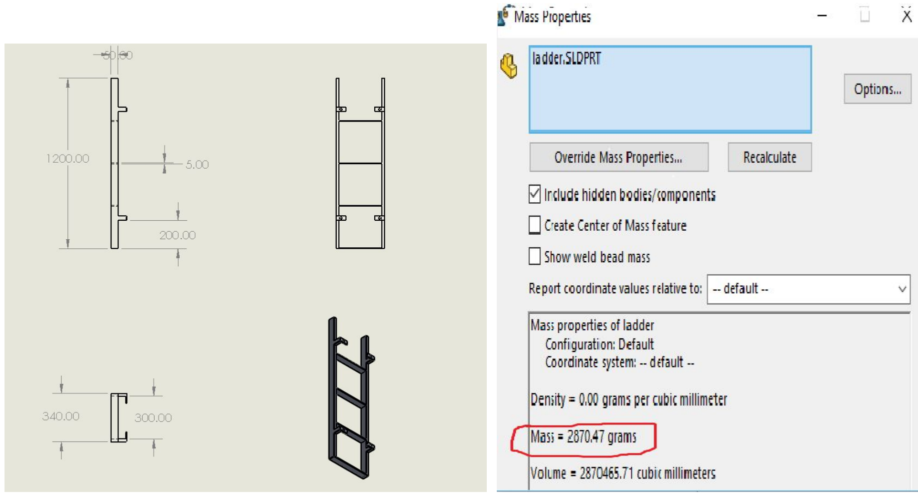


Figure 2 Engineering Drawing and mass properties of Ladder

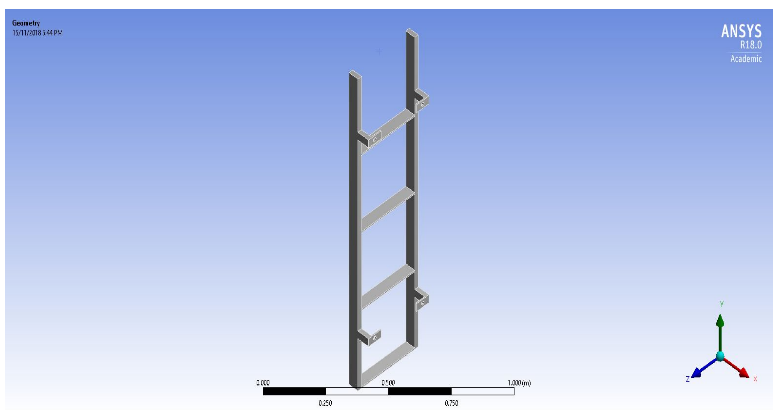


Figure 3 Geometry of Ladder

Table 1 Properties of Material

Material	Height(mm)	Width(mm)	Yield Tensile Strength(Mpa)	Ultimate Tensile Strength(MPa)	Poisson Ratio
Structural Steel	1200	340	250	460	0.3

Based on Table 1, structural steel was selected as the material to analyse in ANSYS. Structural steel is commonly used for making construction structures in a variety of shapes. It is made out of iron and a high percentage of carbon which produces high strength and low ductility material. This is suitable to be used to build a ladder as it can withstand a great amount of load. The fixed ladder was constructed based on real life requirements which states that if a ladder is higher than 20 feet, a cage will be required around the ladder. In this case, the ladder is hovering over 1.2m tall and 0.34m wide with a thickness of 0.05m. This allowed most people to have a better foot grip on the rungs of the ladder. Besides, there's four bracket which is connected to the side member that will be mounted onto the wall.

2.0 Mesh Element & Method

2.1 Construct

The mesh selected for the fixed ladder was tetrahedron. Tetrahedron was chosen as it is capable of creating a mesh regardless of any shape and sizes. Besides, tetrahedron is the sole elements that can be used with adaptive mesh refinement. In addition, tetrahedron is able to generate more number of elements which will further improve the quality of the mesh. By considering the fixed ladder itself, it has a symmetrical body which allows the mesh to be created equally. Tetrahedron is able to have very small elements in the trace which is suitable for the rungs of the ladder as it is only 0.05m thick.

As for hex dominant , the mesh could not be created. This may be due to the topological constraints of the hex dominant mesh. Some examples of topological constraints are such as each internal 2 cell is contained in exactly two distinct 3 cells.While each face contains at least one lower dimensional face. When any of those conditions are not fulfilled , the result will be either a generacy or void regions in the resulting hex dominant mesh.

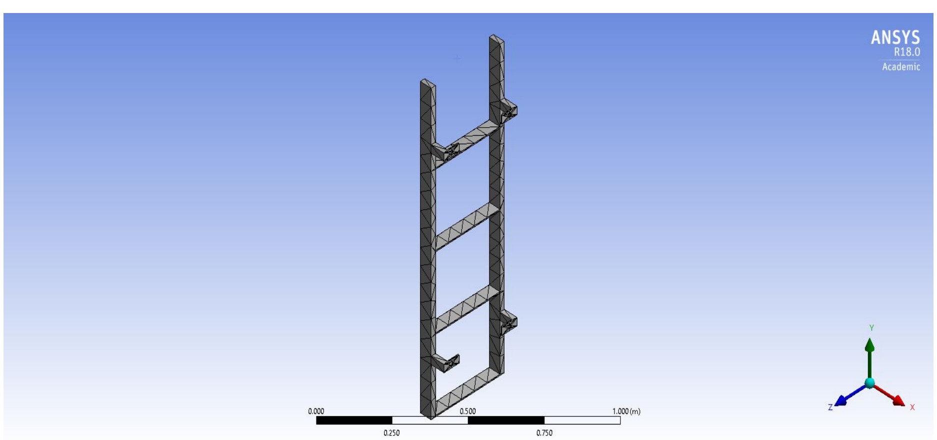


Figure 4 Tetrahedron Mesh

Table 2 Quality of Tetrahedron Mesh before refinement

Element Size(m)	**Elements**	**Average Skewness**	**Maximum Equivalent stress(MPa)**	**Factor of Safety**
0.1	484	0.85708	26.238	9.5281
0.07	**595**	**0.80014**	**44.865**	**5.5723**
0.06	608	0.75889	44.960	5.5605
0.05	772	0.73916	47.655	5.246
0.04	1287	0.61657	53.778	4.6487

Based on **Table 2,** the element size which begins a stagnant maximum equivalent stress was 0.07m. At this point, the average skewness falls slightly out of the good range. As the element size was decreased even further, the maximum equivalent stress only increased slightly which proves that the quality of mesh is good.

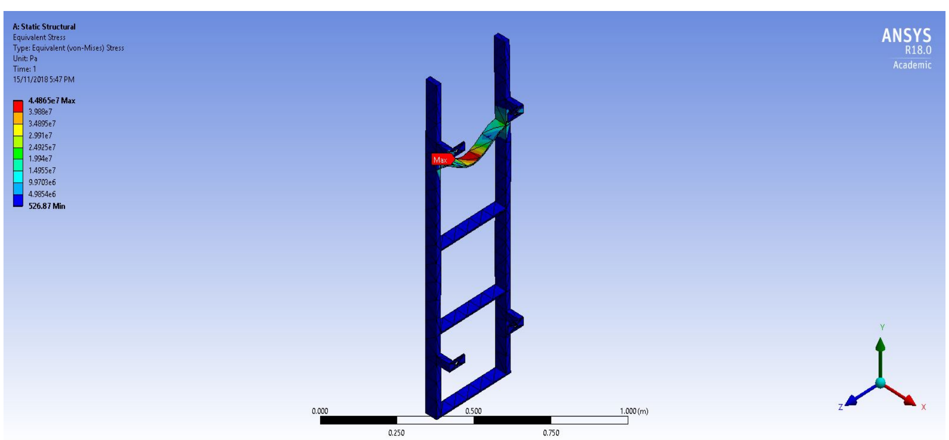
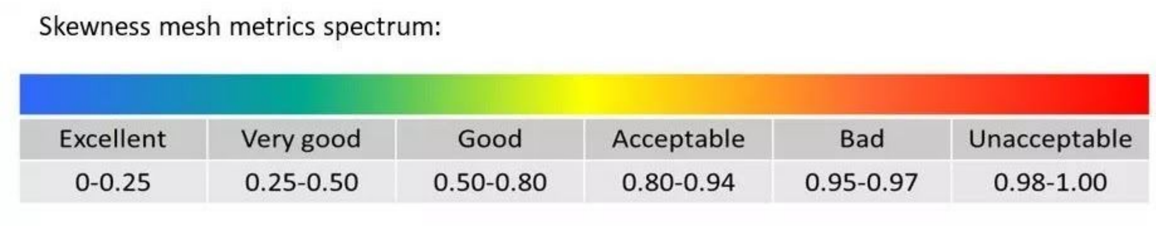


Figure 5 Maximum Equivalent stress at element size of 0.07m

2.2 Assess



Skewness mesh metrics spectrum:

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Figure 6 Skewness Mesh Metrics Spectrum

After selecting the type of mesh, there are a few elements that can be obtained such as the number of elements, average skewness , maximum equivalent stress and minimum safety factor. Subsequently, the element size can be manipulated under the sizing method.

For the fixed ladder, only tetrahedrons method can be meshed on this modal. The difference in element sizing and number of elements brings about a different quality of skewness and maximum equivalent stress. From **table 2,** the best quality of skewness is when the element size is at 0.04m. This brings an average skewness of 0.61657 which falls under the good category.

As for the safety factor, fixed ladder requires a minimum safety factor of 4. From the tabulated results, all element sizes from 0.04m and above possess a safety factor of more than 4 which makes it very safe to use. At the same time, the model does not break as the yield stress of the material is able to support the maximum equivalent stress that is acted upon it.

2.3 Justify

The graph of maximum equivalent stress against number of the elements was plotted based on the tabulated date as shown in **Table 2**. From the graph, it was found that a smaller element size provide a closer value of maximum equivalent stress to the yield stress. At the element size of 0.07m , the graph starts to show a stagnant pattern and a constant was reached. From that point, the element size was refined three times to further analysed and obtain an accurate maximum equivalent stress as shown in **Figure 5.**

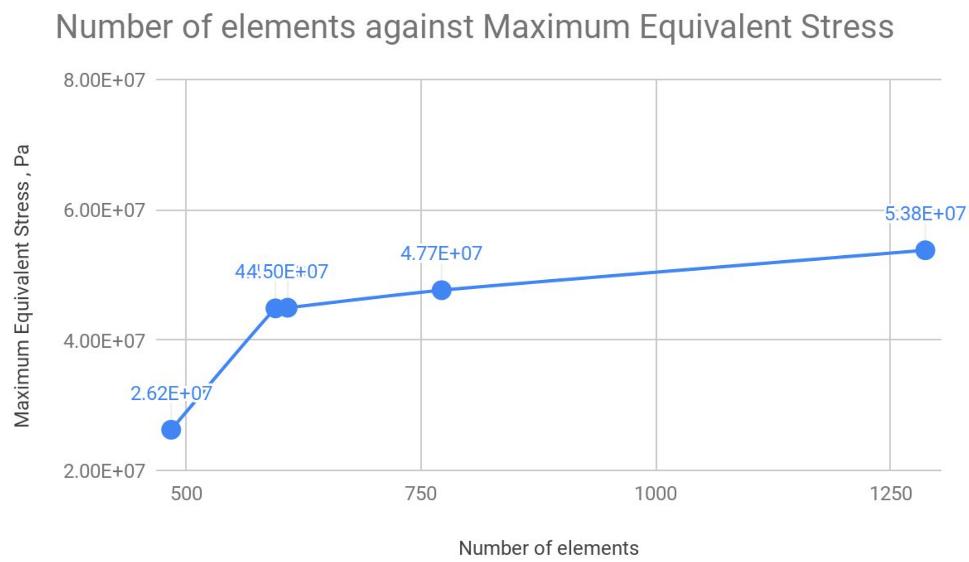


Figure 6 Graph of Tetrahedron Mesh

2.2 Improve

Mesh type : Tetrahedrons

Table 3 Quality of Refined Tetrahedrons Mesh

Element Size(m)	Elements	Average Skewness	Maximum Equivalent stress(MPa)	Refinement
0.07	595	0.80014	44.865	original
0.07	1026	0.79211	82.487	1
0.07	2072	0.74698	82.689	2
0.07	3906	0.68221	83.485	3

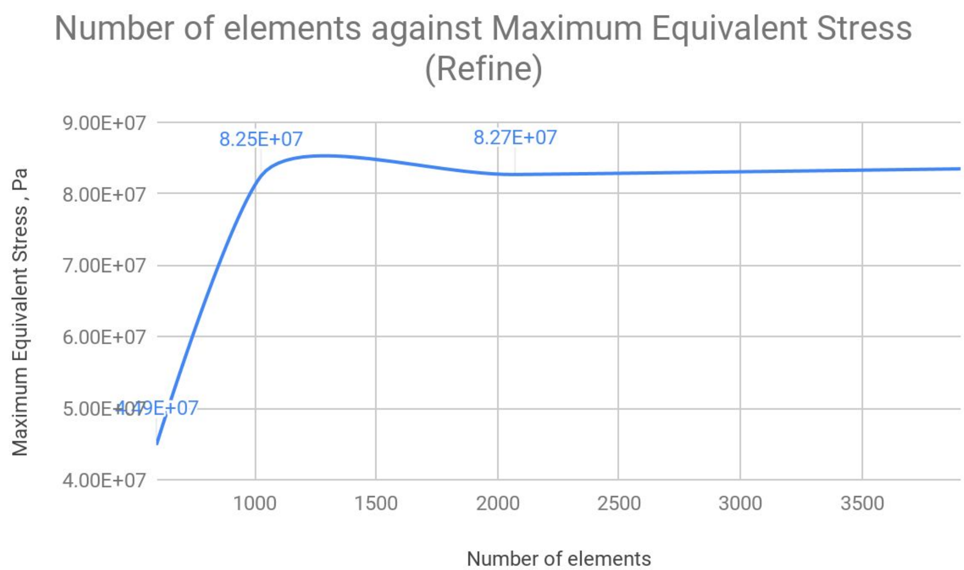


Figure 7 Graph of refined Tetrahedron Mesh

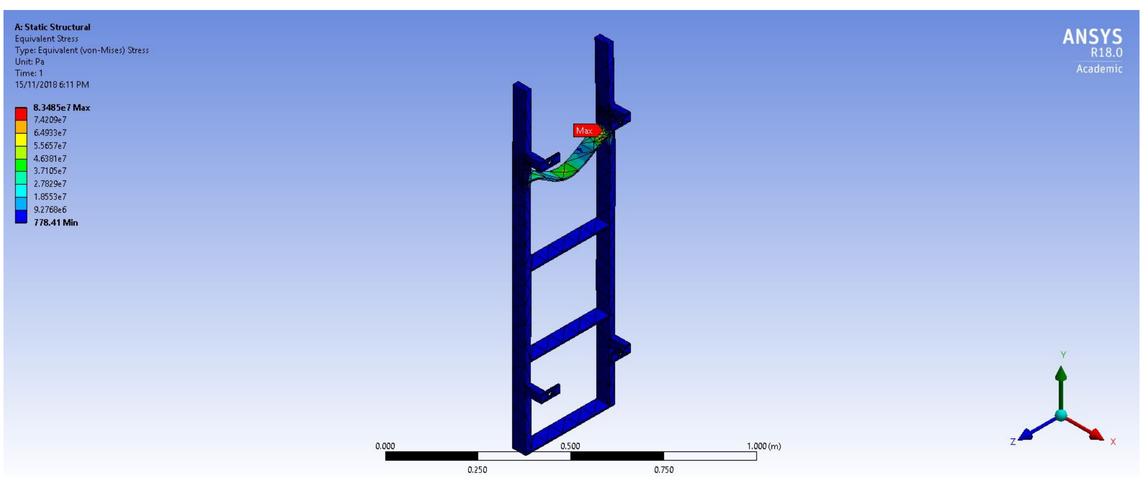


Figure 8 Refinement at element size 0.07m

From **table 3**, the element size of 0.07m was refined a total of three times to obtain the maximum equivalent stress. The graph was then plotted based on the tabulated results as shown in Figure 7. The graph shows that after the first refinement, the maximum equivalent stress increased significantly . After the first refinement, the maximum equivalent stress reached a stagnant pattern as the number of elements could not be further refined. At the same time, the average skewness also decrease after every refinement which improves the quality of the mesh.

3.0 BOUNDARY/ INITIAL CONDITIONS

3.1 Generate

3.2 Develop

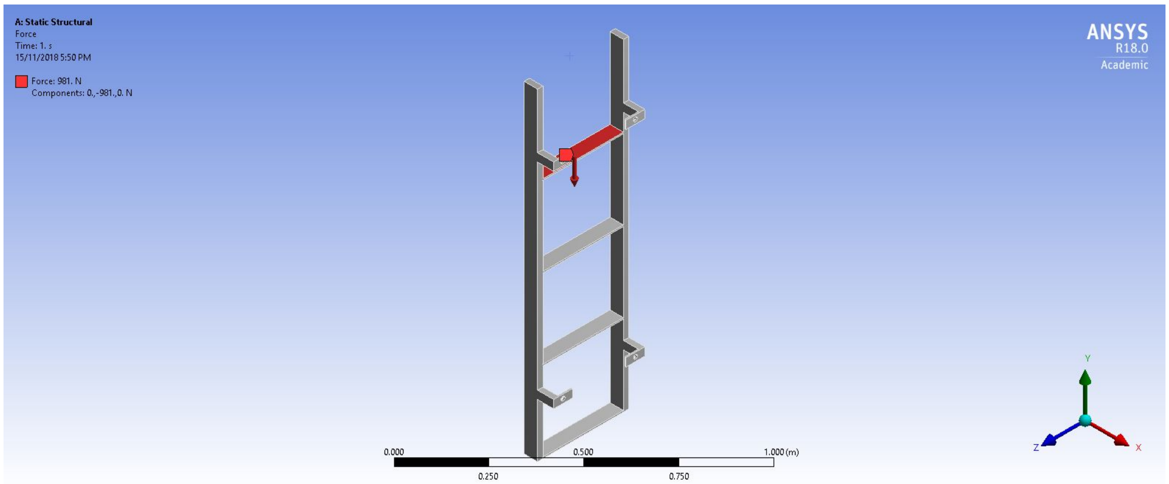


Figure 9 Force applied on the ladder

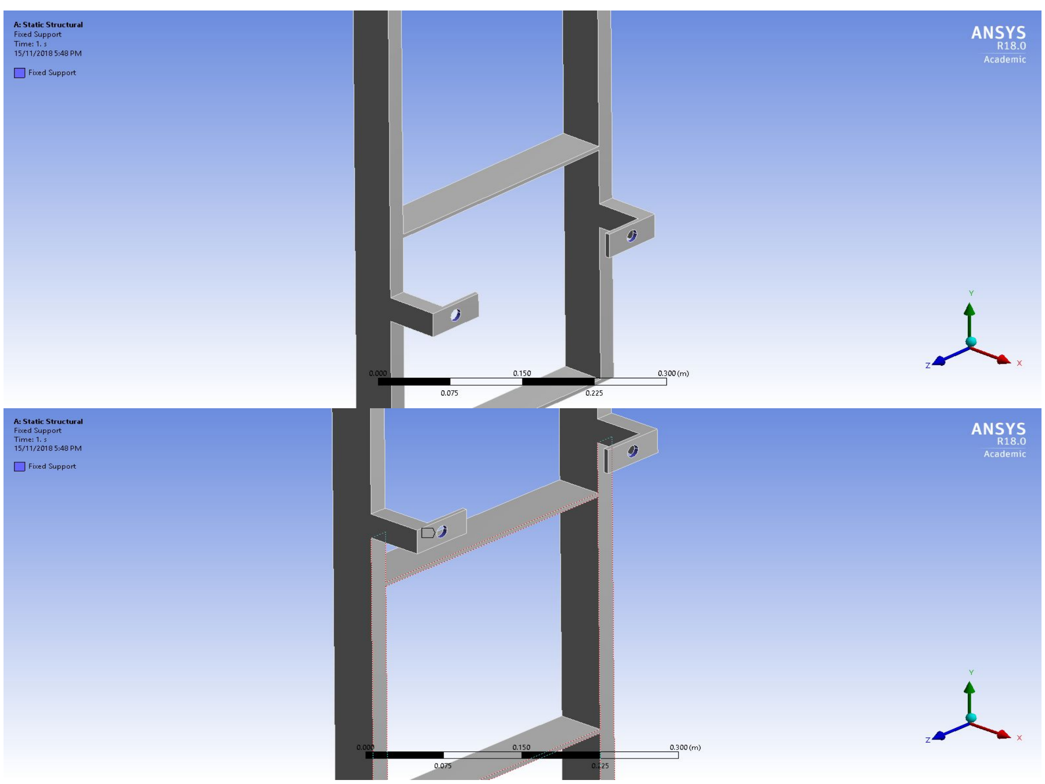


Figure 10 Fixed Supports

A load of 100kg was acted on the y-axis component of the rung of the steps. This condition states that the ladder is able to sustain a maximum mass of 100kg. The gravitational force of $9.81\mathrm{m}/s^2$ must be taken into consideration as this would produce a force of 981N downwards on the rungs. A study will be done to investigate which rung will produce a greater maximum equivalent stress when the same amount of force is exerted on.

The fixed support was fixed at eight faces of the screw holes as shown in **Figure 10** . This faces was chosen as it will be mounted onto the wall which we assume that the ladder does not move in any of the global coordinates direction and undergo any form of deformation.

1.0 Simulation Results and Discussion
1.1 Compile
1.2 Interpretation

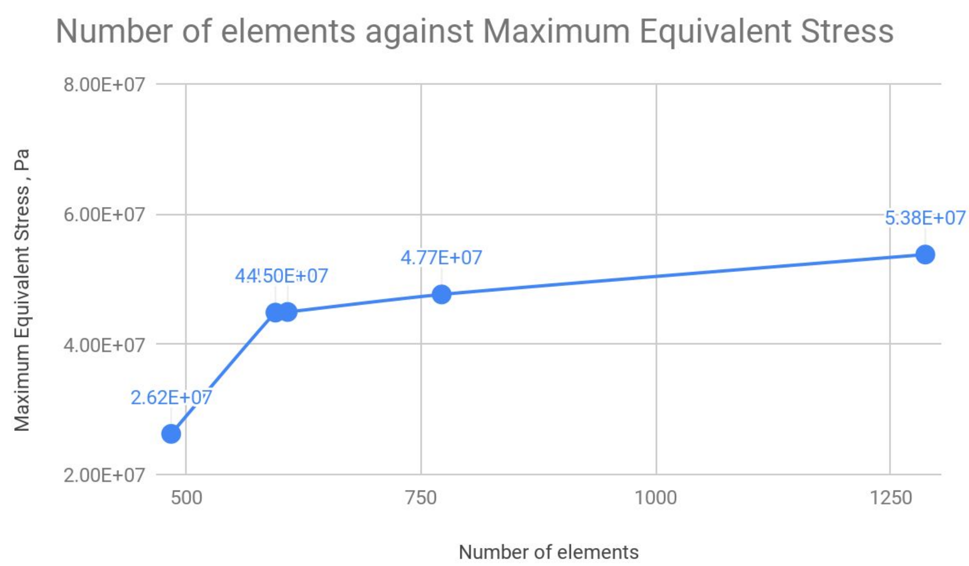
The mesh selected initially in the construction phase was tetrahedron. After finalising the mesh, a few important data can be obtained such as the maximum equivalent stress, average skewness and minimum safety factor. All of these values can be manipulated by adjusting the appropriate element size under the sizing method. The difference in element sizing and number of elements will produce a different quality of skewness.

Table 1 Quality of Tetrahedron Mesh

Element Size(m)	Elements	Average Skewness	Maximum Equivalent stress(MPa)	Factor of Safety
0.1	484	0.85708	26.238	9.5281
0.07	**595**	**0.80014**	**44.865**	**5.5723**
0.06	608	0.75889	44.960	5.5605
0.05	772	0.73916	47.655	5.246
0.04	1287	0.61657	53.778	4.6487

Figure 1 Skewness Mesh Metrics Spectrum

After obtaining the graph of maximum equivalent stress against number of elements as shown in **Graph 1**,it was found that a smaller element size provides a closer value of maximum equivalent stress to the yield stress. The point which begins to show a constant value is at 0.07m. As the element size is decreased even further from 0.07m, it is found that the average skewness shows an improvement in quality of the mesh. All the average skewness below the element size of 0.07m falls in the category of 'good' from the skewness mesh metrics spectrum. As the element size decreases below 0.07m , the maximum equivalent stress shows constant increase from the graph. Hence , the element size of 0.07m was chosen as the optimum point to be further assessed.



Graph 1 Tetrahedron Mesh

1.3 Evaluation

1.4 Justification

Table 2 Quality of Fixed letter at 0.07m sizing

Element size (m)	0.07
Element	595
Skewness	0.80014
Maximum Equivalent Stress(MPa)	44.865
Safety factor	5.5723

Based on the **Table 2**, the element size of 0.07 is able to produce an average skewness of 0.80014 which falls out of the ‘good’ range in the skewness mesh metrics spectrum. This may be due to the meshing feature in ANSYS. The mesh obtained is by dividing the whole component into number of elements when a load is applied onto the component . In this case, the skewness obtained is slightly high as the fixed ladder is symmetrical. Hence, the size of divided element is equal in size and is unable to generate a smaller element size.This results in a lower number of elements which is only 595.

At the same time, the system gets heavy and is unable to produce a fine mesh due to the size of the model. On the other hand, the maximum equivalent stress obtained is 44.865MPa. This is very much lower than the yield tensile strength of Structural Steel which is 250MPa. Structural steel was selected as the material as it is commonly used in making construction structures due to the ability to design it in a variety of shapes. Besides, it has high strength, stiffness , toughness and ductile properties which is suitable for the fixed ladder as it is generally exposed to the outdoor.

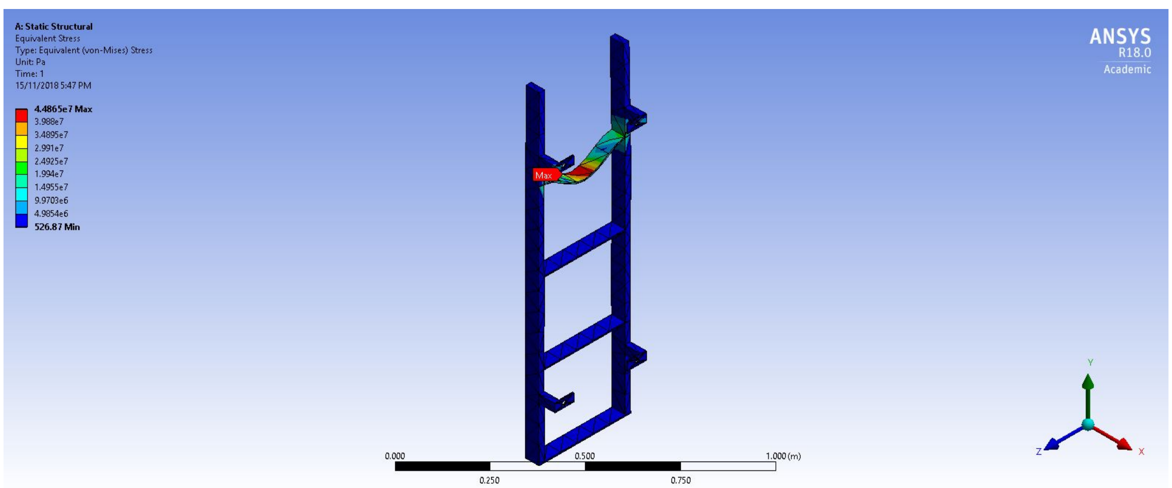


Figure 2 Maximum Equivalent Stress for 0.07m

From the safety and health regulations for construction , it is stated that a fixed ladder should have a minimum safety factor of more than 4.The safety factor obtained for the element size of 0.07 is 5.5723 which satisfy the minimum requirement of the fixed ladder. The safety factor is obtained by dividing the yield stress of structural steel over the maximum equivalent stress obtained. The width of the fixed ladder is 34cm which satisfy the safety requirement of the fixed ladder which states that the minimum clear distance between the side rails for fixed ladder should be at least 29cm. Besides , the maximum load applied set is at 98.1kg . However , the fixed ladder is more than capable to support a higher load due to the huge difference in maximum stress when compared to the yield stress. This satisfy the minimum load of at least 114 kg on each steps of the fixed ladder.

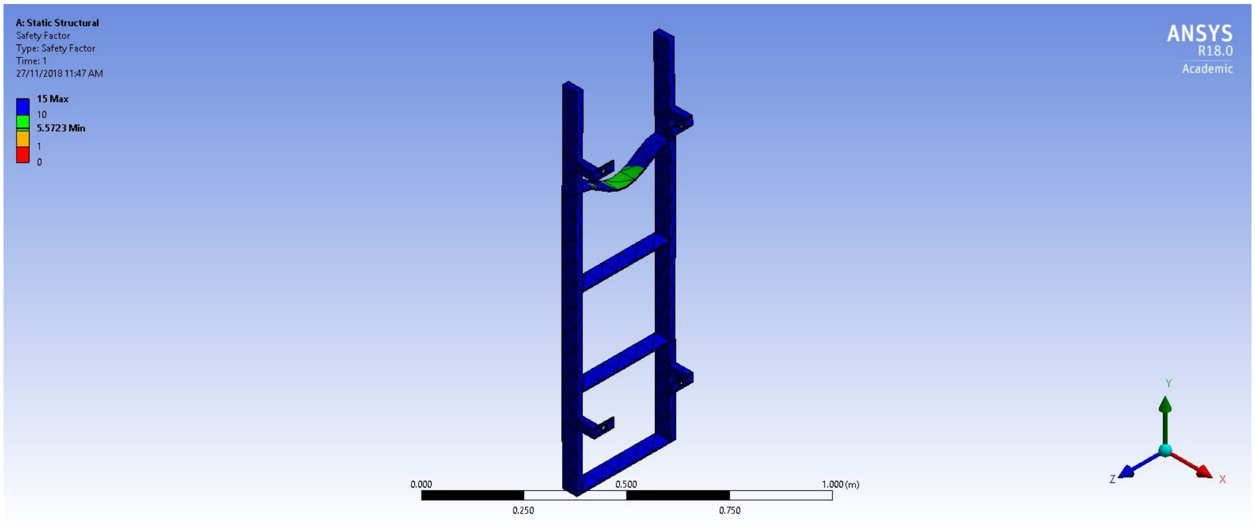


Figure 2 Safety factor at 0.07m

2.0 Modification & Improvement

2.1 Tell

After assessing and evaluating the fixed ladder, it was found that the maximum equivalent stress is concentrated on the steps of the ladder when a person is climbing the ladder. This is because the two side members is strong enough to support the overall weight applied onto the ladder. Besides, structural steel is used as the material to build the fixed ladder because it has high strength, stiffness and ductile properties. It can also be designed into any shape which includes it being welded or bolted in construction. This enables the design to have a strong foundation which causes the maximum stress to be concentrated on the steps as shown in Figure 1 which is the part that can be further modified. Two modifications was done on the overall dimensions and steps of the fixed ladder while maintaining a minimum safety factor of the fixed ladder to be greater than 4.

2.2 Recommendation

After identifying the shortcomings of the proposed design, there are a few recommendation that can be done to further improve the fixed ladder. Firstly, the steps of the ladder can be separated by adding a gap which will distribute the applied load between two surfaces. At the same time , stress can be reduced when the surface area of contact increases. Secondly, the side member can be made hollow instead of a solid piece of steel. This allow the fixed ladder to reduce in material to accommodate for other parts of the ladder which holds a higher stress. At the same time, the thickness of the steps can also be increased. This will enable the ladder to withstand a higher load limit.

2.3 Improvement

Table Quality of Tetrahedron Mesh

Element Size(m)	Element	Skewness	Maximum Equivalent Stress(MPa)	Safety Factor	Design
0.07	595	0.80014	44.865	5.5723	Original
0.07	797	0.83300	35.606	7.0212	1st Modification
0.07	1516	0.86140	32.889	7.6013	2nd Modification

The first modification focuses primarily on the steps of the fixed ladder. All the steps of the fixed ladder has a small gap . This modification was done to replace the solid steps as by adding a gap , the stress applied on the steps can be shared equally. At the same time, the surface area of the contact with load is increased which will reduce the maximum equivalent stress. This results in a 18.7% decrease in maximum equivalent stress. Although, the maximum equivalent stress is very small when compared to the yield tensile strength which is 250MPa , in real life this design is practical as it is able to decrease the maximum stress when the same load is applied on the same contact surface. This modification also recorded an increased in safety factor which further satisfy the minimum requirement of safety factor at 4. The increase in safety factor is due to the decrease in maximum equivalent stress. Although the skewness increased by a small margin, it is still considered as ‘acceptable’ under the skewness mesh matrix spectrum.

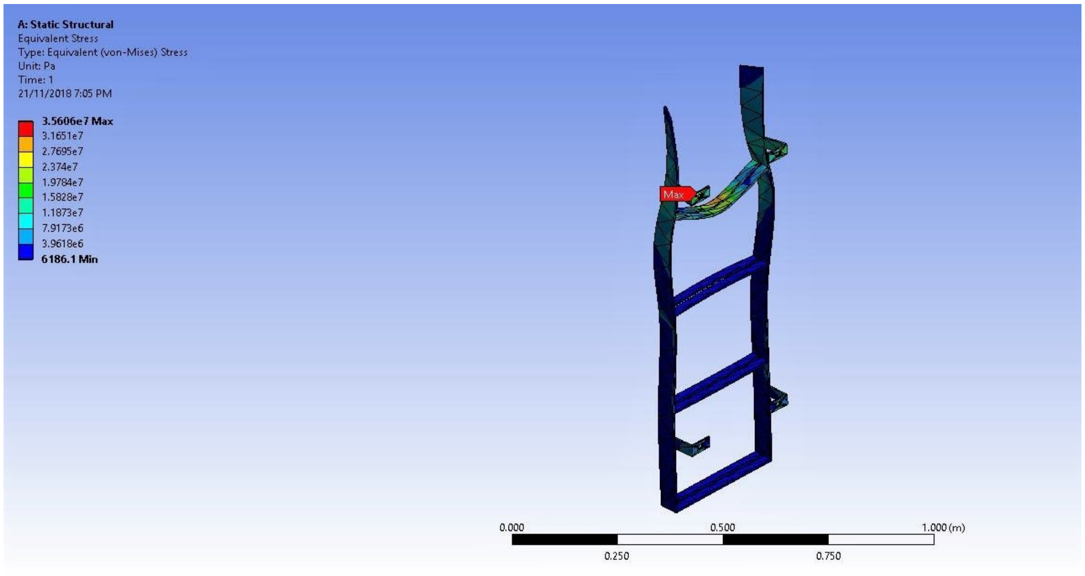


Figure 3 Maximum Equivalent Stress of Modification 1

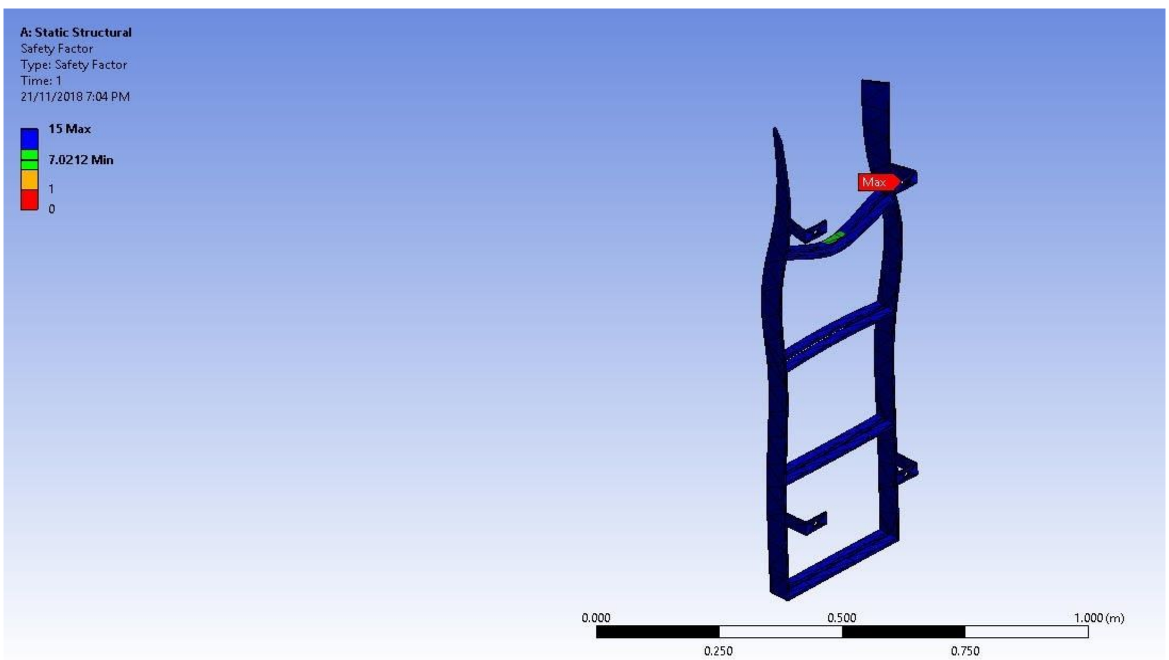


Figure 4 Safety Factor of Modification 1

The second modification focuses on the side member and also the steps of the fixed ladder. The steps has also been separated by a gap in order to increase surface area of contact which will subsequently reduce the maximum equivalent stress. At the same time, the side member has also been made hollow instead of a solid bar. Both this modification has resulted in a 26.69% decrease in maximum equivalent stress compared to the original design. This design is capable of supporting the same amount of load with the lowest maximum equivalent stress. In addition , the safety factor is also significantly higher than the original safety factor which also satisfy the minimum safety factor of 4. The skewness of this modification only increased marginally from the original and still falls in the ‘acceptable’ category in the skewness mesh matrix spectrum.

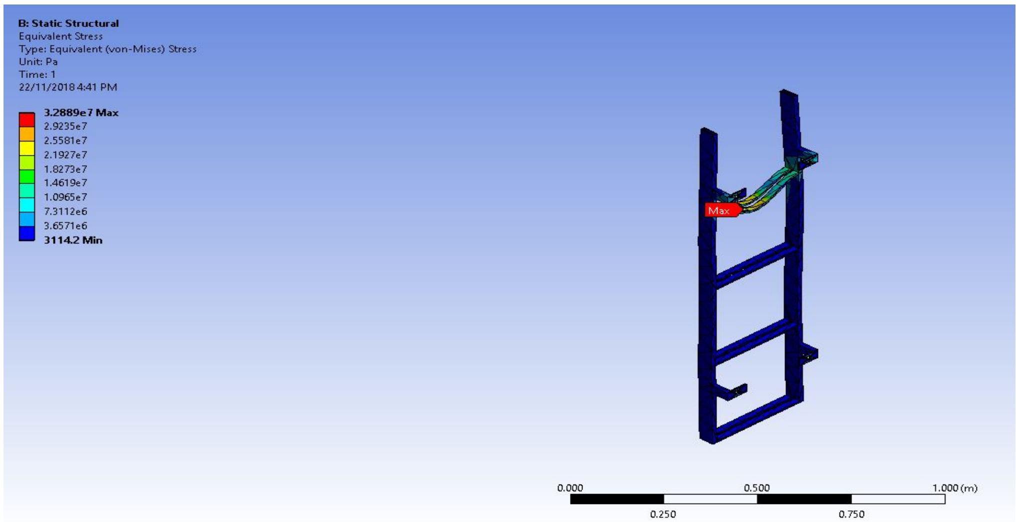


Figure 5 Maximum Equivalent Stress of Modification 2

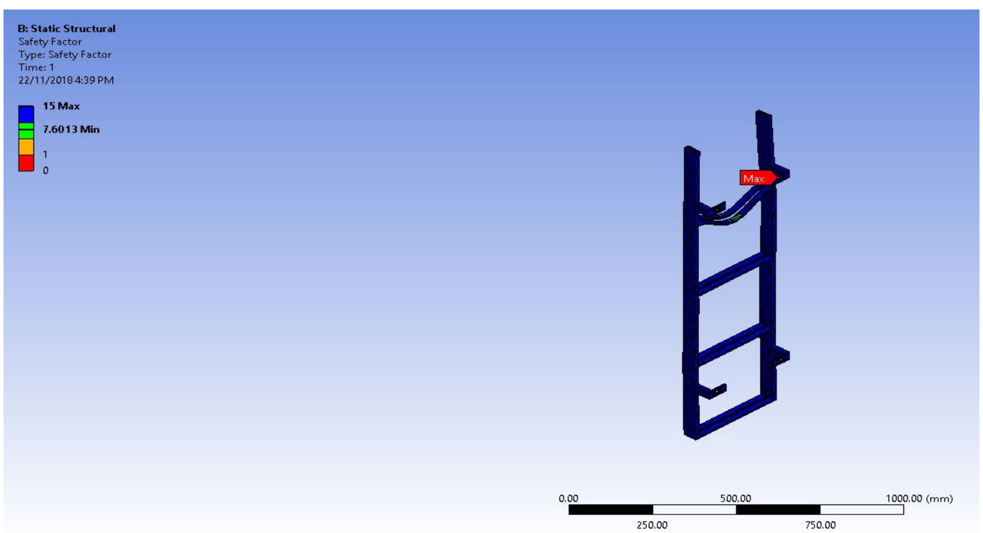


Figure 6 Safety factor of Modification 2

3.0 DESIGN OPTIMIZATION

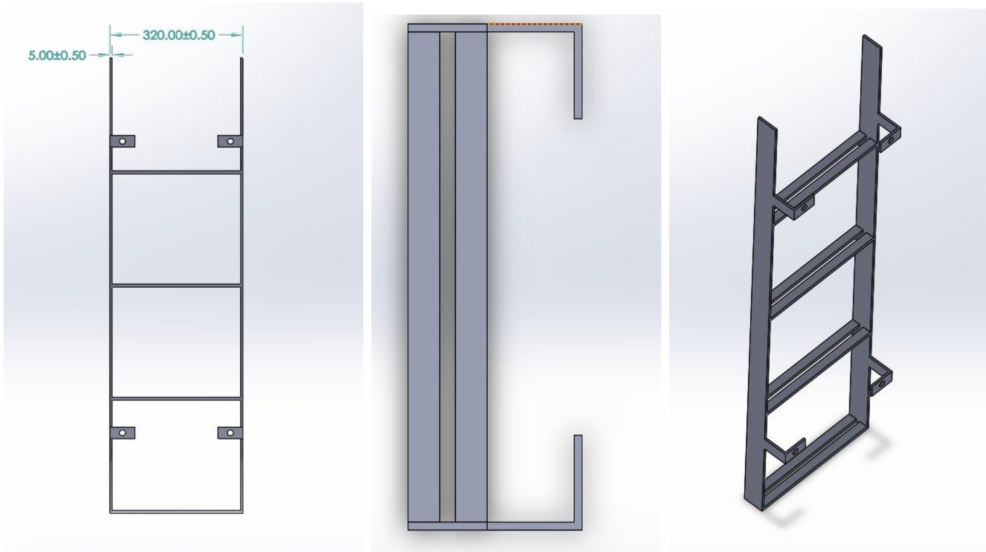


Figure 8 First Modification (from left : front, top and isometric view)

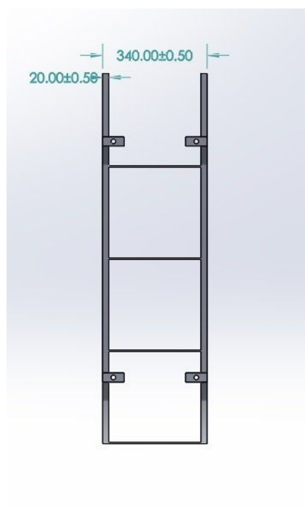


Figure 9 Original Dimensions

As for the first modification, the shape and overall design has been maintained. The only major difference is an addition of a 20cm gap which separates the steps in 2 pieces. This gap will help to increase the surface area of the steps which will subsequently reduce the maximum stress acting on the steps when a load is applied. In addition, the overall width gap of the ladder between the 2 side members has been decreased from 340mm to 320mm. The thickness of the side member has also been decreased from 200mm to 5mm. In addition , the thickness of the steps has also been increased from 5mm to 8mm. These three changes are manipulated to facilitate the equal distribution of stress across the whole ladder. After applying these changes, the ladder still meets the requirement of the fixed ladder which is a minimum safety factor of 4, acceptable skewness and also has a lower maximum equivalent stress when compared the the original design.

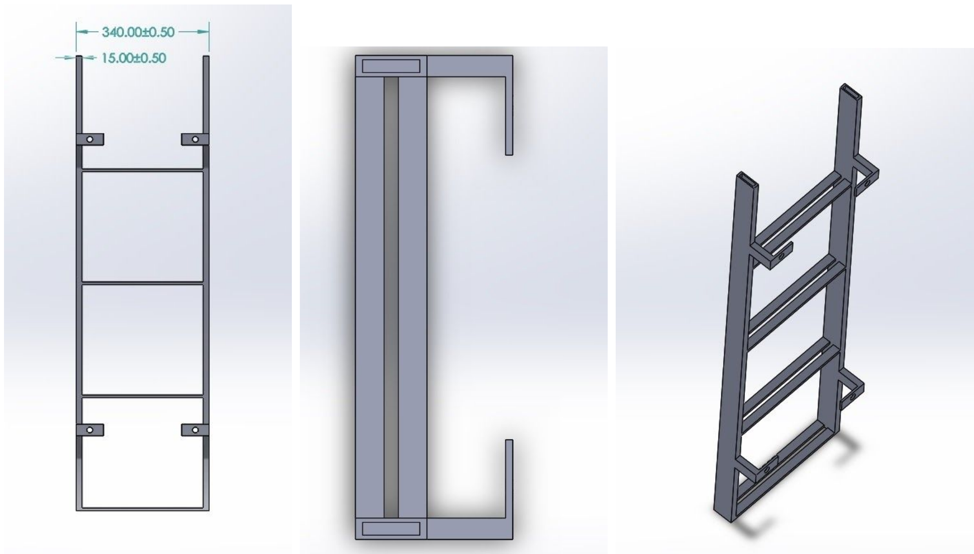


Figure 9 2nd Modification (from left : front, top and isometric view)

As for the second modification, the shape and overall design has also been maintained. The major difference from the first modification is the hollow side member on both ends. A shell of 5mm was applied on the whole side member of the ladder. The gap from modification 1 maintains to increase the surface area of the steps which will increase the surface area of the steps which will ultimately reduce the maximum stress acting on the steps when load is applied. The overall width gap of the ladder has been maintain however the thickness of the side members has been reduce from 20mm to 15mm. These three modifications proof to be useful in distributing the stress equally across the whole ladder. This modification meets the minimum requirement of a fixed ladder which is a minimum safety factor of 4 , acceptable skewness and also a lower maximum equivalent stress when compared to the original design and also the first modification.

3.1 Improvement

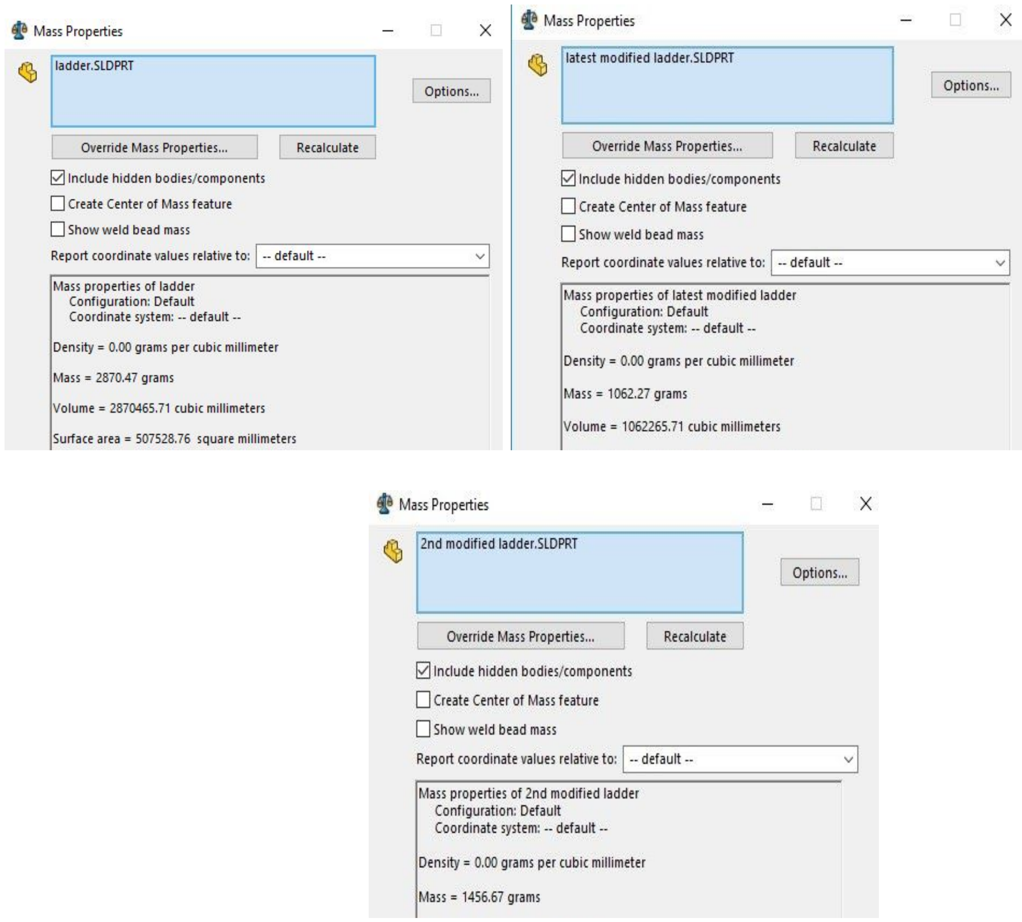


Figure 10 Mass Properties (top from left: Original , 1st Modification; Bottom: 2nd modification)

After considering both modifications, it can be concluded that Modification 2 is the most optimized and cost efficient design among the two modifications. This is because it managed to reduce 49.25% of mass when compared to the original mass of the design. This was also done without changing the material used as Structural Steel was maintained as the material of choice for both modification 1 and 2. Although, modification 1 was able to achieve a reduction of 62.99% of mass when compared to the original design, the safety factor obtained showed that Modification 2 was safer than Modification 1. As for the maximum equivalent stress, modification 2 is able to achieve a lower stress than modification one which shows that the distribution of stress in modification 1 is more optimum and equal. Most importantly, modification 2 is able to reduce the weight without the change of material and also satisfy the minimum safety requirement by the safety and health regulations for construction which is the minimum safety factor of 4 and does not exceed the ultimate yield strength .