ANALYSIS OF LEAF SPRING USING ANSYS WORKBENCH

Project Report Submitted

to

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CHAPTER ONE

INTRODUCTION

A linear spring is a mechanical device capable of only supporting the axial load. The contraction or elongation of the speed is directly proportional to the applied axial load. The constant of proportionality between deformation and load is the spring constant, *K*[1] Leaf spring is the simplest form of spring commonly used in the automobile industry for the suspension system in cars or other commercial vehicles to absorb shocks and vibrations. It is made up of multiple leaves with different lengths in the form of an arc designed to hold the complete vehicle load [2]. In a typical automobile application, a leaf spring is attached directly at both the ends to the frame as seen in figure 1 below.

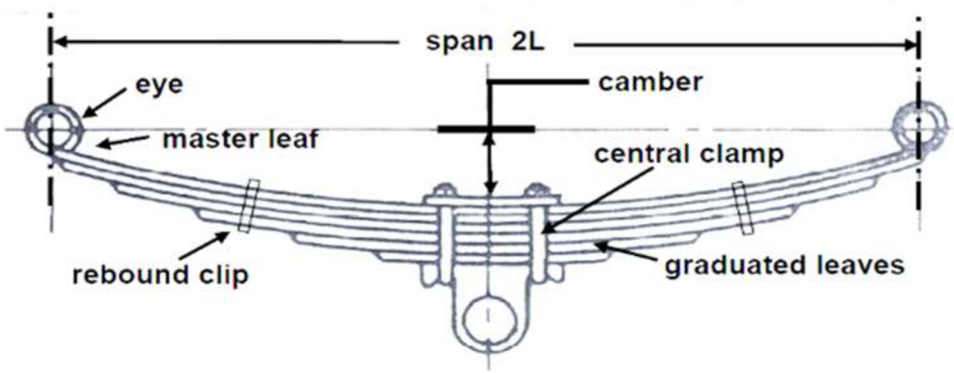

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Figure 1. Typical Leaf Spring with the components

The two major types of leaf springs are helical spring leaf spring. The helical spring is used in two-wheeler or trains to mainly observe mild shocks and impact load. Leaf spring, on the other hand, can absorb very high shocks and impact load. Varying the dimensions of the leaf spring enables it to bear very large vibrations thus preventing the damage on the body of the vehicle and also provides comfort while riding.

In general, the major functions of a vehicle suspension is to provide support to the vehicle and reduce/Absorb impacts from road irregularities Springs in general, and leaf springs in particular, help perform these functions and support the weight of the vehicle while absorbing bumps[3] The major components of a leaf spring are described in figure 1. The spring is connected to the frame of the vehicle through the inner leaf which is the tallest blade and bent from both the ends to form a hole. The smaller leaves are connected using rebound clip and bolts. In normal operation, a spring is connected from its center to the axle of the vehicle. The leaves are commonly made up of steel due to some of the unique characteristics such as uniform load distribution and lower cost [2]. To compensate for the vertical loads, the leaf spring is bent in both the directions and this also facilitates the movement in the y-direction. If the leaf spring is designed straight, the following points below are most likely to occur [2]

1) The negative bending of the bar is of higher stiffness, thus failure due to high loads and fatigue is highly prominent.

2) For the same amount of bounce, more length is required, thus bigger assembly and cost.

3) During normal service, due to the vehicle's load, the leaf spring will bend down and a higher rate of failure is expected.

Leaf springs are long and narrow plates attached to the frame of a trailer that rests above the vehicle's axle. Leaf springs are available in different varieties such as mono-leaf spring(Single-leaf) consisting of one plate of spring steel. These type of leaf springs are generally heavy in the middle and tapered out towards the end. These, however, do not provide higher strength and suspension. Multi-leaf springs consisting of several leaf springs with different lengths and stacked upon each other provides superior suspension [4].

Leaf springs have different ends, depending on where they're connected to the frame. On double-eye leaf springs, the top plate which is also the longest plate has both ends curved into a circle. The ends make two holes, which can be bolted to the bottom of a trailer's frame. Open-eye leaf springs have only one eye called an open hole. The other end of an open eye leaf spring can be a hook end or a flat end [4]. Application of leaf spring in an automotive vehicle is shown below in figure 2.

Figure 2.Use of Leaf spring in the suspension of vehicles

CHAPTER TWO

OBJECTIVE

Leaf springs play an integral part of the vehicle's suspension system. They are designed to support the entire weight of the vehicle. These also provide grip to the tire on the road and regulates the wheelbase lengths during vehicle speed change. Apart from these, leaf springs also control the height of the ride and axle damping [6]. During normal operation, spring leaves are often subjected to many deformation modes such as tension, compression, bending torsion, and shear, etc.[6]

The main objective of this work is to investigate the static analysis, optimization of the factor of safety and stress by changing the depth of the part and further conduct sensitivity analysis of the leaf spring using ANSYS workbench. Leaf Spring is modeled using the Design Modeller in ANSYS software (Version 19.1) and is used further to understand stress, strain, deformation, load carrying capacity, subsequent values of deformation, stiffness and weight savings of a leaf spring. This work mainly focuses on double-eye leaf spring with main optimizations as follows:

- The factor of safety of the spring is optimized by reducing or increasing the depth of the structure.
- The stress of the spring is optimized by considering depth as the input parameter.

CHAPTER THREE

METHODOLOGY

ANSYS software based on finite element analysis is adopted in this research for the analysis of the steel and composite leaf springs. The stresses and forces of the leaf springs were calculated by FEM using ANSYS version 19.1 software for different values of the applied displacements. In this analysis, the spring has been modeled as a two-dimensional plane stress problem. The upper tip on the right is considered to be fixed in the vertical direction and free to move horizontally. At the midline of the spring, the displacement is selected to be fixed in the X direction. Wherein, in Y direction a range of displacement with a maximum value has been applied. Accordingly, the forces and stresses have been calculated due to these displacement values[7]

Double-eyed leaf spring with an ability to carry a load of 1000 N is used for the analysis. The leaf spring was considered to be of full length with the dimensions of 80mm length and 4mm thick. This leaf spring was modeled using Designmodeler in Ansys workbench. Except for the material properties, all the parameters that are used for steel spring were assigned to the model. The results of spring made of structural steel were observed. Following were the assumptions made while designing the model

1) Non-linear effects are neglected
2) Hooke's law applicable while considering the composite materials
3) The load is distributed uniformly at the center of the spring
4) Leaf spring has a uniform rectangular cross-sectional area

Boundary conditions are constraints necessary for the solution of a boundary value problem. In this work, the following boundary conditions are considered. The two ends of the spring are fixed, which means the spring is restricted in both translational and rotational axis, assuming that the z-axis is pointing outwards of the picture as shown in figure 2. Further for the external force (load), it is applied vertically on the center of the bottom surface of the leaf spring which is half of the span from either end. This force will be pushing downwards on the bottom surface of the leaf spring and create displacement in the negative y-axis (downwards).

The following design variables are considered for modeling [6]

Parameter	**Value**
Material Selected	Structural Steel
Young’s Modulus	210 Gpa
Poisson’s ratio	0.266
Tensile strength ultimate	1962 Mpa
Tensile strength yield	1500 Mpa
Spring Stiffness	221.5 N/mm
Normal Static Loading	6388 kgf
Density	7860 kg/m^3
Behavior	Isotropic

Table 1: Material Properties of the Structural Steel

CHAPTER FOUR

MODELING, MESHING AND LOADING CONDITIONS

Below figure (figure 3) shows the geometry modeled in Design Modeler of Ansys Workbench taking the scaled-down dimensions of the standard dimensions. The dimensions considered for the leaf spring are tabulated below:

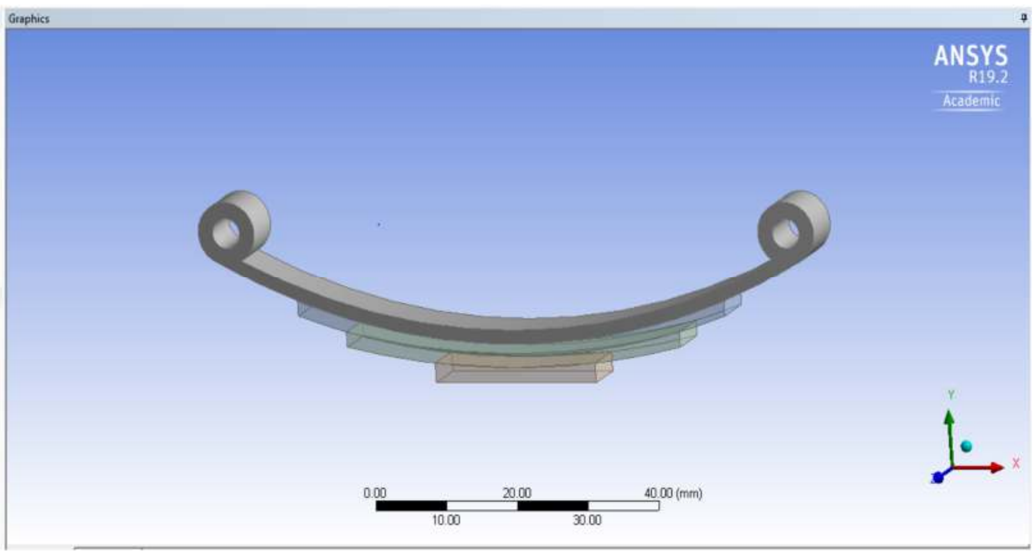


Fig 3: Geometry Modeled in Design modeler

PROPERTIES	DIMENSIONS
Length of the Spring	80 mm
The thickness of the leaf Spring	2 mm
Width of the leaf Spring	7 mm
Number of graduated leaves	4
The diameter of the eye	4 mm
The effective length of the Spring	76 mm

Table 2: Dimensions of the leaf spring

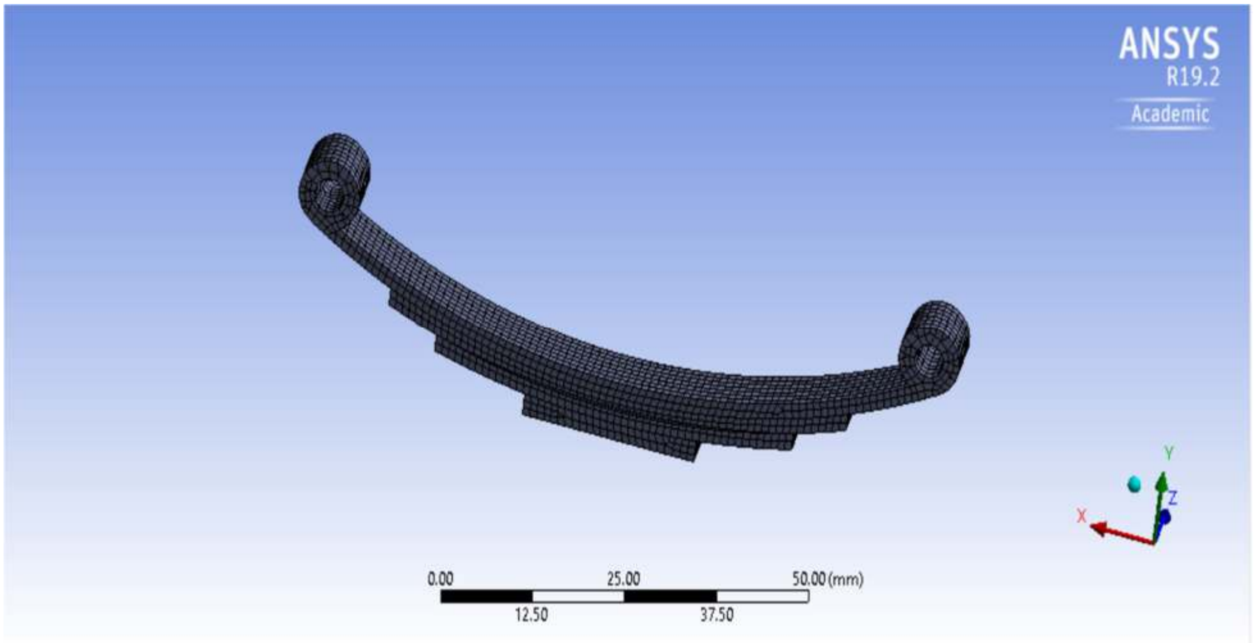


Figure 4: Mesh

The number of nodes of the leaf spring: 25637

The number of elements of the leaf spring: 5039

Meshing is nothing but the discretization of the object into the small parts called as the element. The figure shows the meshed model of leaf spring with an element size of 1 mm mesh. The type of mesh generated is coarse.

4.1 Boundary and loading conditions:

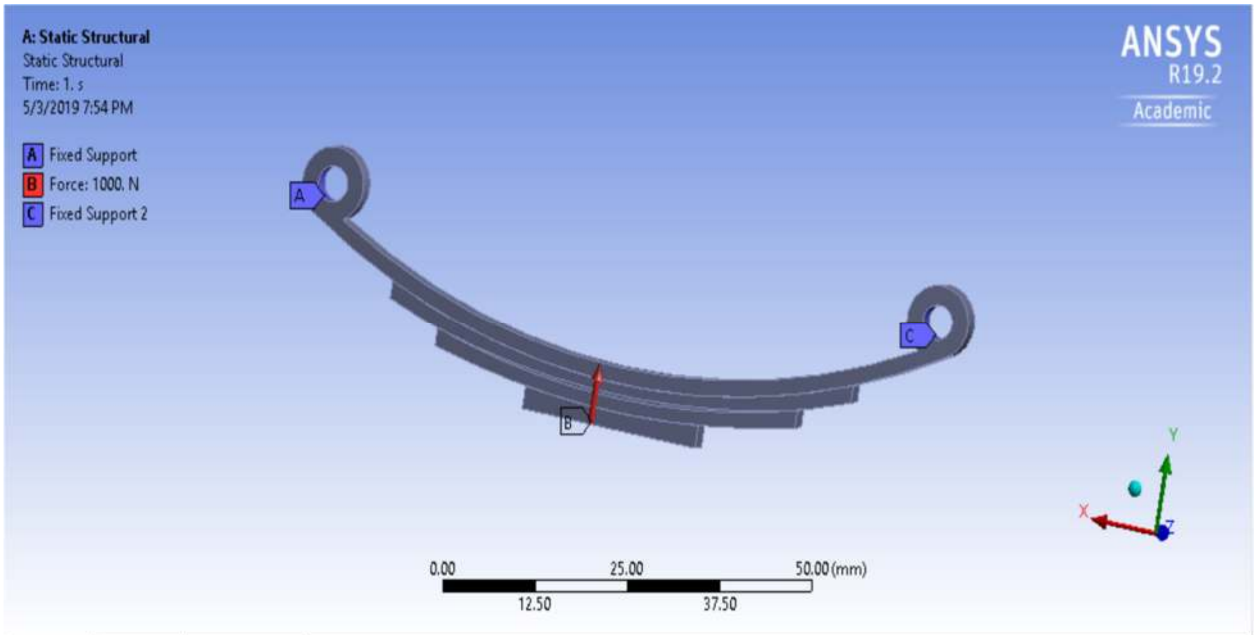


Fig 5: Boundary and Loading conditions

Fixed Supports: Fixed support has restriction to move in X and Y direction as well as a reaction about that particular point.

Force: We have given a force of 1000N at the center of the leaf spring in the Y direction.

CHAPTER FIVE

RESULTS AND DISCUSSION

The fig below shows the leaf spring made of structural steel under the application of a force of 1000 N, the maximum deflection observed in the leaf spring is 0.05 mm. The red zone indicates the area where the maximum deflection occurs and the blue zone indicates the area where the minimum deflection occurs. By comparing the values of the spring it can be observed that the stresses are in the permissible limits.

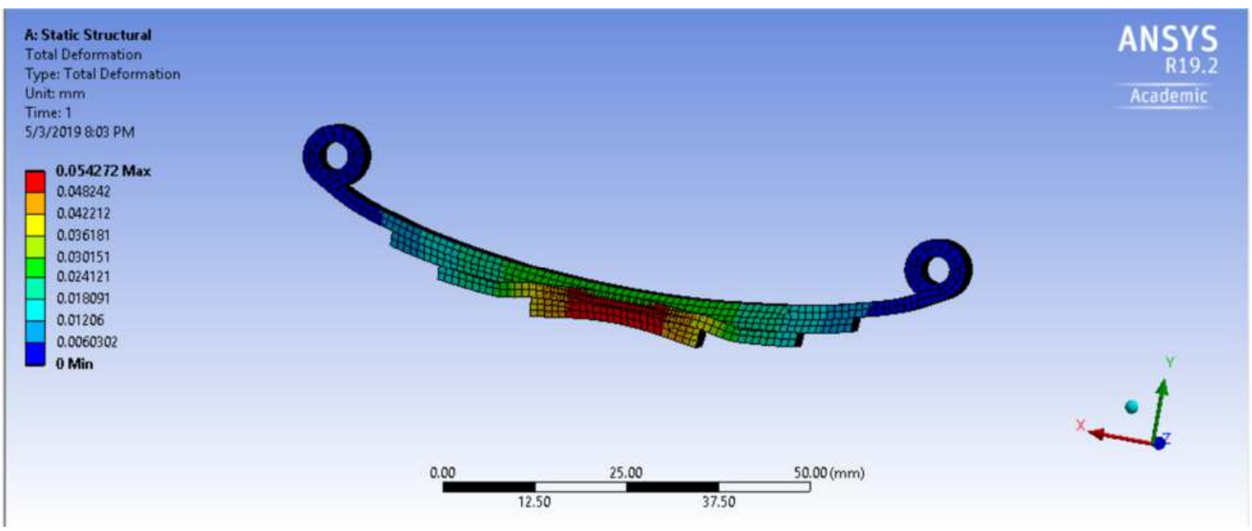


Fig 6 Total Deformation

The Directional deformation in x-axis is calculated and it is observed to measure up to 0.005 mm

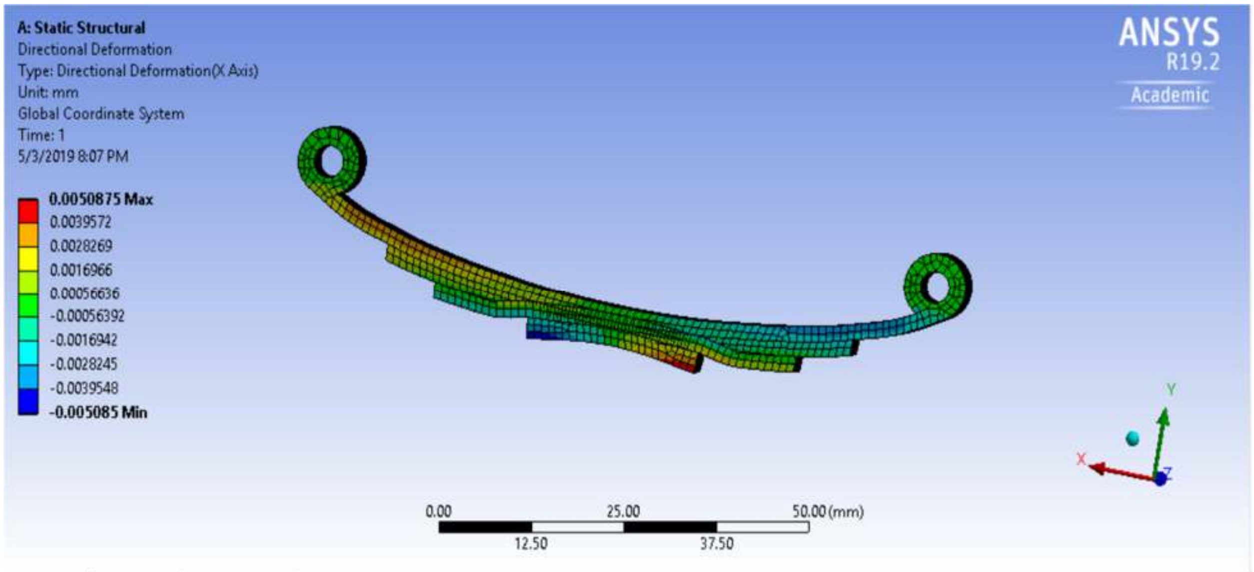


Figure 7 Directional deformation in the x-axis

In the figure below we observed that the max stress acting on the leaf spring is about 350 Mpa. By analyzing the design we understood that all the stresses in the leaf spring are within the permissible limits and with a good factor of safety of about 1.3.

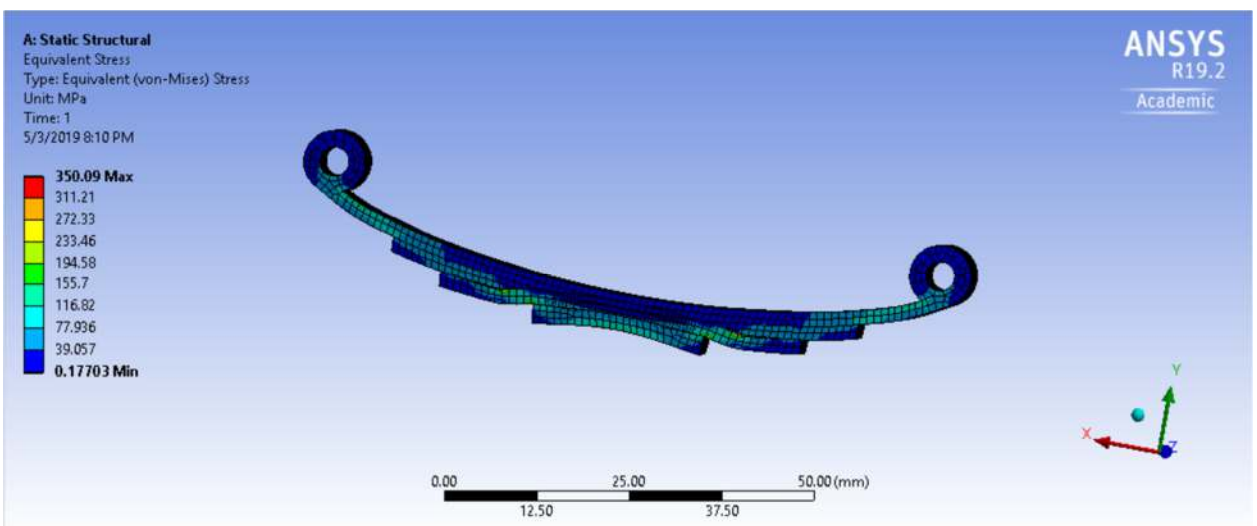


Figure 8 Equivalent stress (von-mises)

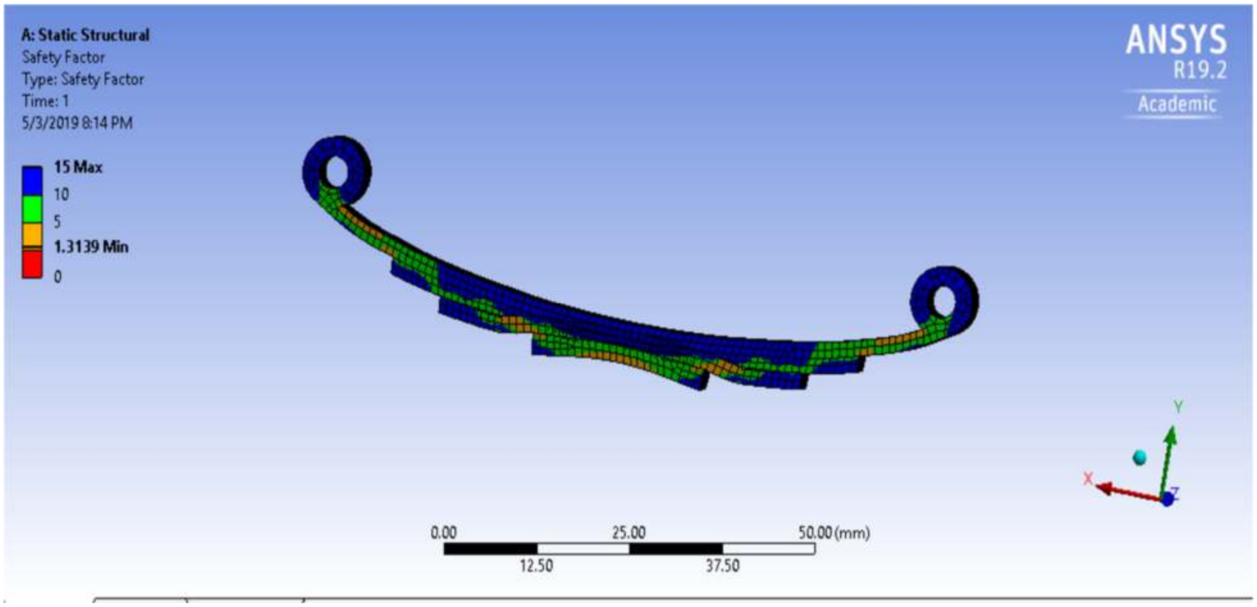


Figure 9: Factor of safety

Results			
	Total Deformation	**Equivalent Stress**	**Factor of Safety**
Minimum	0 mm	0.17703 MPa	1.3139
Maximum	5.4272e-002 mm	350.09 MPa	15
Average	2.1415e-002 mm	39.084 MPa	-

Table 3 Results

5.1 OPTIMIZATION OF FACTOR OF SAFETY - Leaf Spring

Optimization is the iterative process for finding a design that maximizes or minimizes the objective by searching the design space. There are two major types of optimization algorithms: *gradient-based methods* are useful when the objective is differentiable. They are fast but can only find local solutions; *Gradient-free methods* are useful when the evaluation of the objective (and its gradient) is expensive or when the gradient is noisy [9]. ANSYS offers both options.

By setting the input parameters of the spring we get to optimize the output parameters of the spring.Here the input parameter considered for the spring is the depth of the spring while the output parameter set is the factor of safety obtained by the analysis of the spring. Figure 10 and figure 11 illustrates the project schematic diagram and the layout of design of parameters on ANSYS when creating the optimized parameters.

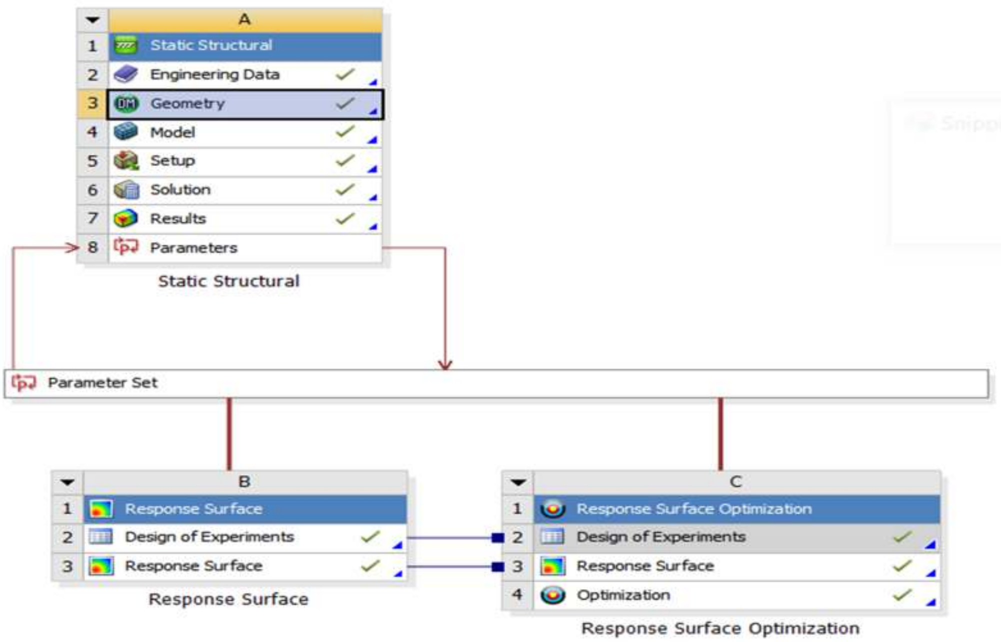
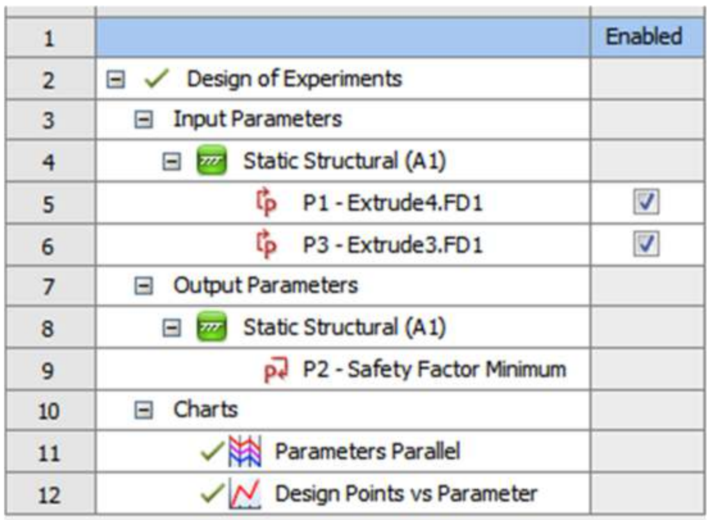


Figure 10: Project schematic

5.2 DESIGN OF EXPERIMENTS

Many engineering design problems have objectives that are evaluated through expensive simulations/experiments, e.g., CFD analysis. In such cases, each function evaluation during the optimization takes a long time, and thus could making the optimization intractable. DOE is a set of methodologies that determine which design to evaluate from a potentially large design space, so that we can create a statistical model to predict the objective values of other designs with low uncertainty in prediction. Through the predictive model, we can also tell the sensitivity of variables, i.e., whether the objective changes much with respect to each of the variables. DOE is often used as part of the gradient-free optimization algorithm[9].



1		Enabled
2	Design of Experiments	
3	Input Parameters	
4	Static Structural (A1)	
5	P1 - Extrude4.FD1	☑
6	P3 - Extrude3.FD1	☑
7	Output Parameters	
8	Static Structural (A1)	
9	P2 - Safety Factor Minimum	
10	Charts	
11	Parameters Parallel	
12	Design Points vs Parameter	

Figure 11: Design of experiments

In Design of experiments we can observe the parameters set for the experiment are depth of the leaves of the spring and the factor of safety. The design points generated are observed below in the figure 12.

Table of Schematic B2: Design of Experiments (Central Composite Design : Auto Defined)

	A	B	C	D
1	Name	P1 - Extrude4.FD1 (mm)	P3 - Extrude3.FD1 (mm)	P2 - Safety Factor Minimum
2	1	7.15	7	1.2836
3	2 DP	6.3	7	1.1452
4	3	8	7	1.1299
5	4	7.15	6.3	1.2347
6	5	7.15	7.7	1.3134
7	6	6.3	6.3	1.4504
8	7	8	6.3	0.97607
9	8	6.3	7.7	1.1297
10	9	8	7.7	1.3799

Figure 12: Design points

These design points are further used to obtain the parameter parallel charts and the graph of the input vs the output parameters.

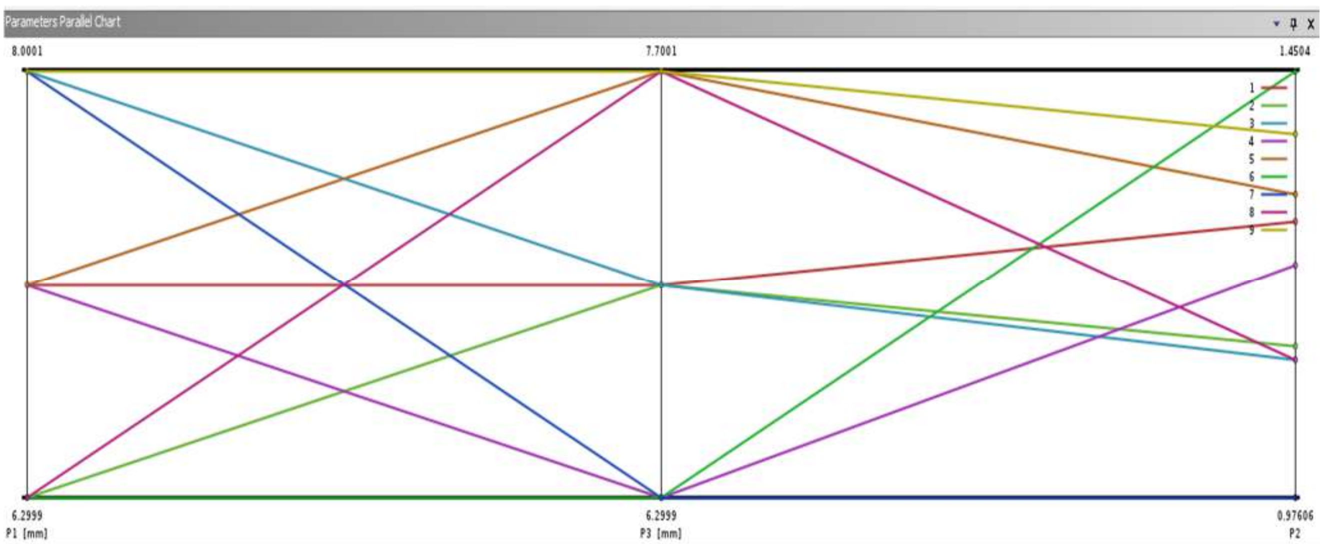


Figure 13: Parameter parallel chart

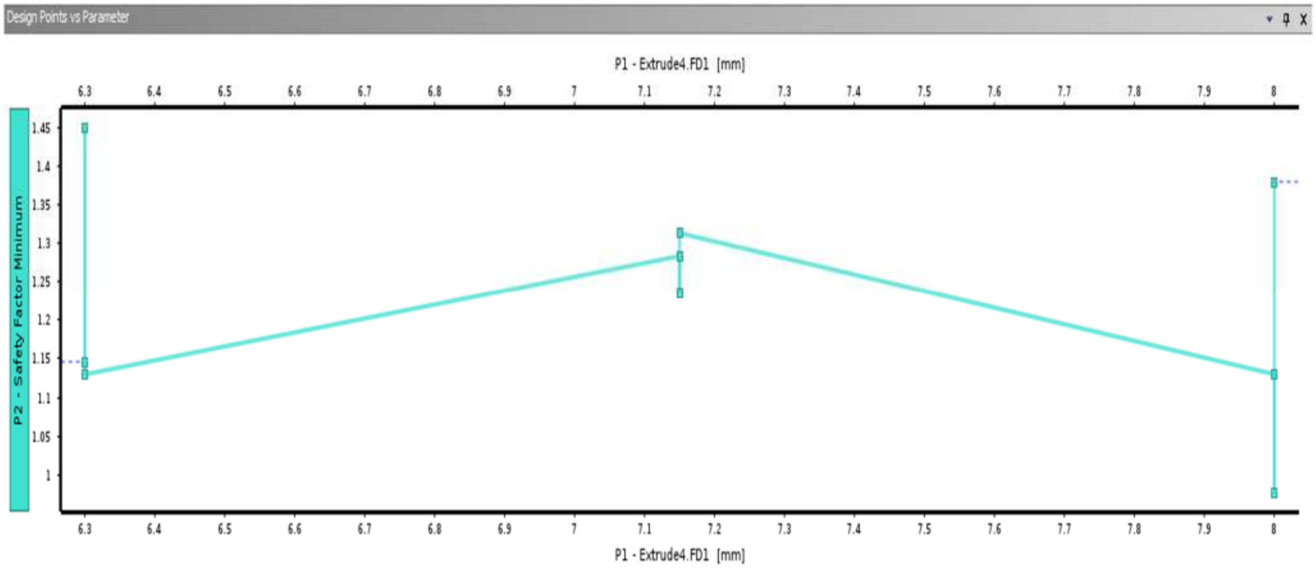


Figure 14: Depth of a leaf vs factor of safety

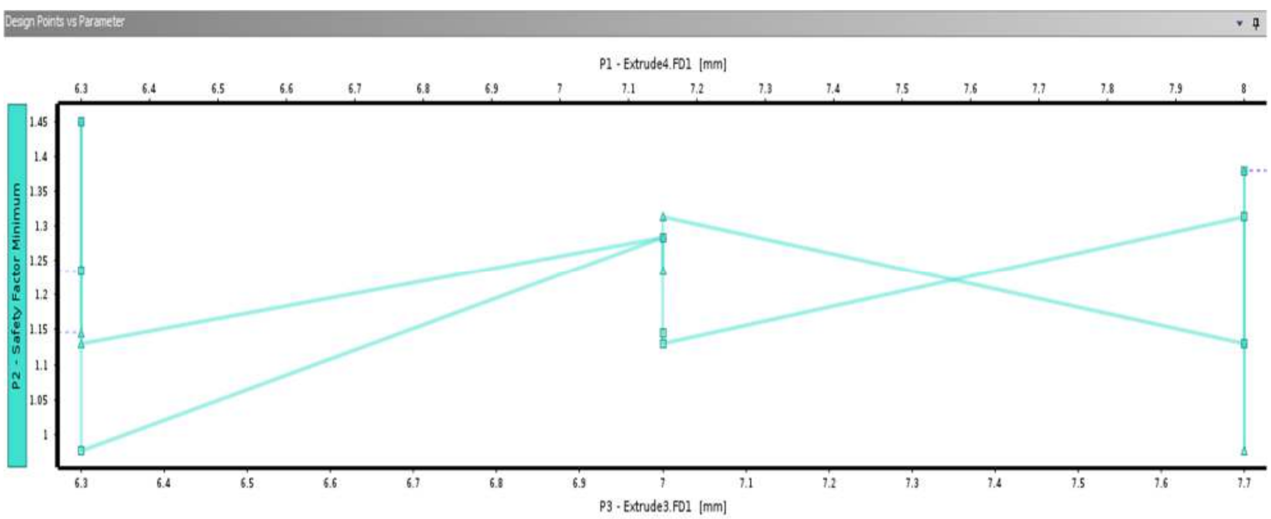


Figure 15: Depth of the second leaf and the factor of safety

Fig 14 and 15 indicates range of factor of safety for the first and second leaf respectively.

5.3 GOODNESS OF FIT

The observed vs the predicted goodness of fit of the leaf spring is also plotted on the graph as a part of response surface optimization.

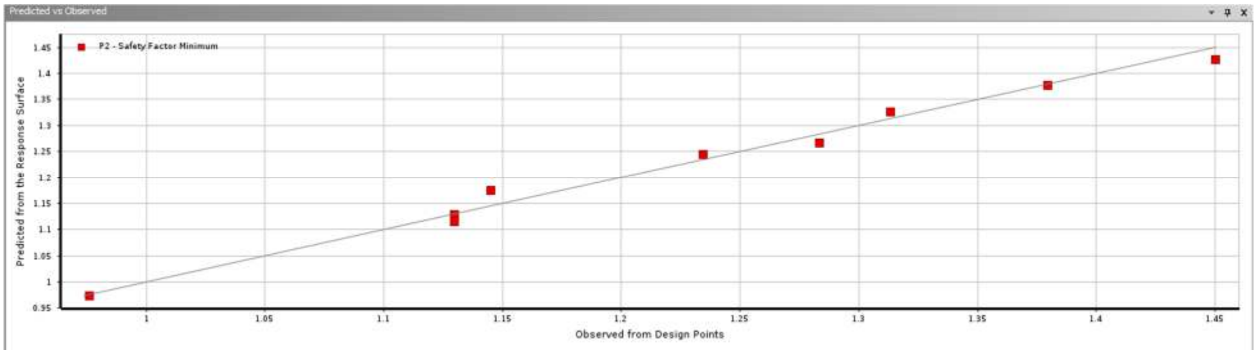


Figure 16: Goodness of the fit

5.4 RESPONSE CHART

Response surfaces fit through the calculated points to interpolate the space similar to a best fit curve in MS Excel. In this work, a response surface is created for each output parameter and the results are evaluated.It is used for an enhanced design process and can also help us to refine the process and design points and can also limit the refinement points.

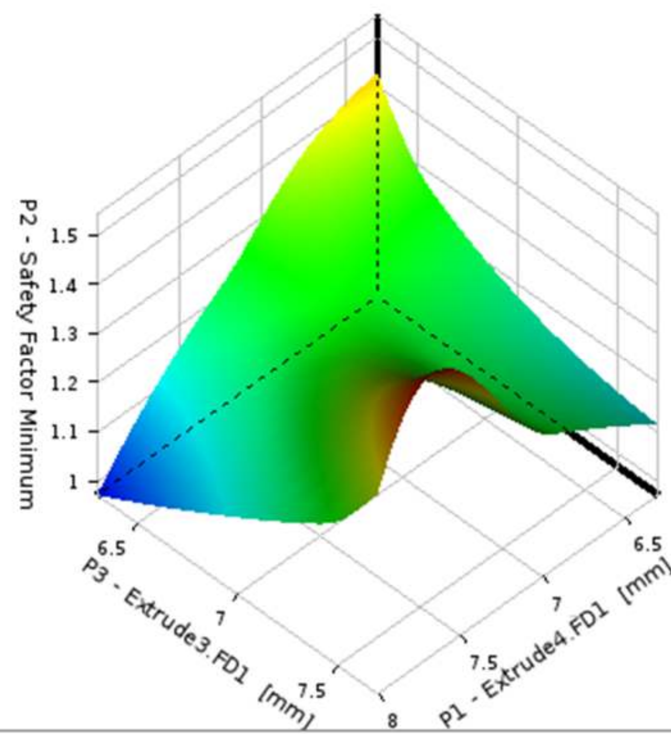


Figure 17: Response chart for minimum factor of safety

5.5. SENSITIVITY ANALYSIS

Building the response surface also allows us to perform sensitivity analysis, i.e., to see how much the objective changes when each variable changes. When a large number of variables exist, sensitivity analysis allows us to figure out the most important variables to design for, and thus reduce the computational cost of the optimization.

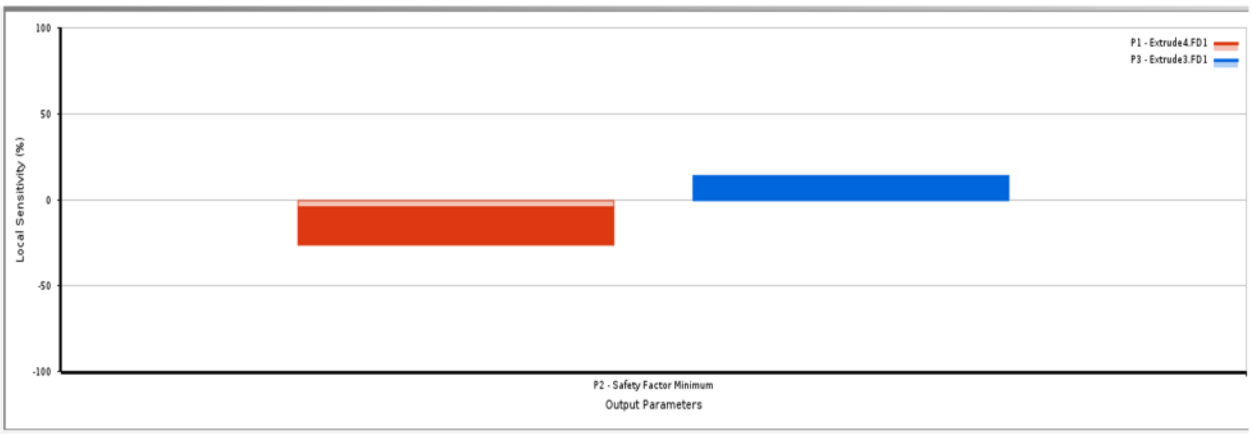


Figure 18 Sensitivity Analysis

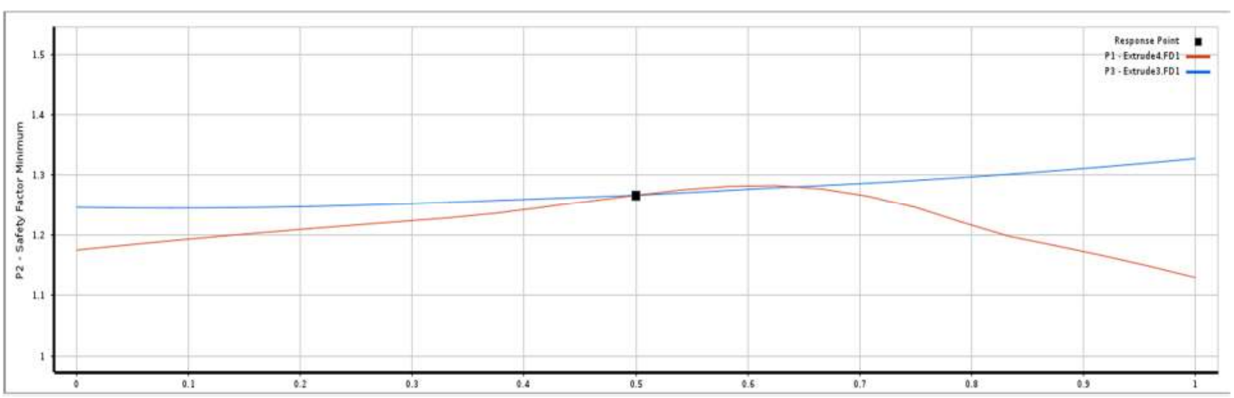


Figure 19 Sensitivity Curve

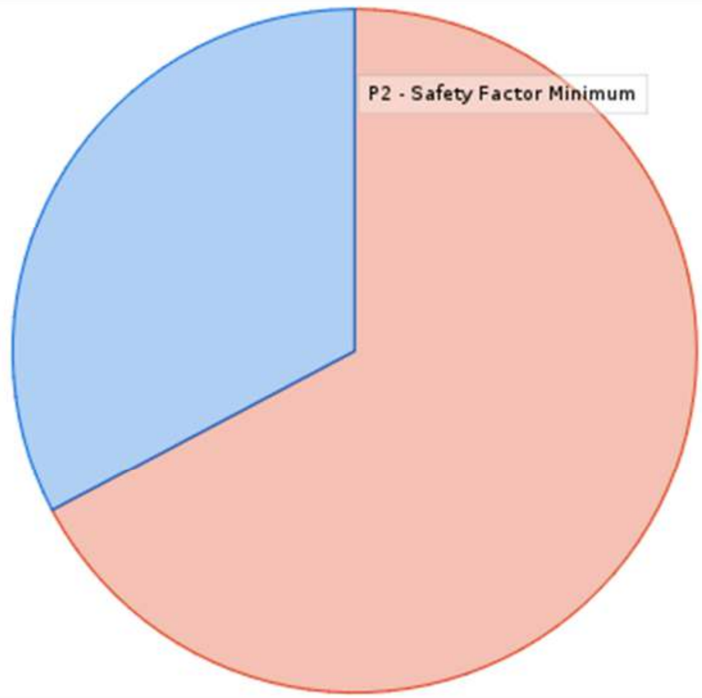


Figure 20 Pie Chart of Sensitivity

Referring to fig 18,19 and 20, the red color denotes for the factor of safety for the main leaf while the blue is factor of safety for the second leaf. These plots clearly shows that the depth of the main leaf has a higher sensitivity compared to the depth of the second leaf. This means that changes on the depth of the main leaf will create more changes to the results.

CHAPTER SIX

CONCLUSION

The main objective of the proposed new design is to improve shock absorb quality and the overall life of leaf spring. In this report, it covers the total deformation of the leaf spring using structural steel as its material, Von-Mises stress, and the factor of safety under static loading condition. The results for each category are summarized below:

Factor	Maximum Value	Minimum Value	Average
Total Deformation	0.05 mm	0 mm	0.02 mm
Von-Mises Stress	390 Mpa	0.17 Mpa	39.17 Mpa
Factor of Safety	15	1.313	-

From the analysis, it can be concluded that the factor of safety increases as the depth of the leaf spring increases.

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