CHAPTER – 1

INTRODUCTION

1.1 INTRODUCTION

A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Originally called a laminated or carriage spring, and sometimes referred to as a semi-elliptical spring, elliptical spring, or cart spring, it is one of the oldest forms of springing, appearing on carriages in England after 1750 and from there migrating to France and Germany.

A leaf spring takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. In the most common configuration, the center of the arc provides location for the axle, while loops formed at either end provide for attaching to the vehicle chassis. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason, some manufacturers have used mono-leaf springs.

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swiveling member.

Fig. 1.1

Fig.1.2

The suspension system in automobiles is a very important component in deciding vehicle drive comfort and the stability of the vehicle. As the tyre revolves, the suspension system is in a state of dynamic balance, continuously compensating for and adjusting to changing driving conditions. The components of the suspension system perform basic functions such as maintaining the correct vehicle ride height, reducing the effect of the shock forces, supporting the vehicle weight, carrying the driving torque, etc (Lupkin et al 1989).

In a vehicle, the leaf spring is located between the axle housing and the vehicle chassis, and it can be considered as a simply supported beam with a concentrated load at the center. The bending moment is the maximum at the center of the spring, and it reduces towards the ends, and hence, the spring selection is varied from a maximum at the center to a minimum at the ends. In a conventional multi-leaf steel spring construction, this is achieved by assembling a number of leaves of variable length in such a way, that the thickness is maximum at the center and reduces towards the ends.

The leaves are placed one over the other, and are held together by clamps and a bolt at the center. The leaf that extends the full length of the spring is known as the master leaf. The ends of the master leaf are formed into loops which are called eyes. Each metallic leaf has a hole at the center through which the spring bolt passes to hold the leaves together. Spring clips are used to hold the outer ends of the shorter leaves with the master leaf. When the leaf spring bends during operation, the leaves rub against one another. This rubbing produces frictional resistance due to leaf flexing. If the inter laminar friction is high due to the absence of lubrication, the spring will stiffen considerably. Leaf springs are sometimes fitted with inserts, such as rubber waxed cloth or oil bronze disks between the leaves, in order to reduce inter laminar friction (Sternberg 1976).

A leaf spring commonly used in automobiles is semi–elliptical assembly. It is built with number of plates. The leaves are usually given an initial curvature or cambered, so that they will tend to straighten under load. The leaves are held together by means of a band shrunk around them at the center, or by a bolt passing through the centre. Since the load exerts stiffening and strengthening effect, the effective length of the spring for bending will be the overall length of the spring minus the width of the band. In the case of the central bolt, two thirds distance between the centers of the u- bolt should be subtracted from the overall length of the spring, in order to find the effective length. The spring is clamped to the housing by means of u- bolts (Nakhaie Jazar (2008), Shigley (2008).

The longest leaf known as the main leaf or master leaf has its ends formed in the shape of an eye through which the bolts are passed to secure the spring to its supports. Usually the eyes, through which the spring is attached to the hanger or shackle, are provided with bushings of some antifriction material, such as bronze or rubber. The other leaves of the spring are known as the graduated leaves. In order to prevent digging in the adjacent leaves, the ends of the graduated leaves are trimmed in various forms. The master leaf has to withstand vertical bending loads as well as the loads due to the slanting of the vehicle while taking a turn (Nakhaie Jazar (2008), Shigely (2008). Due to the presence of the stresses caused by the loads, it is usual to provide two full length leaves and the rest graduated leaves.

Rebound clips are located at intermediate positions in the length of the spring, so that the graduated leaves also share the stresses borne by the full length leaves when the spring rebounds. The general leaf spring assembly is shown in the Figure 3.

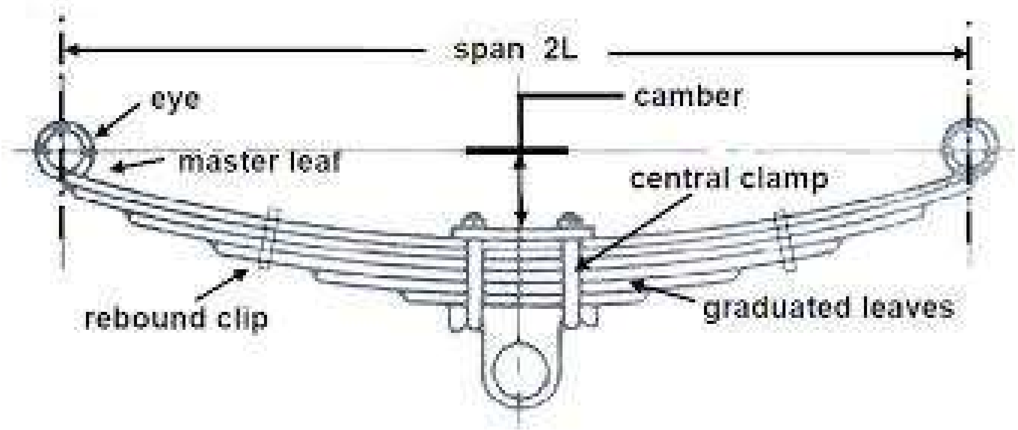


Fig.1.3 Semi–Elliptical Leaf Spring Assembly

Types of Leaf Springs

Several designs of leaf springs are employed in automobiles.

These are

- Semi-elliptical and quarter-elliptical (or cantilever) type leaf springs.
- Longitudinally and transversely located type leaf springs.
- Tapered and progressive (or helper) type leaf springs.

Among these, the semi-elliptical leaf springs are most common.

Semi-elliptical leaf spring

The leaf spring is made-up of a number of steel leaves. Each leaf is of a different length, but with equal width and thickness. The uppermost longest leaf having bushes at its two ends, is called the master leaf. The ends are directly connected to the side member of the vehicle frame.

Quarter-elliptical leaf spring

This is also known as the cantilever type leaf spring, since it's one of the end is fixed on the side member of the frame while the other end is 6 freely connected to the front axle. In such springs the camber is provided on the upward side so that the leaves tend to straighten when the front axle beam is subjected to shock load.

Transversely mounted semi-elliptical inverted leaf spring

In this arrangement, a semi-elliptical leaf spring is mounted transversely along the width of the vehicle. The springs are placed, so inverted that the longest leaf is located at the bottom. The speciality of this arrangement is the use of two shackles. The rolling tendency of this type leads to its unsuitability for vehicles.

Taper leaf spring

The leaf springs discussed above are prepared with leaves of constant cross-section throughout their lengths. Such leaves may be called conventional leaves, and the springs as conventional leaf springs. The taper leaf spring consists of a single leaf having a varying cross-section. Such a spring is termed as a taper leaf spring or taperlite spring. This is of a parabolic profile. This type of spring is pre stressed to withstand higher stresses.

Helper spring (progressive spring)

Many heavy commercial vehicles are provided with an auxiliary leaf spring in addition to the main leaf spring. This is done, so as to combine the soft suspension with adequate resistance to heavy loads. It is mounted above the main leaf spring. The helper spring is cambered while the mainspring is of a flat type. The helper spring performs no functions until the main spring is loaded beyond the flat stage (acquiring a negative camber). When the vehicle is lightly loaded, the load is borne by the main spring only. But in the case of 7 a heavy load, the helper spring comes into operation and shares the load on the vehicle. In that case, the upward deflection of the main spring transfers the load to the helper spring. The combination of the helper spring and the main spring is known as a progressive spring.

Three quarter, full elliptic type leaf springs

The three quarter elliptical spring is clamped to the axle in the usual manner. One end is bolted to the frames while the other being rigidly held by spring clips to the frame. A spring shackle holds the two members of the spring together, allowing enough movement to compensate for the elongation of the main leaves when the spring is compressed. The full elliptical spring is attached rigidly to both: the axle and the frame, in the usual manner. Spring shackles are not necessary, since both the top and bottom members will elongate by the same amount when compressed. Figure 1.2 shows the types of leaf springs used in vehicles.

Spring Material Characteristics

From the consideration of vehicle dynamics, it is required to minimize the unsprung weight of a vehicle. Any amount of weight reduction achieved in the unsprung weight will have a direct bearing on the fuel efficiency. It is due to this reason, that the weight reduction in automobiles is mainly aimed at parts such as the leaf spring, drive shaft and road wheel, which constitute the unsprung weight (SAE 1996). Leaf springs constitute about 20-25 % of the unsprung weight. Several studies have revealed that the fuel savings in vehicles due to weight reduction is estimated to be about 0.26 gallons for every pound weight reduction, obtained for the life period of the vehicles (SAE 1996).

Further, the energy absorbed by the leaf spring is stored in the form of elastic strain energy. The elastic strain energy absorbed, is equal to the work done by the external load, when the leaf spring moves through a distance equal to the deflection in the spring. Therefore, the material used for the making of the leaf spring should have the maximum elastic energy capacity.

The energy absorbed has to be displaced faster, so that the spring does not continue to oscillate after the initial deflection. The energy release rate depends on the damping characteristics of the spring material. Hence, in order to arrest spring oscillation after the initial deflection, the spring material should have a good damping. If the damping of the spring is not adequate, external damping devices, such as shock absorbers, are used along with the springs. Also, since the leaf springs are subjected to fatigue loading, the spring material should have good fatigue strength. The optimum properties of the truck leaf spring are with respect to the influence of amplitude and frequency. The desired characteristics of an ideal automotive suspension leaf spring material can be summarized as follows:

1) High strength to weight ratio

2) High elastic strain energy storage capacity

3) High fatigue strength

4) Good damping characteristics

5) Good corrosion resistance

Spring Loading

The Suspension springs experience three loading conditions. Initially, the weight of the vehicle alone acts under the unloaded condition. Subsequently, the weight of the loaded vehicle acts on the spring. Finally, the dynamic or inertia load will act, as the vehicle moves over uneven road surfaces. The suspension system has to provide the same quality of ride under all the three load conditions. Vehicles, such as trucks, have a high ratio of loaded to unloaded weight. These vehicles require a variable rate suspension spring, to minimize the change in ride heights, under varying load conditions. The variable rate is accomplished in the leaf springs by attaching an auxiliary leaf spring to the main leaf spring. As the spring deflects to a particular height, the auxiliary spring gets engaged along with the main spring, and increases the base spring rate.

Spring Materials

The material used for the leaf spring is usually a plain carbon steel having 0.9 to 1% carbon. According to Indian standards the recommended materials are (Robert C. Creese 1999, JAI 2002):

1. For automobiles: 50Crl, 50CrlV23, and 55Si2Mn90, all used in the hardened and tempered state.
2. For rail road springs: C55 (water-hardened), C75 (oil hardened), 40Si2Mn90 (water-hardened) and 55Si2Mn90 (oil hardened).
3. The physical properties of some of these materials are given in the Table 1.1. All the values are for the oil quenched condition and for single heat only.

Table 1.1 Physical properties of materials commonly used for leaf springs

Sr. no.	Material	condition	Ultimate tensile strength (MPa)	Tensile yield strength (MPa)	Brinell hardness number
1.	50Crl	Hardened and Tempered	1680-2200	1540-1750	461-601
2.	50CrlV23		1900-2200	1680-1890	534-601
3.	55Si2Mn90		1820-2060	1680-1920	534-601

Elliptic	

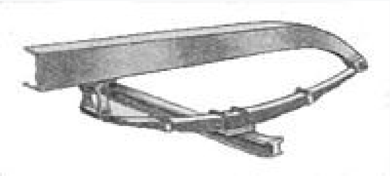
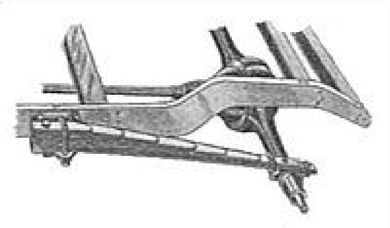
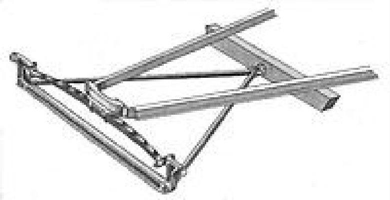
Semi-elliptic	
Three quarter-elliptic	
Quarter-elliptic	
Transverse	

Fig 1.4

CHAPTER – 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Zliahu Zahavi [1] the leaf spring works is very complicated from the point of view of mechanics and numerical computations. The magnitude of loading is high as well as spring deformations. Multi-surfaces 3D contact between subsequent leafs also takes place. The main advantage of leaf springs is that the ends of the spring are guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Practically, a leaf spring is subjected to millions of load cycles leading to fatigue failure. Free vibration analysis determines the frequencies and mode shapes of leaf spring.

A. Strzat and T. Paszek [2] performed a three-dimensional contact analysis of the car leaf spring. They considered static three-dimensional contact problem of the leaf car spring. Different types of mathematical models were considered. The static characteristics of the car spring was obtained for different models and later on, it is compared with one obtained from experimental investigations.

Fu-cheng Wang [3] performed a detailed study on leaf spring.. His work mainly discusses the active suspension control of vehicle models. The employing active suspension through the analysis of the mechanical networks is discussed. He derived a parameterization of the set of all stabilizing controllers for a given plant. He considered practical parameters and applications of a leaf spring model through his work, thus supporting both the situations, that is active and passive suspension cases, individually.

Rajendran and S. Vijayarangan [4] performed a finite element analysis on a typical leaf spring of a passenger car. Finite element analysis has been carried out to determine natural frequencies and mode shapes of the leaf spring. A simple road surface model was considered.

Gulur Siddaramanna SHIVA SHANKAR [5] performed test on the leaf springs under static loading condition & the stresses and deflection are listed. These results are also compared with FEA. Testing has been done for unidirectional E-Glass/Epoxy mono composite leaf spring only. Since the composite leaf spring is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by composite leaf spring. Since, the composite spring is designed for same stiffness as that of steel leaf spring, both the springs are considered to be almost equal in vehicle stability. The major disadvantages of composite leaf spring are chipping resistance. The matrix material is likely to chip off when it is subjected to a poor road environments (that is, if some stone hit the composite leaf spring then it may produce chipping) which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness.

VINKEL ARORA, Dr. M.L AGGARWAL, Dr. GIAN BHUSHAN [6] perform computer aided design and analysis of a conventional leaf spring, with experimental design considerations and loading conditions. This conventional leaf spring model consists of 37 parts. The material of the leaf spring is 65Si7.The CAD model of the leaf spring is prepared in CATIA and analyzed using ANSYS. The CAE analysis of the leaf spring is performed for the deflection and stresses under defined loading conditions, using ANSYS. The experimental and CAE results are compared for validation. Using CAE tools the ideal type of contact and meshing element is determined in leaf spring model.

M.VENKATESAN , D.HELMEN DEVARAJ [7] perform design and experimental analysis of composite leaf spring made of glass fiber reinforced polymer & compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. A weight reduction of 76.4% is achieved by using optimized composite leaf spring.

S. VENKATESH, DR. S. S. MOHAMED NAZIRUDEEN, DR. A. K. SHAIK DAWOOD, R. KARTHIKEYAN [8] research work describes about the development of porous Aluminium foam for making commercial vehicle leaf spring made of Aluminium. The Aluminium foamed leaf spring has stresses much lower than steel leaf spring and weight of aluminium foamed leaf spring was reduced upto 20%. Using FEA stress and deflection is analysed.

G. HARINATH GOWD & E VENUGOPAL GOUD [9] perform static analysis on leaf spring by using ANSYS software and it is concluded that for the given specifications of the leaf spring, the maximum safe load is 7700N. It is observed that the maximum stress is developed at the inner side of the eye sections, so care must be taken in eye design and fabrication and material selection. The selected material must have good ductility, resilience and toughness to avoid sudden fracture for providing safety and comfort to the occupants.

SETHILKUMAR MOULEESWARAN [10] performs design and experimental analysis of composite multi leaf spring using glass fibre reinforced polymer are carried out. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and International Journal of Technical Research and Applications e-ISSN: 2320-8163, www.ijtra.com Volume 3, Issue 1 (Jan-Feb 2015), PP. 145-156 147 | P a g e 126.98% higher natural frequency than that of existing steel leaf spring. The conventional multi leaf spring weighs about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weighs only 4.3 kg. Thus the weight reduction of 68.15% is achieved. Besides the reduction of weight, the performance of the leaf spring is also increased. Compared to the steel leaf spring (13.5 kg), the optimised composite leaf spring weighs nearly 76.4% less than the steel spring. Ride comfort and life of CLS are also more when compared to SLS. Therefore, it is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in light passenger vehicles.

KUMAR KRISHAN AND AGGARWAL M. L. [11] perform design and stress-deflection analysis of a multi leaf spring is carried out by finite element approach using CAE tools (i.e. CATIA, ANSYS). When the leaf spring is fully loaded, a variation of 0.632 % in deflection is observed between the experimental and FEA result, and same in case of half load, which validates the model and analysis. On the other hand, bending stress in both the cases is also close to the experimental results. The maximum value of equivalent stresses is below the Yield Stress of the material including that the design is safe from failure.

DAKSHRAJ KOTHARI, RAJENDRA PRASAD SAHU AND RAJESH SATANKAR [12] perform static and fatigue life analysis of to conventional leaf springs made of respectively SUP 9 & EN 45. These springs are comparing for maximum stress, deflection and stiffness as well as fatigue life. The CAD models are prepared in CATIA and analyzed by using ANSYS 12.1. Computer algorithm using C++ language has been used in calculating maximum stress, deflection and stiffness. SUP 9 springs has lower value of maximum stress, deflection and stiffness in compare to EN45 spring. Predicted fatigue life of SUP 9 spring is higher than EN45 spring. Although, market price is much lower than Sup 9 spring.

Y. N. V. SANTHOSH KUMAR & M. VIMAL TEJA [13] It was observed that the deflection in the composite leaf spring was almost equal so we can say that composite spring had the same stiffness as that of steel spring. It was observed that the composite leaf spring weighed only 39.4% of the steel leaf spring for the analyzed stresses. Hence the weight reduction obtained by using composite leaf spring as compared to steel was 60.48 %.

M. M. Patunkar, D. R. Dolas [14] shows under the same static load conditions deflection and stresses of steel leaf spring and composite leaf spring are found with the great difference. Deflection of Composite leaf spring is less as compared to steel leaf spring with the same loading condition. Indicating reduction in weight by 84.40% same level of performance. Conventional Leaf spring show failure at eye end only. At maximum load condition also Composite Leaf Spring shows the minimum deflection as compared to Steel Leaf Spring. Composite leaf spring can be used on smooth roads with very high performance expectations. However on rough road conditions due to lower chipping resistance failure from chipping of composite leaf spring is highly probable.

M. RAGHAVEDRA, SYED ALTAF HUSSAIN, V. PANDURANGADU, K. PALANIKUMAR [15] Perform design and analysis of laminated composite mono leaf spring. The dimensions of an existing mono steel leaf spring of a Maruti 800 passenger vehicle is taken for modeling and analysis of a laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, Sglass/Epoxy and Carbon/Epoxy subjected to the same load as that of a steel spring. The design constraints were stresses and deflections. The three different composite mono leaf springs have been modeled by considering uniform cross-section, with unidirectional fibre orientation angle for each lamina of a laminate. Static analysis of a 3-D model has been performed using ANSYS 10.0. Compared to mono steel leaf spring the laminated composite mono leaf spring have 47% lesser stresses, 25%~65% higher stiffness, 27%~67% higher frequency and weight reduction of 73%~80%.

K. A. SAIANURAAG & BITRAGUNTA VENKATASIVARAM [16] they compared static, dynamic & shock analysis for two & five layered composite leaf spring. The composite material used is E-Glass Epoxy. In static analysis the maximum displacement is observed in two layered i.e. 101.5mm compared to 83.23mm in five layered. Also during the static analysis Von-mises stress for the five layered is more than two layered i.e. 948Mpa for five layered compared to 795.4Mpa for two layered. For modal analysis various nodes are obtained and a comparative table is drawn for various nodes. The range of frequencies for two layers is 19.2 Hz to 1433 Hz and for five layers is 21.2 Hz to 1612 Hz. In Harmonic analysis amplitude vs. frequency graph for two layered and five layered are considered. For two layered amplitude decreases to a minimum and then increases & remains constant. For five layered amplitude remains constant initially but increases rapidly in the end. For shock analysis as time increases, the displacement initially increases, reaches a maximum and then decreases for a two layer mode, for five layered the deflection v/s time for five layer mode where the displacement initially decreases, reaches a minimum and then increases as the time progresses.

2.2 RESEARCH MOTIVATION

The automobile industries are showing increasing interest in replacement of steel spring with composite materials like fiber glass composite leaf spring due their higher strength to weight ratio. The analysis includes estimation of the deflection, stress and mode of frequency induced in the leaf spring. The spring is intended to bear heavy jerks and vibrations and are almost universally used for suspension in light and heavy commercial vehicles. For cars there are widely used in rear suspension.

2.3 OBJECTIVE OF PROJECT

The automobile industry is showing increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. Therefore; this project aims at comparative study of design parameters of a traditional steel leaf spring assembly and mono composite leaf spring with bonded end joints.

By performing static analysis using ANSYS software and mathematical calculations, the maximum bending stress and corresponding payload have to be determined by considering the factor of safety.

Determining and assessing the behavior of the different parametric combinations of the leaf spring, their natural frequencies are compared with the excitation frequencies at different speeds of the vehicle with the various widths of the road irregularity. These excitation frequencies are calculated mathematically.

CHAPTER – 3

MODELLING

3.1 Introduction

In computer – aided design, geometric modeling is concerned with the computer compatible mathematical description of the geometry of an object. A cad model of a typical LCV leaf spring is modeled on based on mathematical calculations on Pro/Engineer software.

After geometric modeling of the leaf spring with given specifications it has to be subjected to analysis. ANSYS software is used to analyze the stresses by performing static analysis for the given leaf spring specification to assess the behavior of the leaf spring with various parametric combinations. Analysis involves discrimination called meshing, boundary conditions, and loading conditions.

A. Steel leaf spring assembly

Pro Engineer software was used for this particular model and the steps are as follows:

1) Start a new part model with Metric units set.

2) Draw the sketches of the trajectories of each leaf of spring with the radius obtained from calculations with span1220mm camber 80.

3) Using sweep command draw a section 60 mm X 7 mm thick sweep along the above drawn curves of leaf.

4) According the spring design manual the eye diameter is formed on the first leaf. 5) Thickness of leaves = 7mm.

6) After all the features of all leaves as are modeled, generate family table for each leaf.

7) Generate models for u-clams, axle rod, top support plate etc.

8) Assemble each of the leaf in an assembly model and assemble all other models.

9) Provide a ½ inch dia hole in the leaf spring for bolt.

10)Export the model to iges – solid – assembly – flat level.

B. Composite mono leaf spring

The steps for modeling are as follows:

1. Start a new part model with Metric units set.

2. Draw the sketch of the trajectory with dimensions of first leaf of spring of steel spring assembly without eyes, span is same as 1220mm and camber 80.

3. The geometrical dimensions are carried forward from the steel leaf spring except for the number of plates and thickness in order to maintain the required cross section area. Generate sketches cross section dimensions at center and ends as mentioned in table follows:

4. Using swept blend

5. Select trajectory

6. Pivot direction

7. Select plane for pivot direction

8. Select origin trajectory

9. Select cross section sketches. The model is ready.

10.Export the model to iges – solid – part – flat level.

3.2 Specification

A. Steel leaf spring assembly

The following are the model dimensions.

1. Camber = 80mm

2. Span = 1220mm

3. Thickness of leaves = 7mm

4. Number of leaves = 10

5. Number of full length leaves nF = 2

6. Number of graduated length leaves nG = 8

7. Width = 60

8. Ineffective length = 60mm

9. Eye Diameter = 20mm

10. Bolt Diameter = 10mm

B. Composite mono leaf spring

Parameters	At center	At end
Thickness at ends in mm	70	70
Thickness at mid in mm	150	21

Table 3.1

3.3 Figures

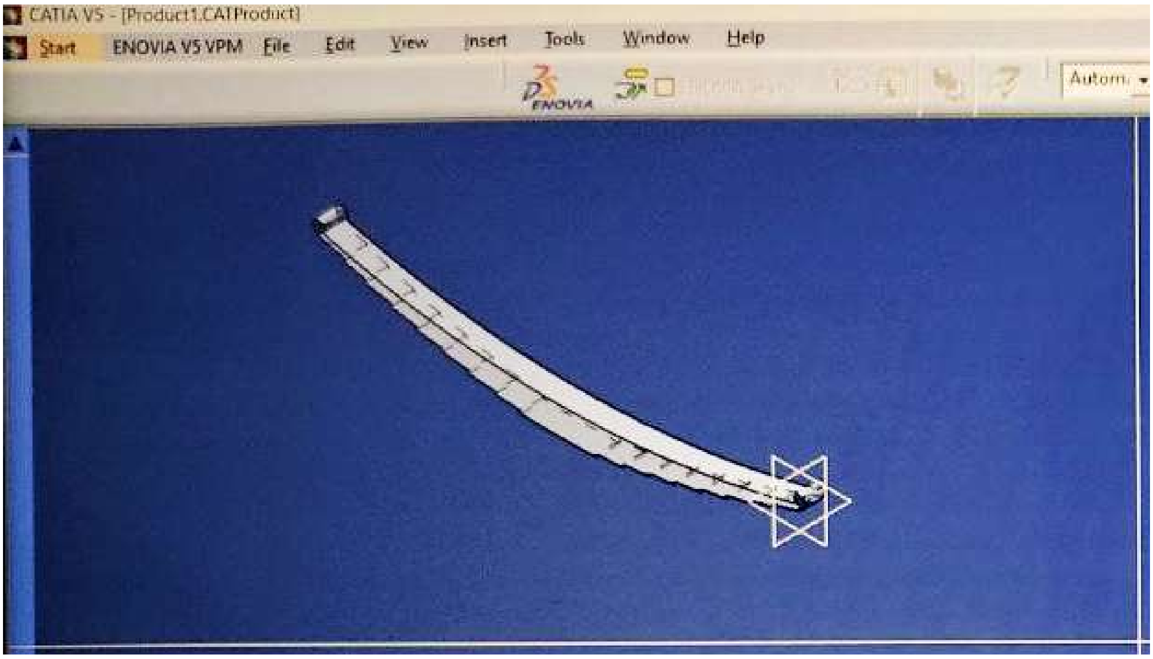


Fig.3.1 Isometric view

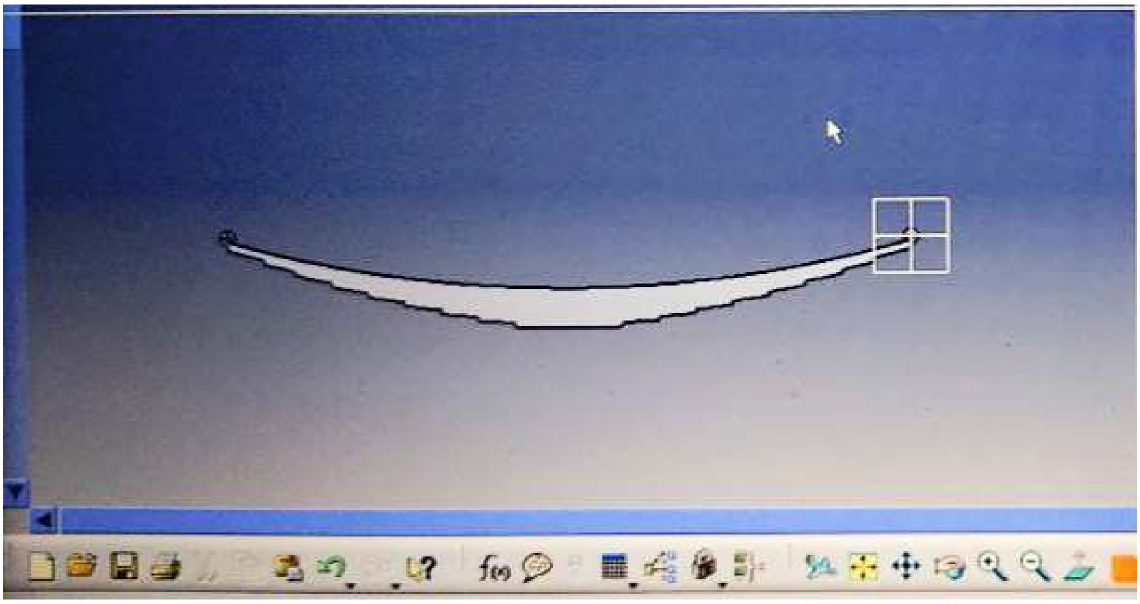


Fig.3.2 side view

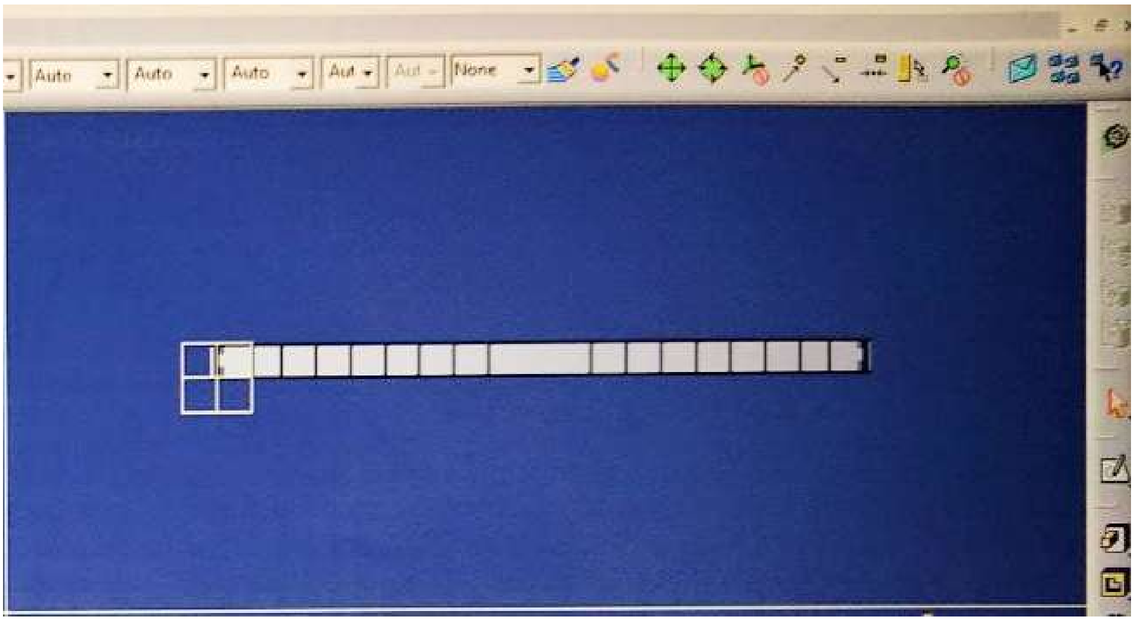


Fig.3.3 top view

CHAPTER – 4

ANALYSIS

4.1 FINITE ELEMENT MODELING AND BOUNDARY CONDITIONS

4.11 Element Type

For steel leaf spring brick 20 node95 is well suited to modal irregular meshes (such as produced from various CAD/CAM Systems.) the element is defined by four nodes having six degrees of freedom at each node: translation in the nodal x, y, and z directions and rotations about the nodal x, y, and z directions. The element also has stress stiffening capability. A 10 – node tetrahedral element without rotational degrees of freedom is also available called solid 92.

For mono composite leaf spring Shell 99 linear layer 99 with 6 degrees of freedom is a typically used standard element type.

4.12 Meshing

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is Brick 20 node 95. shell 99 linear layer 99 for composite leaf spring.

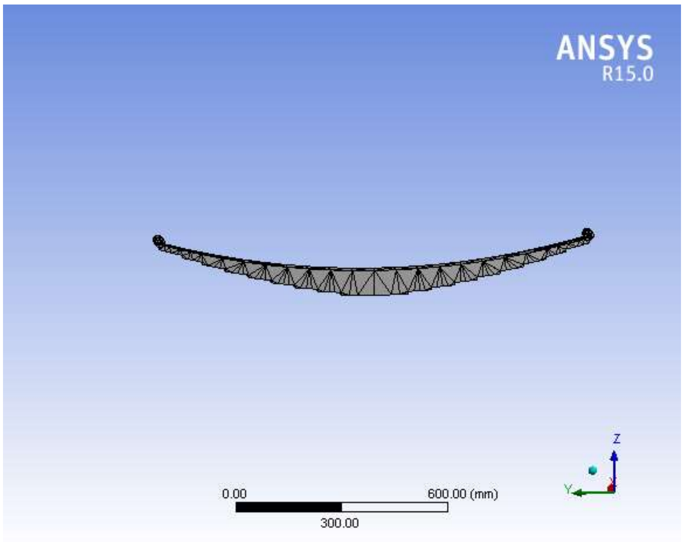


Fig.4.1

4.13 Boundary Conditions

The leaf spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the leaf spring. The ends of the leaf spring are formed in the shape of an eye. The front eye of the leaf spring is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation is occurred. The rear eye of the leaf spring is connected to the shackle, which is a flexible link; the other end of the shackle is connected to the frame of the vehicle. The rear eye of the leaf spring has the flexibility to slide along the X – direction when load applied on the spring and also it can rotate about the pin. The link oscillates during load applied on the spring and also it can rotate about the pin. The link oscillates during load applied and removed.

Therefore the node of rear eye of the leaf spring is constrained in all translational degree of freedom, and constrained the two rotational degrees of freedom. So the front eye is constrained as UX, UY, UZ, ROTX, ROTY and the nodes of rear eye is constrained as UY, UZ, ROTX, ROTY, fig shows the boundary conditions of the leaf spring.

The load is distributed equally by all the nodes associated on the bottom surfaces of bottom most leaf. The load is applied along Fy direction to apply load. For this problem the load is 2000 N, and the numbers of associated nodes are bottom surface of bottom plate. For steel leaf spring pressure is applied .

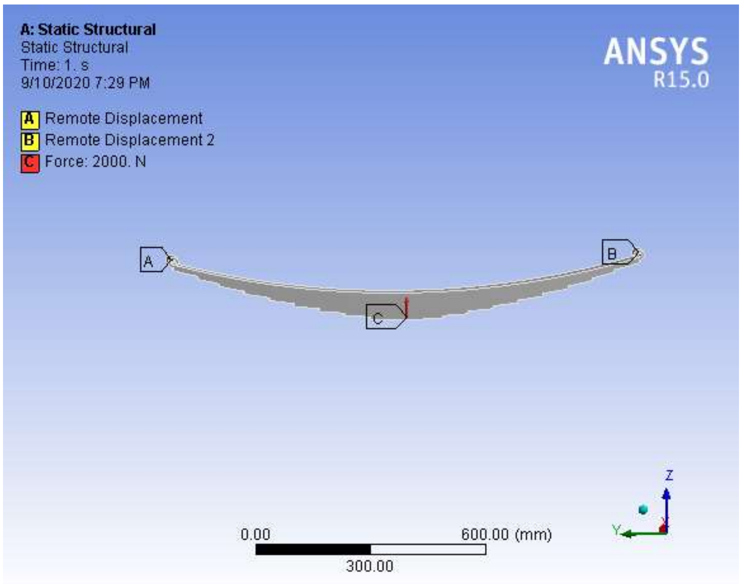


Fig.4.2

4.14 Material

The material properties of the leaf spring have to decided, it is necessary to give young's modules of the material, density, poison's ratio to carryout modal analysis and density is not necessary in the case of static analysis.

A. The following are the material properties considered for steel spring.

Material = Manganese Silicon Steel

Young's modulus E = 2.1 E5 N/mm2

Density þ= 7. 86 E – 6 kg/mm3

Poisson's ration = 0.3

Yield Stress = 1680 N/ mm2.

B. The following are the material properties considered for composite leaf spring.

Material = Carbon epoxy

Young's modulus E = 1.34E11 N/mm2

Density þ= 1600 Kg/mm3

Poisson's ration = 0.2

Shear modulus = 5.8e9 N/mm2

C. The following are the material properties considered for composite leaf spring.

Material = E-Glass/Epoxy

Young's modulus E = 1.4E10 N/mm2

Density þ= 1833 Kg/mm3

Poisson's ration = 0.22

Shear modulus = 5.73e9 N/mm2

4.2 STATIC ANALYSIS

Static analysis determines the safe stress and corresponding pay load of the leaf spring and also to study the behavior of structures under practical conditions. The present work attempts to analyze the safe load of the leaf spring, which will indicate the speed at which a comfortable speed and safe drive is possible.

After the preprocessing, the solution has to be done. From solution phase, choose the new analysis as static. Then solve the current load step option. The solution will be done, the following table given the Von – Mises stress at various loads Static analysis is to be performed to find the allowable stresses. The leaf spring is mounted on the axle of the leaf spring. So load applied from bottom surface of both the leaf springs. All the steel leaves are bounded together with the centre bolt, so the entire load is concentrated on the bottom surface of the leaf spring.

Bending Stress of Leaf Spring Leaf springs (also known as flat springs) are made out of flat plates. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. Consider a single plate fixed at one end and loaded at the other end. This plate may be used as a flat spring.

Let

t = thickness of plate

b = width of plate, and

L = length of plate or distance of the load W from the cantilever end,

We know that the maximum bending moment at the cantilever end

$$M = W.L$$

And section modulus,

$$Z = I/Y \quad (\text{where } I = (b.t3 / 12) \text{ and } Y = t/2)$$

$$\text{So} \qquad Z = b.t2 / 6$$

The bending stress in such a spring,

$$f = M / Z = (6W.L) / b.t2 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\;..\;(i)$$

We know that the maximum deflection for a cantilever with concentrated load at free end is given by

$$\partial = W.L3\partial / 3.E.I = 2f.L2 / 3.E.t \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\;(ii)$$

It may be noted that due to bending moment, top fibers will be in tension and bottom fibers are in compression, but the shear stress is zero at the extreme fibers and the maximum at centre, hence for analysis, both stresses need not to be taken into account simultaneously. We shall consider bending stress only.

If the spring is not of cantilever type but it is like a simply supported beam, with length 2L and load 2W in the centre

Maximum bending moment in the centre,

$$M = W.L$$

$$\text{Section modulus } Z = b.t2 / 6$$

$$\text{Bending stress } f = 6W.L / b.t2$$

We know that maximum deflection of a simply supported beam loaded in the centre is given by

$$\partial = W.L3\partial / 3.E.I$$

From above we see that a spring such as automobile spring (semi-elliptical spring) with length 2L and load in the centre by a load 2W may be treated as double cantilever. If the plate of cantilever is cut into a series of n strips of width b and these are placed as shown, then equations (i) and (ii) may be written as

$$f = 6W.L / n.b.t2 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\;(iii)$$

$$\partial = 4.W.L3\partial / n.E.b.t3 = 2.f.L2 / 3.E.t \;\ldots\ldots\ldots\ldots\;(iv)$$

4.21 Length of Leaf Spring Leaves

The length of the leave springs are calculated by using the formulas given below

$$\text{Length of smallest leaf} = \frac{\text{Effective length}}{n-1} \times 1 + \text{Ineffective length}$$

$$\text{Length of next leaf} = \frac{\text{Effective length}}{n-1} \times 2 + \text{Ineffective length}$$

Similarly,

$$\text{Length of (n-1)}^{\text{th}}\text{ leaf} = \frac{\text{Effective length}}{n-1} \times (n-1) + \text{Ineffective length}$$

$$\text{Length of master leaf} = 2L_1 + 2\prod(d+t)$$

Where $2L_1$ = Length of span or overall length of the spring,
l=distance between centers of U-bolts (ineffective length (I.L) of the leaf spring),
n_F = Number of full length leaves,
n_G = Number of graduated leaves,
n = Total number of leaves = $n_F + n_G$,
E.L = Effective length of the spring = $2L_1 - (2/3)l$,
d = Inside diameter of eye and
t = Thickness of master leaf.

4.3 MODAL ANALYSIS

4.31 What Is Modal Analysis?

The most common type of analysis is quasi-static analysis, where the load is applied at a very slow rate so that the acceleration is negligible (or almost zero). Dynamic analysis is where the effects of acceleration cannot be ignored. Both types provide a one-to-one relationship between a particular input (for example, a force applied on a system) to its system response (for example, a displacement of the system due to its load).

In contrast to quasi-static and dynamic, modal analysis provides an overview of the limits of the response of a system. For example, for a particular input (like an applied load of certain amplitude and frequency), what are the limits of the system's response (for example, when and what is the maximum displacement).

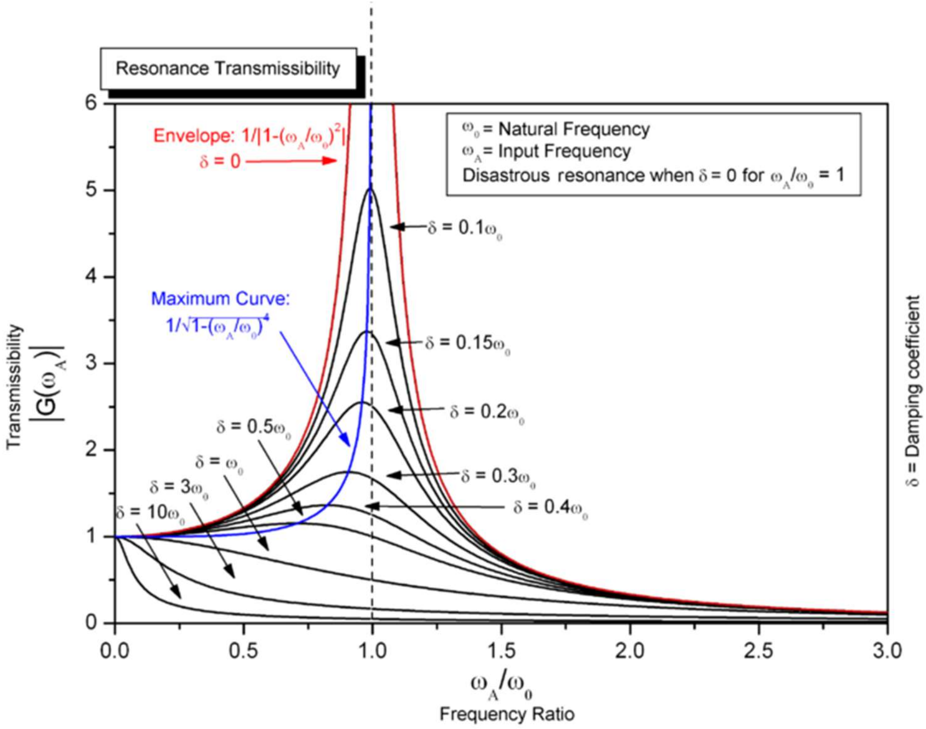


Fig.4.3

As shown in Fig.10 every object has an internal frequency (or resonant frequency) at which the object can naturally vibrate. It is also the frequency where the object will allow a transfer of energy from one form to another with minimal loss—here it is from vibrational to kinetic. As the frequency increases towards the "resonant frequency," the amplitude of response asymptotically increases to infinity. In other words, the result of modal analysis are these frequencies at which the amplitude increases to infinity.

4.32 Why Are These Frequencies Important?

Every system can be described in terms of a stiffness matrix that connects the displacements (or system response) and forces (or system inputs). These frequencies are known as natural frequencies of the system and are provided by the eigenvectors of the stiffness matrix. These frequencies are also known as the resonant frequencies.

The resonant frequencies related to mechanical structures are known as mechanical resonance. Similarly, every system—like acoustic, thermal, or electromagnetic—has its own resonant frequencies at which resonance occurs. As illustrated in Fig. 03, as the frequency of the applied load (or input on the x-axis) nears the resonant frequency, the amplitude of response (on the y-axis) nears infinity!

As governed by the first law of thermodynamics, one form of energy is only converted to another. However, energy is neither created nor destroyed. In any mechanical system, when an external time-varying load is applied, it is equivalent to supplying the system with some kinetic or vibrational energy. This is transmitted through the system resulting in a displacement of the structure. However, due to the presence of friction, some of this energy is also dissipated as heat. To understand this process more physically, imagine that structure is in a constant state of motion sub-atomically. The energy supplied is transported from one part of the structure to the other through energy transfer by atomic processes. However, when the frequency of loading is the same as the averaged vibrational frequency of the atoms in the structure, the energy is transferred with minimum loss. In other words, one can think of it as two waves (one being the external load and the other being that of the internal atomic structure) that are being superimposed. When the frequencies are the same, they tend to add up.

Therefore, it is important to know the frequencies at which the structure can behave erratically.

4.3.3 Practical Examples for Modal Analysis

There are several examples where a prior accurate modal analysis could have prevented loss of lives and property. Some famous ones include:

1. Tacoma Narrows Bridge Disaster of 1940

2. Mexico City Earthquake of 1985

3. Taipei 101 and Burj Khalifa

CHAPTER 5

RESULTS

5.1 Result for leaf spring

5.1.1 Von- mises stress

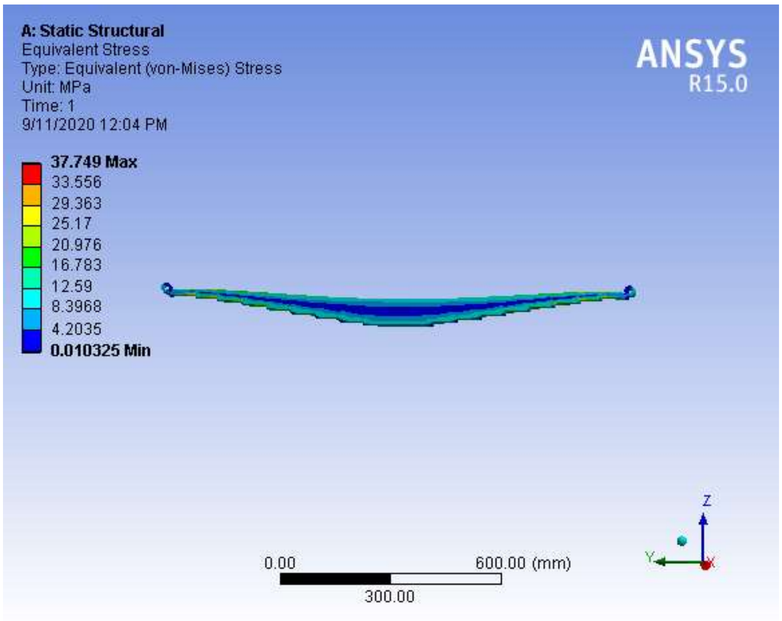


Fig 5.1 Distribution of Von mises stresses at a load 2000 N

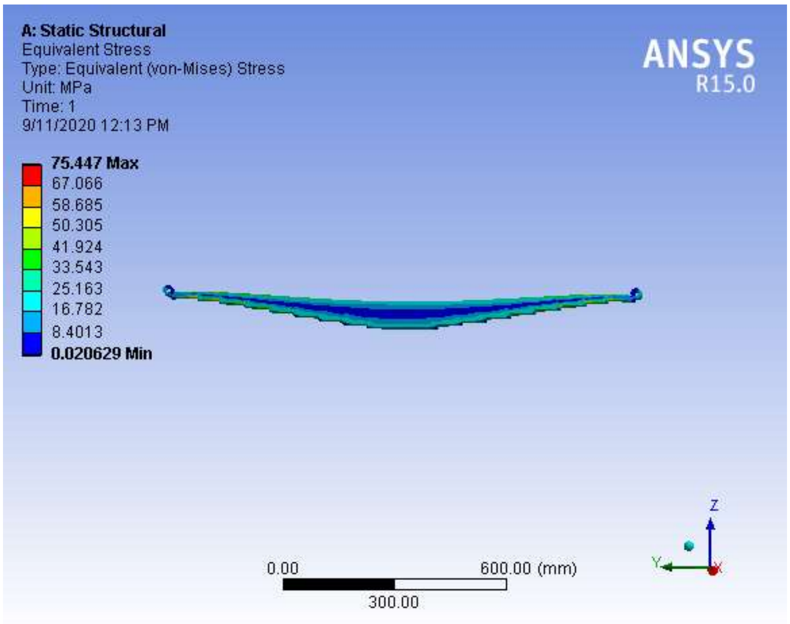


Fig 5.2 Distribution of Von mises stresses at a load 4000 N

5.1.2 Deformation

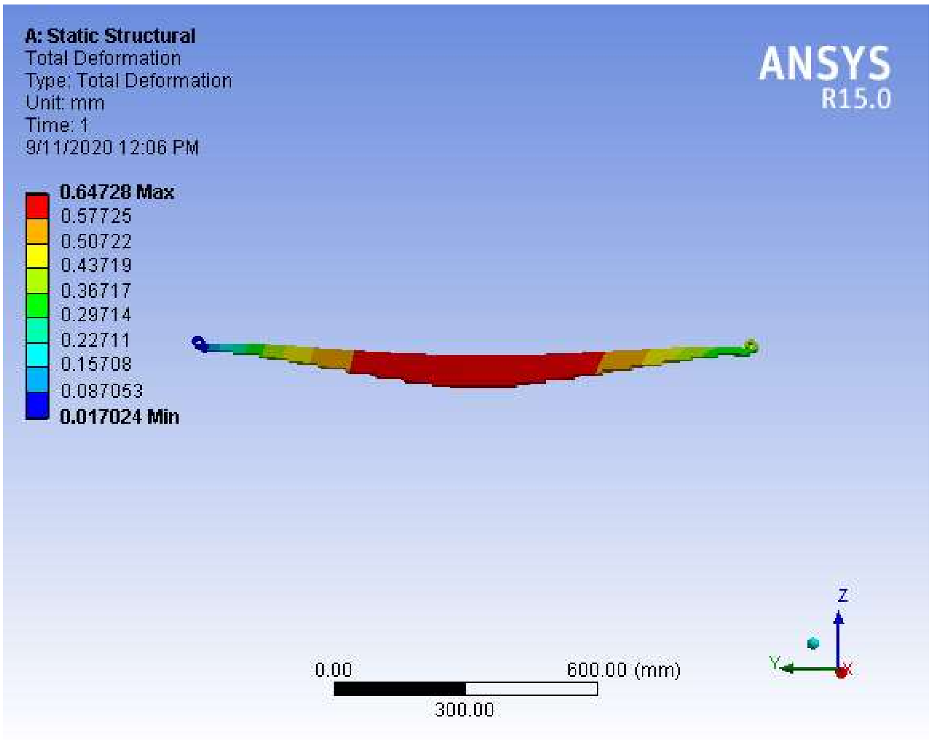


Fig 5.3 Distribution of Deformation plots at a load of 2000 N on steel leaf spring

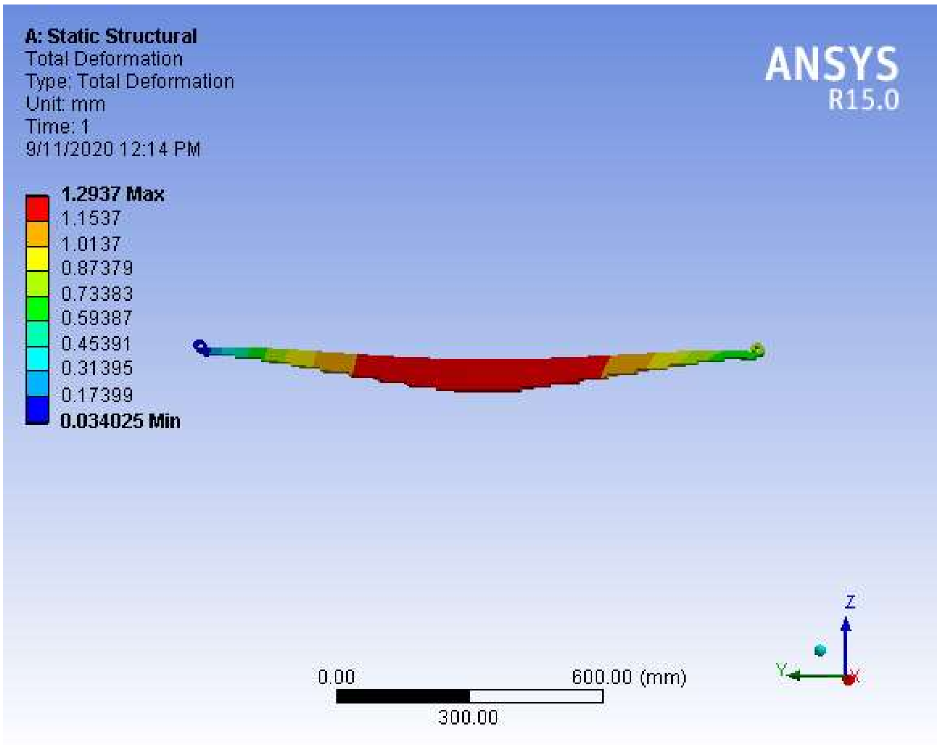


Fig 5.4 Distribution of Deformations plots at a load of 4000 N on steel leaf spring

5.2 Result for carbon epoxy

5.2.1 Von mises stress

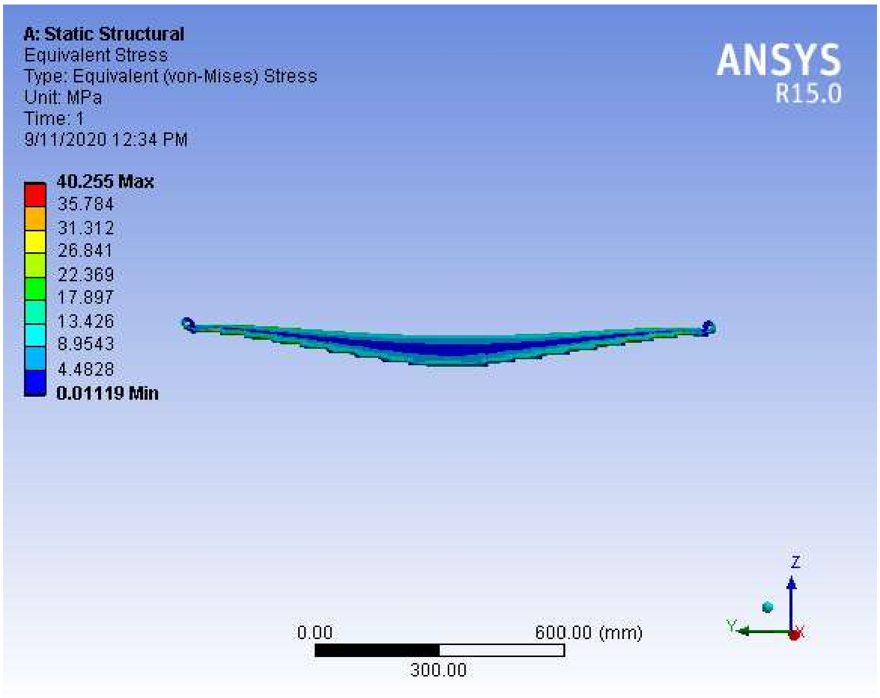


Fig 5.5 Distribution of Von mises stresses at a load 2000 N on Carbon epoxy

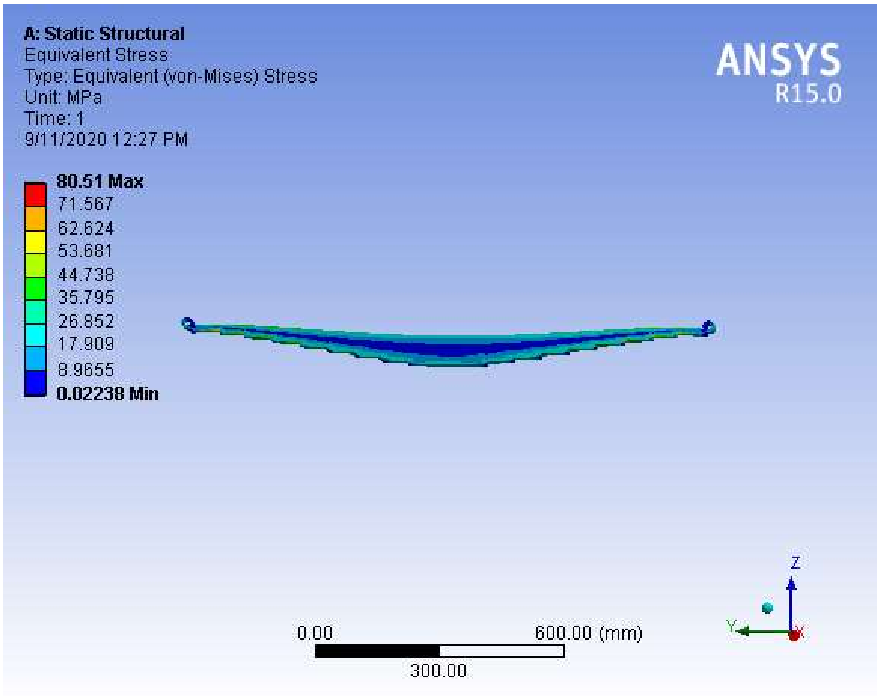


Fig 5.6Distribution of Von mises stresses at a load 4000 N on Carbon epoxy

5.2.2 Deformation

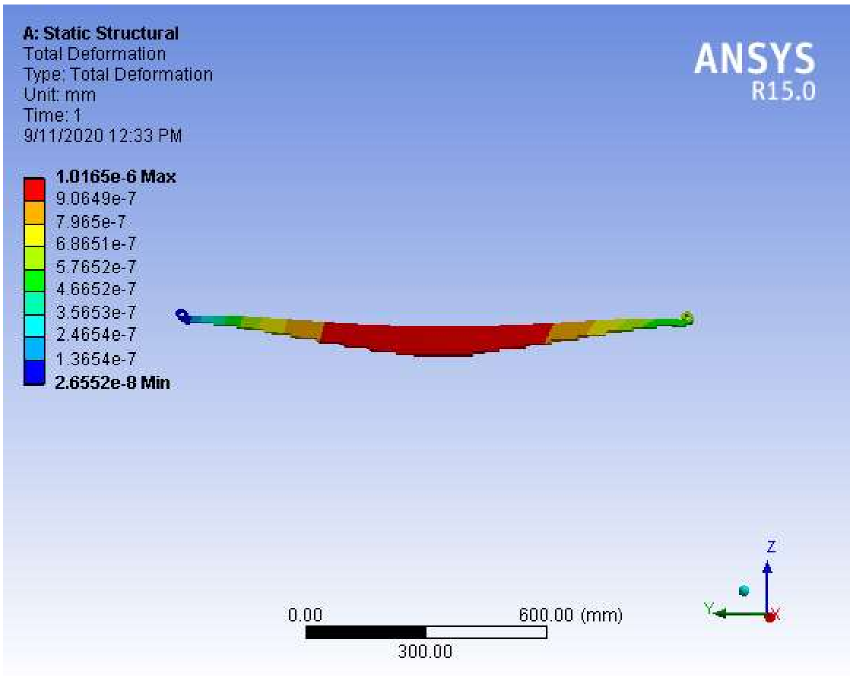


Fig 5.7 Distribution of Deformations plots at a load of 2000 N on Mono composite carbon epoxy leaf spring

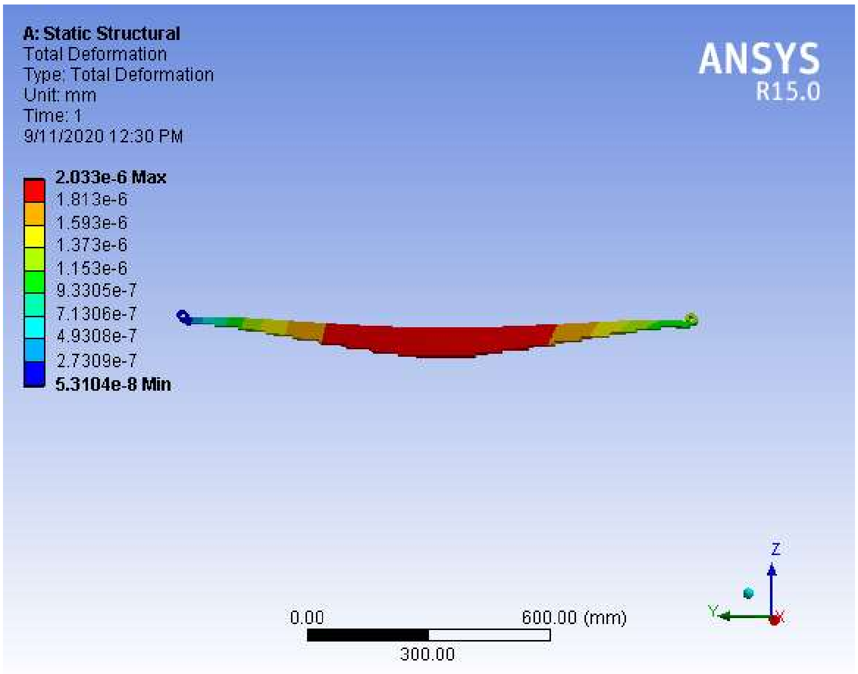


Fig 5.8 Distribution of Deformations plots at a load of 4000 N on Mono composite carbon epoxy leaf spring.

5.3 Result for E GLASS EPOXY

5.3.1 Von mises stress

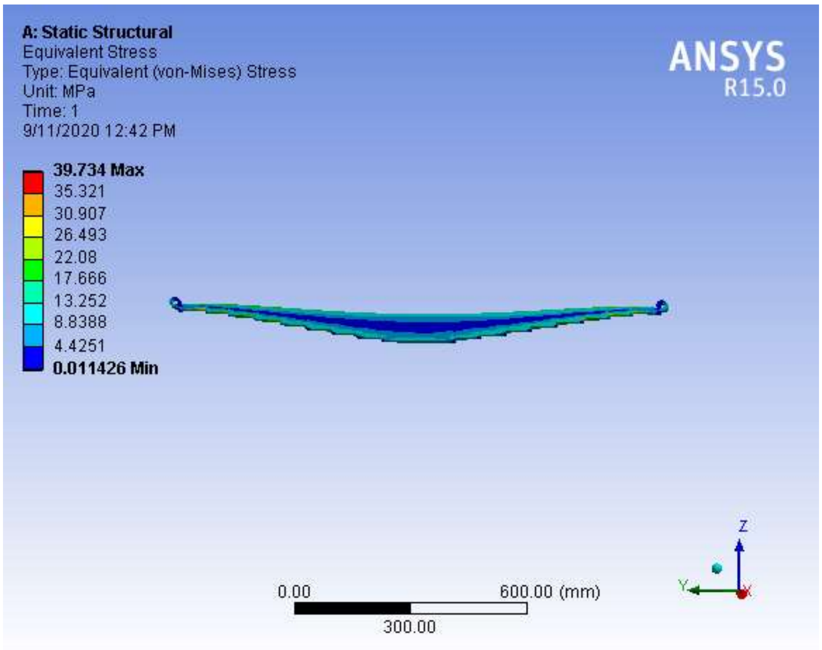


Fig 5.9 Distribution of Von mises stresses at a load 2000 N on E Glass epoxy

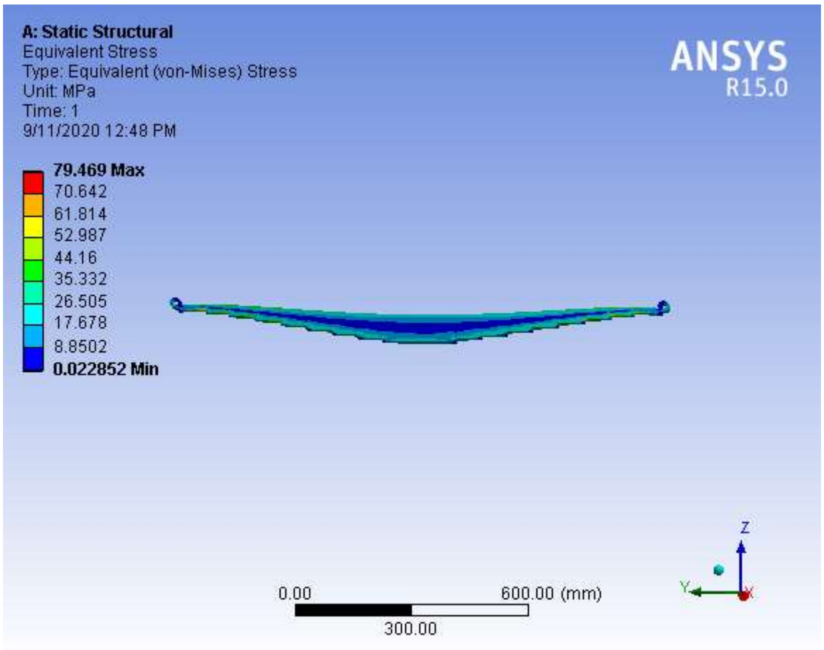


Fig 5.10 Distribution of Von mises stresses at a load 4000 N on E Glass epoxy

5.3.2 Deformation

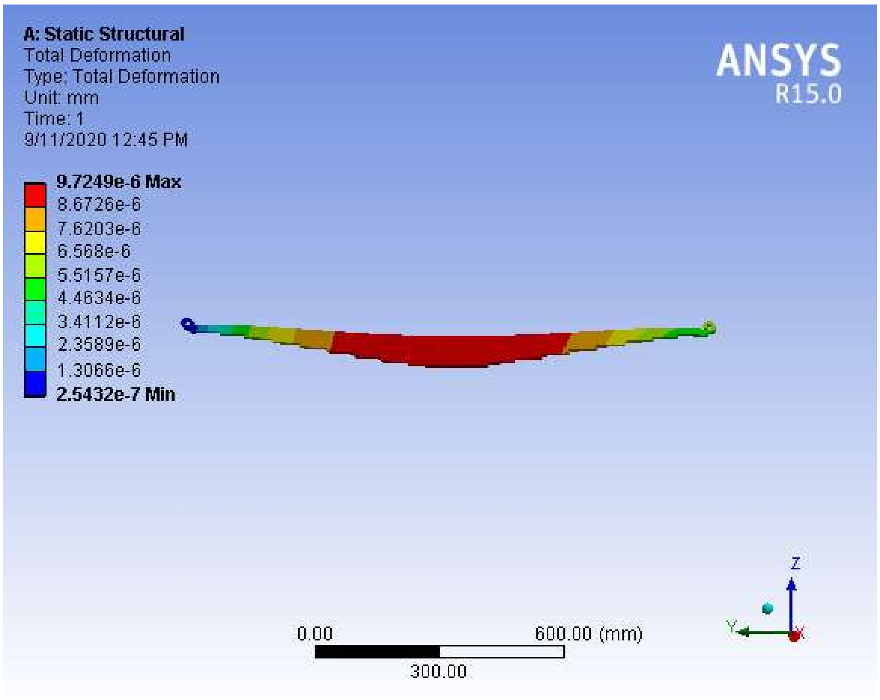


Fig 5.11 Distribution of Deformations plots at a load of 2000 N on Mono composite e glass epoxy leaf spring

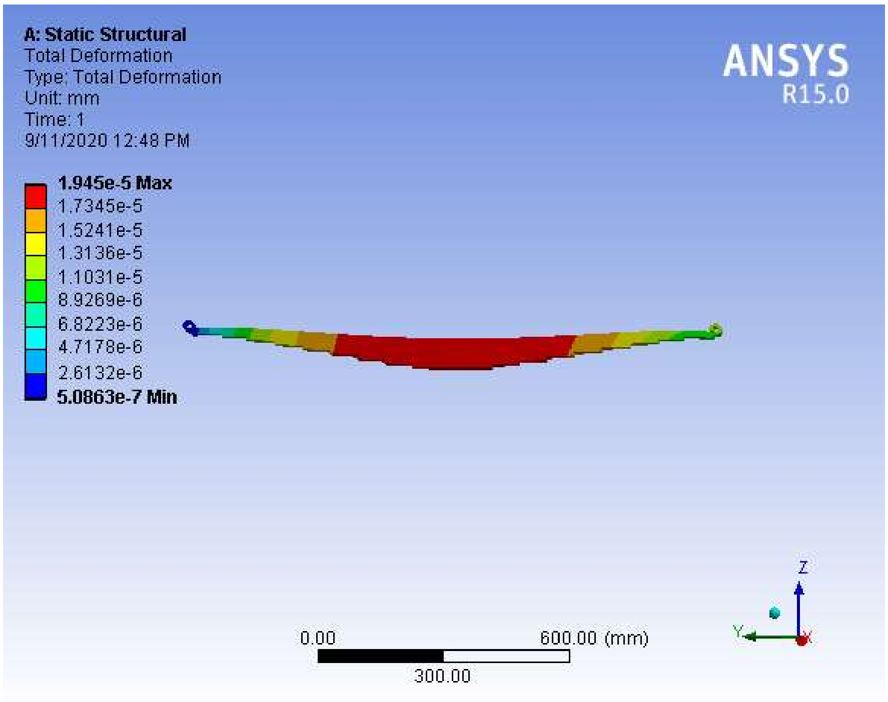


Fig 5.12 Distribution of Deformations plots at a load of 4000 N on Mono composite e glass epoxy leaf spring

5.4 Result table:

5.4.1 For von mises stress

Materials	Theoretical values	Research paper observation		Our observation		
		Steel spring	Carbon spring	Steel spring	Carbon spring	E Glass spring
2000 N	266	339	228.4	37.7	40.25	39.74
4000N	533	679	411.2	75.4	80.51	79.46

Table 5.1

5.4.2 For Deformation

Materials	Research paper observation		Our observation		
	Steel spring	Carbon spring	Steel spring	Carbon spring	E Glass spring
2000 N	.49	.287e-5	.64	101e-6	9.72e-6
4000N	.75	.575e-5	1.29	2.033e-6	1.94e-5

Table 5.2

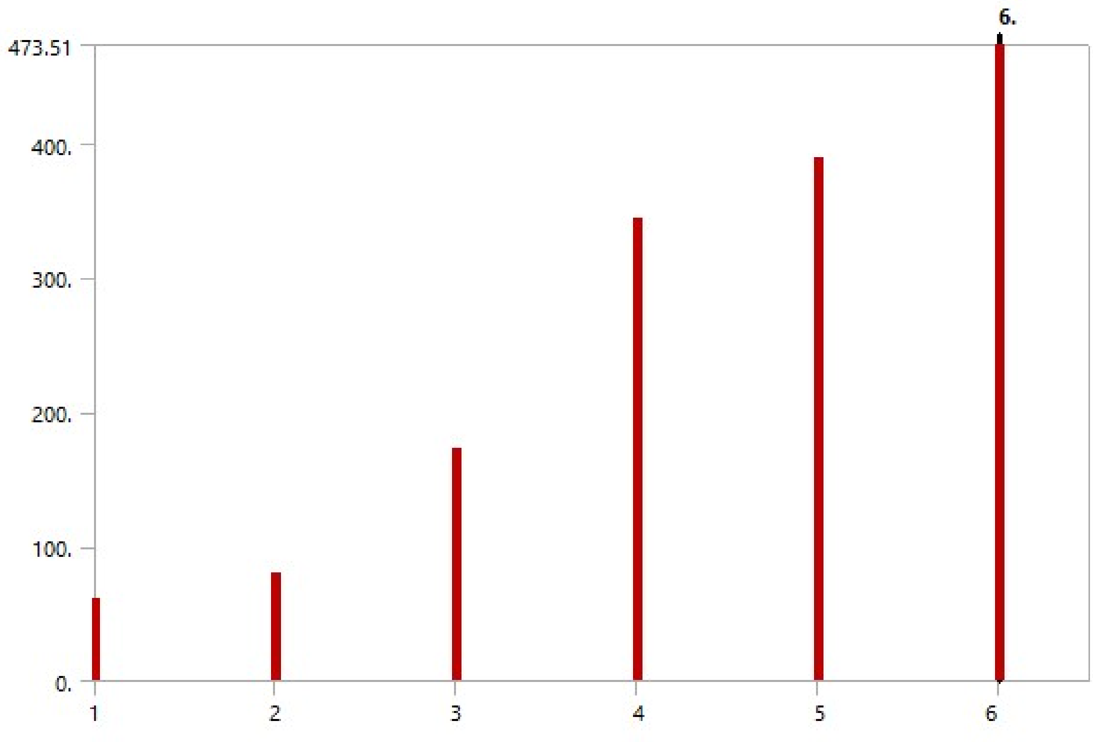
5.5 Modal results

5.5.1 Table

Mode	Frequency [Hz]
1.	60.917
2.	79.652
3.	172.28
4.	344.21
5.	388.75
6.	473.51

Table 5.3

5.5.2 Graph



Graph 5.1

5.5.3 Figures

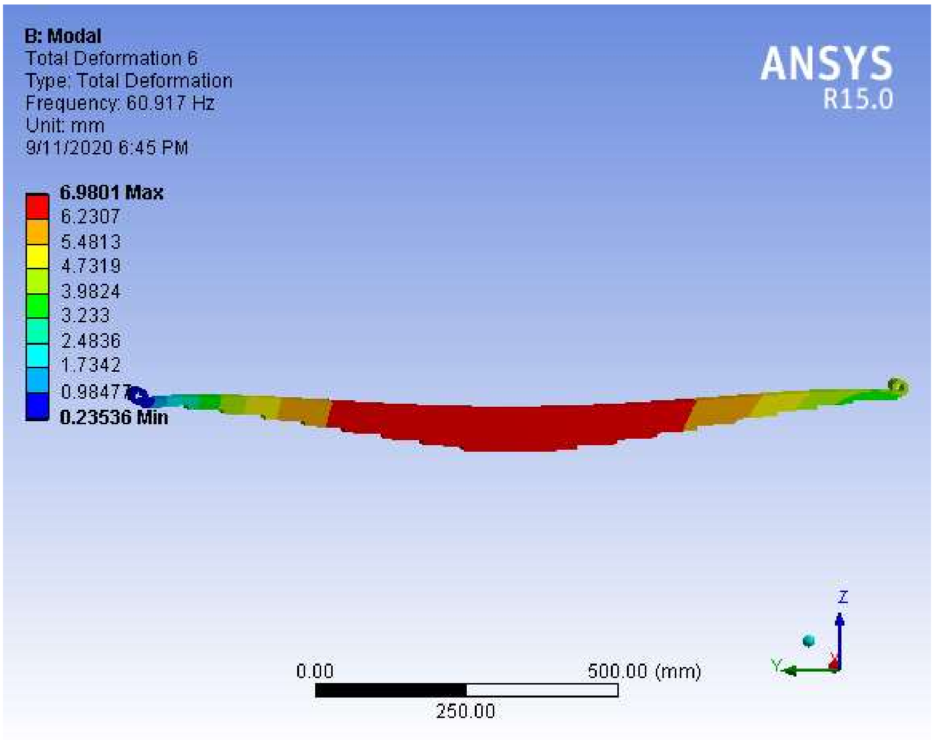


Fig. 5.13 For node 1

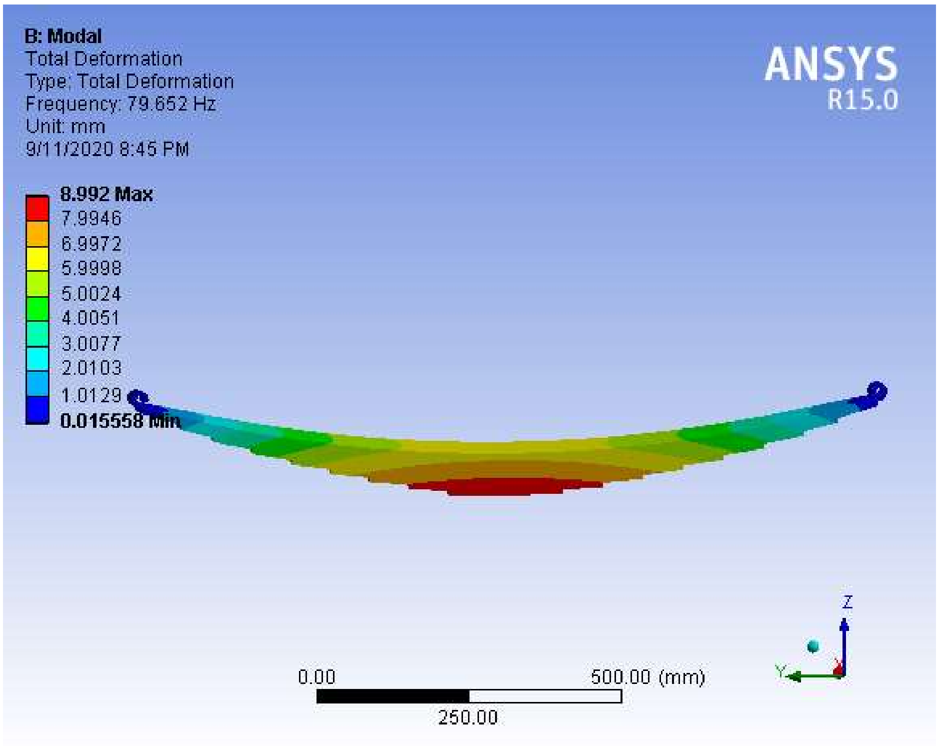


Fig. 5.14 For node 2

CHAPTER 6

CONCLUSION

6.1 Conclusion

The leaf spring has been modeled using solid tetrahedron 4 – node element. By performing static analysis, it is concluded that the maximum safe load is 4000 N for the given specification of the leaf spring. These static analysis results of mono composite Carbon Epoxy leaf springs are compared to steel leaf spring.

The results show:

1) The stresses in the composite leaf spring are much lower than that of the steel spring.

2) The composite spring can designed to strengths and stiffness much closer to steel leaf spring by varying the layer configuration and fiber orientation angles.

3) The strength to weight ratio is higher for composite leaf spring than conventional steel spring with similar design,

The major disadvantages of composite leaf spring are the matrix material has low chipping resistance when it is subjected to poor road environments which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problem will not be there. Composite leaf springs made of polymer matrix composites have high strength retention on ageing at severe environments.

The steel leaf spring width is kept constant and variation of natural frequency with leaf thickness, span, camber and numbers of leaves are studied. It is observed from the present work that the natural frequency increases with increase of camber and almost constant with number of leaves, but natural frequency decreases with increase of span. The natural frequencies of various parametric combinations are compared with the excitation frequency for different road irregularities. The values of natural frequencies and excitation frequencies are the same for both the springs as the geometric parameters of the spring are almost same except for number of leaves.

This study concludes that it is advisable to operate the vehicle such that its excitation frequency does not match the above determined natural frequencies i.e. the excitation frequency should fall between any two natural frequencies of the leaf spring.

An extended study of this nature by varying the layer configuration higher strengths can be achieved. Replacing the conventional leaf spring by composite leaf spring can be considered from strength, stiffness and vehicle stability point of view in vehicle stability. Instead of mono composite material, multi composite materials with multiple layers can be considered for study. An efficient design and manufacturing process of composite material leaf spring can reduce the cost and weight of the vehicle

CHAPTER 7

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