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# INFLUENCE OF PARAMETERS ON SAFE DESIGN OF LEAF SPRING FOR STATIC AND DYNAMIC LOADING USING FINITE ELEMENT ANALYSIS

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**Abstract**:-*In this paper, the static and dynamic analysis of leaf is carried out using Finite Element Analysis. The ANSYS 18.0 is used to analyze the model. The leaf spring is modeled in CATIA software. Analytical method is used to predict the maximum pay load of the vehicle and natural frequencies of leaf spring to compare with excitation frequency. With due consideration of factor of safety, the maximum bending stress and corresponding pay loads are computed analytically and validated with the results obtained in static analysis using ANSYS software. To assess the behavior of the different parametric combinations of the leaf spring, the modal analysis is carried out using ANSYS software to determine the natural frequencies and the corresponding mode shapes. These 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 validated with the analytical results.*

**Keywords** - *Leaf Spring, Natural frequency, ANSYS, Pay load, model shapes*

## I. INTRODUCTION

A spring is an elastic body, whose function is to distort when loaded and to recovers its original shape when the load is removed. Semi-elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension. The spring consists of a number of leaves called blades. The blades are varying in length. The blades are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining blades are called graduated leafs. All the blades are bound together by means of steel straps.

The leaves of the leaf spring require lubricant at periodic intervals. If not, the vehicle is jacked up so that the weight of the axle opens up the leaves. The spring is then cleaned thoroughly and sprayed with graphite penetrating oil. However, it is important to remember that in some vehicles, (e.g. Ambassador, TATA - 407) it is specified that the lubricant of spring leaves should not be done. In such cases the instruction must be followed.

The lubrication of shackle pins at regular intervals, say 1000 km., should also be done with S.A.E 140 oil. However, no lubrication is required when rubber bushes are used, as in case of the Hindustan Ambassador car. A.strzat and T.Paszek performed a three dimensional contact analysis of the car leaf spring. Shahriar Tavakkoli, Farhang Aslani, and David S. Rohweder performed analytical prediction of leaf spring bushing loads using MSC/NASTRAN and MDI/ADAMS.

Reddy et al [1] observed the variations of span, camber, thickness and no. of leaves will influence the design of the leaf spring. The resonance will not occur due to natural and exiting frequency coincident as they are varied by considerable difference.

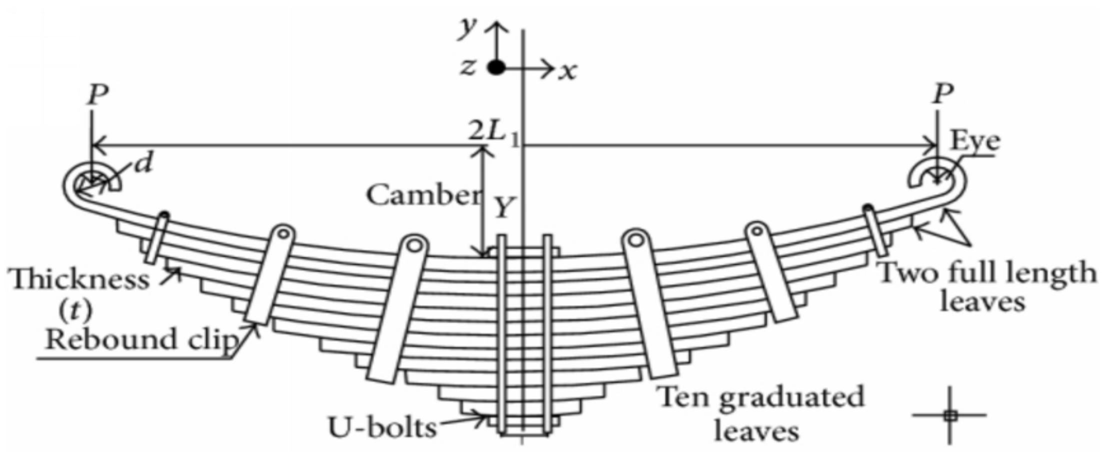



**Fig 1 Elements of Leaf Spring**

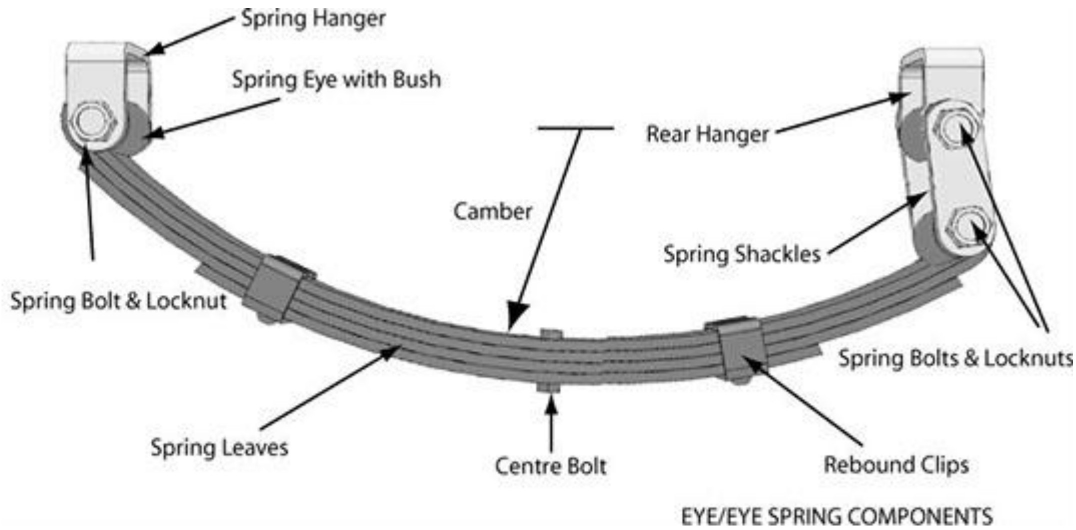



**Fig 2. Parametric elements of Leaf Spring**

## II. PROBLEM MODELING

### A. Problem Statement

The objective of this investigation is to perform the modal analysis. The natural frequencies and the corresponding mode shapes are dogged to assess the behavior of the different parametric combinations of the leaf spring. These 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 intended mathematically.

### B. Methodology

The bending stresses at different loading conditions under static and dynamic conditions are computed. The maximum bending stress and the corresponding pay loads are identified using analytical approach. The static analysis is performed using ANSYS software and validated the bending stresses are computed for safe design conditions. The natural frequencies and the corresponding mode shapes obtained by simulation under model analysis in ANYSY are compared with analytical results.

### C. Geometry

In computer-aided design, geometric modeling is concerned with the computer compatible mathematical description of the geometry of an object. The mathematical description allows the model of the object to be displayed and manipulated on a graphics terminal through signals from the CPU of the CAD system. The software that provides geometric modeling capabilities must be designed for efficient use both by the computer and the human designer.

An automobile assumed as a single degree of freedom system traveling on a sine wave road having wavelength of L. The contour of the road acts as a support excitation on the suspension system of an automobile .The period is related to ω by t=2/ω and L is the distance traveled as the sine wave goes through one period.

In the geometrical modelling, length of leaf spring leaves, consequently the rotation angle and the radius of curvatures of each leaf are considered. The bending stresses are obtained under different loading conditions.

#### i. Geometric Properties of leaf springs

The following geometric properties are considered for modelling: Camber = 80 mm; Span = 1220 mm; Thickness = 7 mm; Width = 70 mm; Number of full length leaves $n_F = 2$; Number of graduated leaves $n_G = 8$; Total Number of leaves n = 10; Material Properties of leaf spring; Material = Manganese Silicon Steel; Young's Modulus E = 2.1E5 N/mm$^2$; Density = 7.86E-6 kg/mm$^3$; Poisson's ratio = 0.3; Yield stress = 1680 N/mm$^2$

#### ii. Length of Leaf Spring Leaves

The Effective length of the spring is computed using the equation $2L_1 – (2/3)$ t.

#### iii. Bending Stress of Leaf Spring

Leaf springs (also known as flat springs) as shown in Fig.1 are made out of flat plates. The leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. A single plate fixed at one end and loaded at the other end is considered for analysis. This plate may be used as a flat spring. The maximum bending moment at the cantilever end is M = W.L where t = thickness of plate, b = width of plate, and L = length of plate or distance of the load W from the cantilever end, the Section Modulus Z = I/Y, where I = $(b.t^3/12)$, Y = t/2. The bending stress in such a spring, f is determined using the relation $(6W.L) / b.t^2$. The maximum deflection for a cantilever with concentrated load at free end is computed using the equation $WL^3 /3EI$.

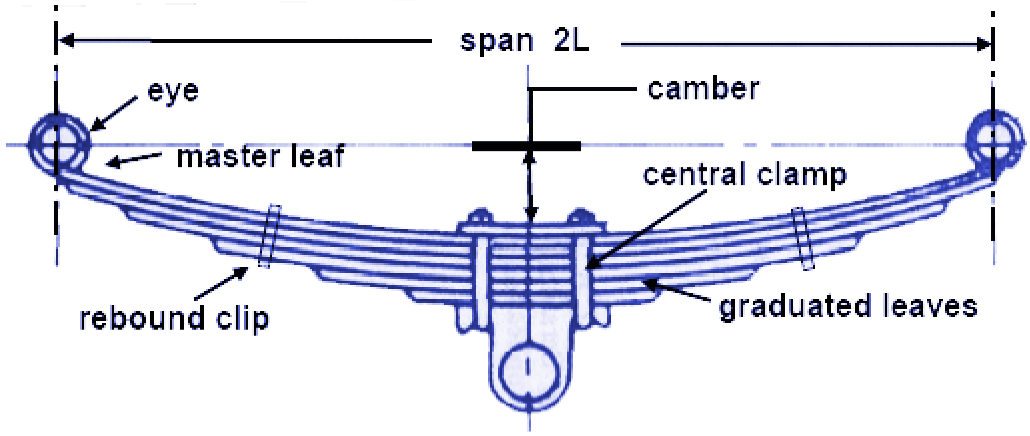



**Fig 3. Modelling of Leaf spring for bending stress computation**

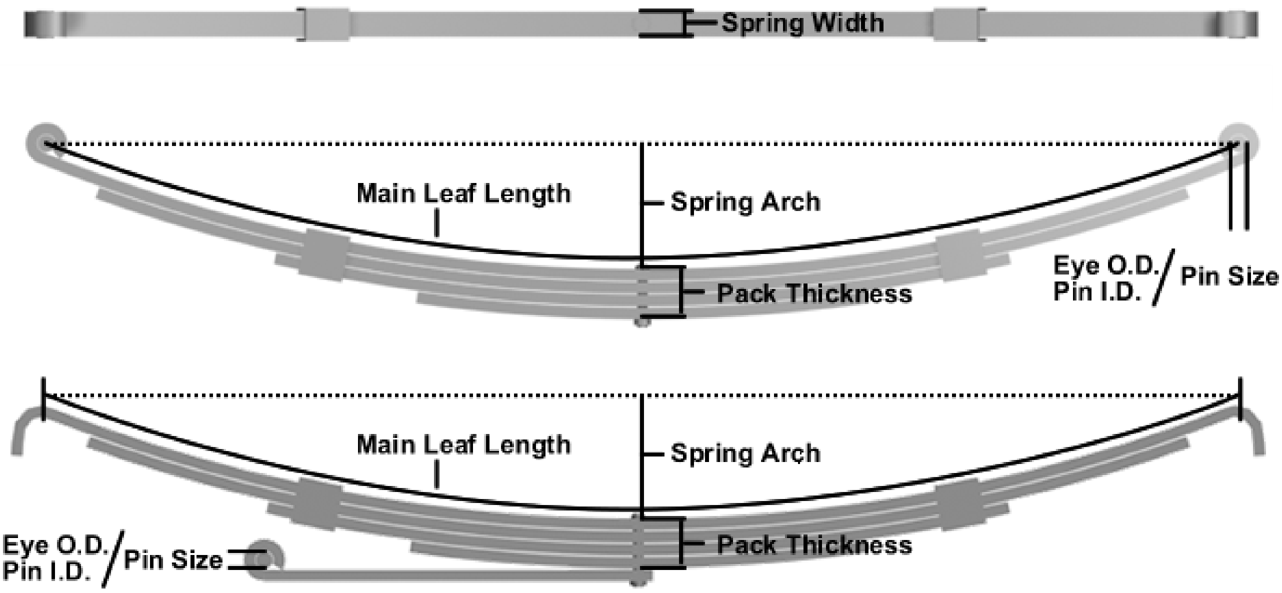



**Fig 4. Modelling of Leaf spring for maximum deflection**

## III. MODAL ANALYSIS

In many engineering applications, the natural frequencies of vibration are of primary interest. This is probably the most common type of dynamic analysis and is referred to as an 'eigen value analysis'. In addition to the frequencies, the mode shapes of vibration which arise at the natural frequencies are also of primary interest. These are the undamped free vibration response of the structure caused by an initial disturbance from the static equilibrium position. This solution derives from the general equation by zeroing the damping and applied force terms. Thereafter, it is assumed that each node is subjected to sinusoidal functions of the peak amplitude for that node. A finite element structure for which there is more than one d.o.f, D is the vector of nodal d.o.f ,R is the load which contains the moments as well as forces, K is the stiffness matrix, C is the damping matrix and M the mass matrix, then $KD + C\dot{D} + M\ddot{D} = R$ where $\dot{D}$ *is the nodal velocity*, $\ddot{D}$ is nodal acceleration and amplitude (global) d.o.f. With no damping C=0 .Vibration is free if loads are either zero or constant. Vibration motion, consist of displacements that vary sinusoidally with time relative to the mean configuration $D_m$ created by constant loads $R_c$. The equation for $D = D_m + D \sin \omega t$ Where $D_m$ is the vector of nodal displacements in vibration and ω is the natural frequency in radians per second. The governing equation of undamped free vibrations$[K - \omega^2 M]\bar{D} = 0$, is called ***eigenvalue*** problem. A natural frequency may also be called as resonant frequency and $\omega_i^2$ is various called as eigenvalue, latent root or characteristic number. A mode may also be called an eigen vector, mode shape, normal mode or principal mode the smallest nonzero $\omega_i$ is called the fundamental natural frequency of vibration, where the eigenvalue is equal to the total number of degrees of freedom in the model. Each eigenvalue or frequency has a corresponding eigenvector or mode shape. Since each of the eigenvectors cannot be null vectors, the mode shapes are also of interest of the engineer. These are normalized to the maximum displacement of the structure. The theoretical solution implies that the structure will vibrates in any mode shape indefinitely. However, since there is always some ***damping*** present in any structure, the vibrations eventually decay.

## IV. MATHEMATICAL ANALYSIS

No. Of leaves, length of leaf spring, rotation angle and radius of curvature of the each leaf can be used to model and compute the bending stresses in the leaf spring. The Table1 shows different parameters required for modelling the leaf spring when thickness is 7 mm; similar tabular values are obtained for thickness of 8, 9 and 10 mm.

**Table 1. Length of leaves when thickness is 7 mm**

| Leaf Length | Full leaf length (mm) | Half leaf length (mm) | Radius of curvature (mm) | Half Rotation Angle (degrees) |
|---|---|---|---|---|
| 1 | 1240 | 620 | 2372.625 | 14.972 |
| 2 | 1240 | 620 | 2379.625 | 14.928 |
| 3 | 1108 | 554 | 2386.625 | 13.299 |
| 4 | 978 | 489 | 2393.625 | 11.708 |
| 5 | 846 | 423 | 2400.625 | 10.096 |
| 6 | 716 | 358 | 2407.625 | 8.519 |
| 7 | 584 | 292 | 2414.625 | 6.929 |
| 8 | 454 | 227 | 2421.625 | 5.371 |
| 9 | 322 | 161 | 2428.625 | 3.798 |
| 10 | 190 | 95 | 2436.625 | 2.235 |

The Table 2 shows different parameters required for modelling the leaf spring when Camber is 80 mm; similar tabular values are obtained for Camber of 90, 100 and 110 mm.

**Table 2. Length of leaves when Camber is 80 mm**

| Leaf Length | Full leaf length (mm) | Half leaf length (mm) | Radius of curvature (mm) | Half Rotation Angle (degrees) |
|---|---|---|---|---|
| 1 | 1240 | 620 | 2372.625 | 14.972 |
| 2 | 1240 | 620 | 2379.625 | 14.928 |
| 3 | 1108 | 554 | 2386.625 | 13.299 |
| 4 | 978 | 489 | 2493.625 | 11.705 |
| 5 | 846 | 423 | 2400.625 | 10.096 |
| 6 | 716 | 358 | 2407.625 | 8.519 |
| 7 | 584 | 292 | 2414.625 | 6.929 |
| 8 | 454 | 227 | 2421.625 | 5.371 |
| 9 | 322 | 161 | 2428.625 | 3.798 |
| 10 | 190 | 95 | 2436.625 | 2.235 |

The Table 3 shows different parameters required for modelling the leaf spring when Span is 1120 mm; similar tabular values are obtained for span of 1220, 1320, 1420 mm.

**Table 3. Length of leaves when Span is 1120 mm**

| Leaf Length | Full leaf length (mm) | Half leaf length (mm) | Radius of curvature (mm) | Half Rotation Angle (degrees) |
|---|---|---|---|---|
| 1 | 1140 | 570 | 2007 | 16.272 |
| 2 | 1140 | 570 | 2014 | 16.216 |
| 3 | 1020 | 510 | 2021 | 14.459 |
| 4 | 900 | 450 | 2028 | 12.714 |
| 5 | 780 | 390 | 2035 | 10.981 |
| 6 | 660 | 330 | 2042 | 9.259 |
| 7 | 540 | 270 | 2049 | 7.55 |
| 8 | 420 | 210 | 2056 | 5.852 |
| 9 | 300 | 150 | 2063 | 4.166 |
| 10 | 180 | 90 | 2070 | 2.489 |

The Table 4 shows different parameters required for modelling the leaf spring when number of leaves are 9; similar tabular values are obtained for number of leaves of 10, 11 and 12.

**Table 4. Length of leaves when number of leaves 9**

| Leaf Length | Full leaf length (mm) | Half leaf length (mm) | Radius of curvature (mm) | Half Rotation Angle (degrees) |
|---|---|---|---|---|
| 1 | 1240 | 620 | 1917.5 | 18.526 |
| 2 | 1240 | 620 | 1924.5 | 18.459 |
| 3 | 1092 | 546 | 1931.5 | 16.196 |
| 4 | 946 | 473 | 1938.5 | 13.980 |
| 5 | 798 | 399 | 1945.5 | 11.751 |
| 6 | 650 | 325 | 1952.5 | 9.537 |
| 7 | 502 | 251 | 1959.5 | 7.339 |
| 8 | 356 | 178 | 1966.5 | 5.186 |
| 9 | 208 | 104 | 1973.5 | 3.019 |

The variation of bending stress of leaf spring is tabulated in Table 5.

**Table 5 Variation of Bending Stress with load**

| Load (N) | Bending Stress (N/mm$^2$) |
|---|---|
| 1000 | 48.502 |
| 2000 | 97.005 |
| 3000 | 145.075 |
| 4000 | 194.010 |
| 5000 | 242.512 |
| 6000 | 291.015 |
| 7000 | 339.517 |
| 8000 | 388.020 |
| 9000 | 436.52 |
| 10000 | 485.025 |
| 11000 | 533.527 |
| 12000 | 582.03 |
| 13000 | 630.532 |
| 14000 | 679.035 |
| 15000 | 727.537 |

The leaf is analyzed under the conditions of road irregularity, for varying speeds ranging from 20 Kmph to 140 Kmph at different frequency levels are considered. The table 6 will shows the variation of exciting frequencies under different speeding conditions.

**Table 6. Variation of Exciting Frequency with Vehicle Speed**

| Speed (Kmph) | Frequency Hz (at WRI = 1m) | Frequency Hz (at WRI = 2m) | Frequency Hz (at WRI = 3m) | Frequency Hz (at WRI = 4m) | Frequency Hz (at WRI = 5m) |
|---|---|---|---|---|---|
| 20 | 5.5500 | 2.77 | 1.8518 | 1.3888 | 1.11111 |
| 40 | 11.1111 | 5.54 | 3.7037 | 2.7777 | 2.22222 |
| 60 | 16.6666 | 8.31 | 5.5555 | 4.1664 | 3.33333 |
| 80 | 22.2222 | 11.08 | 7.4074 | 5.5552 | 4.44444 |
| 100 | 27.7777 | 13.85 | 9.2593 | 6.9440 | 5.55555 |
| 120 | 33.3333 | 16.66 | 11.1111 | 8.3333 | 6.66666 |
| 140 | 38.8888 | 19.44 | 12.9630 | 9.7222 | 7.77777 |

## V. GEOMETRICAL MODELING OF LEAF SPRING

CATIA software is used to design the geometric model of the leaf spring. Using appropriate features of the software it is modeled and are shown in Figs 5 and 6.

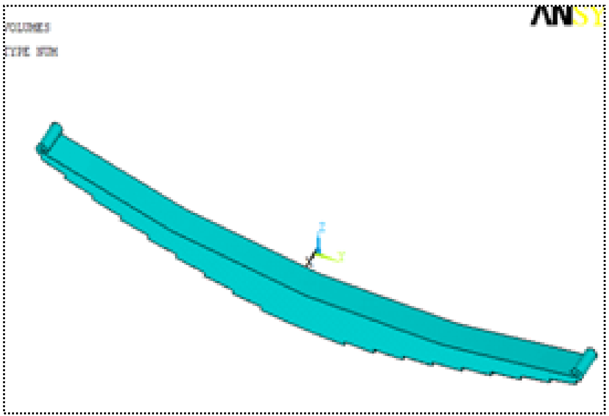


**Fig.5 Full model of leaf spring**

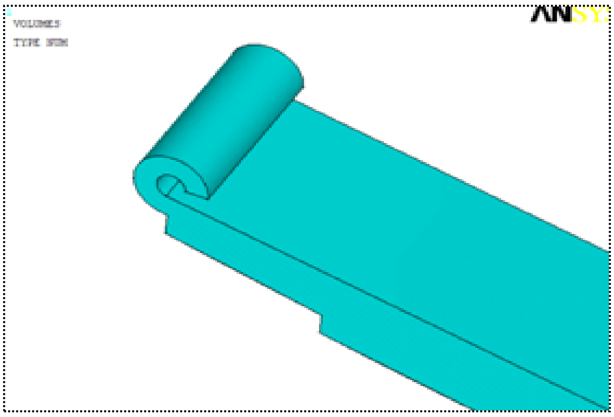


**Fig. 6 front eye the of leaf spring**

## VI. ANALYSIS OF LEAF SPRING

For a given leaf spring specifications, the static analysis is performed using **ANSYS** software. The modal analysis determines the natural frequencies and mode shapes to assess the behavior of the leaf spring with various parametric combinations. Static analysis involves discritization called meshing, boundary conditions, loading. However modal analysis does not need loading. The element considered for analysis is Solid 92: 3D- 10 Node Tetrahedral Structural solid with Rotations as shown if Fig 7. Solid92 has a quadratic displacement behaviour and is well suited to model irregular meshes. Besides structured nodes, orthotropic material properties are considered. Nodes, degrees of freedom, real constants, material properties, surface loads, body loads with appropriate assumptions and restrictions are defined. The free meshing condition is considered as the leaf spring has shape curves.

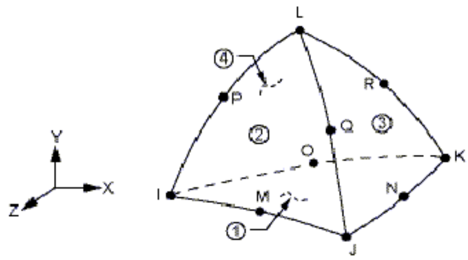



**Fig. 7 Solid 92 3D- 10 Node Tetrahedral Structural solid with Rotations**

The boundary conditions are given based on the assumptions. 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 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 Y-direction when load applied on the spring and also it can rotate about the pin. The link oscillates during load applied and removed. Therefore the nodes of rear eye of the leaf spring are constrained in all translational degrees of freedom, and constrained the two rotational degrees of freedom. So the front eye is constrained as UX, UY, UZ, ROTY, ROTZ and the nodes of rear eye are constrained as UX, UZ, ROTY, ROTZ. Fig shows the boundary conditions of the leaf spring.

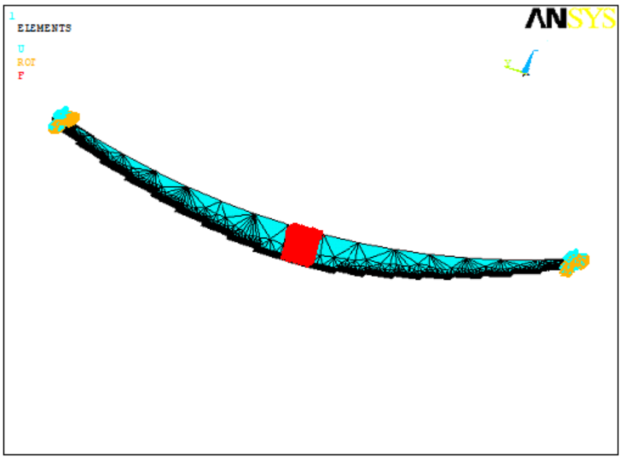
During static analysis, to determine the allowable stresses, the load applied from bottom surface of the leaf spring as it is mounted on the axle of the leaf spring. Hence, all the leaves are bounded together with the center bolt. Thus the entire load is concentrated around the centre bolt of the leaf spring. The load is distributed equally by all the nodes associated with the center bolt. The load is applied along FZ direction as shown in *Fig. 7 and Fig.8.* To apply load, it is necessary to select the circumference of the bolt hole and consequently the nodes associated with it. It is necessary to observe the number of nodes associated with the circumference of the bolt hole, because the applied load need to divide with the number of nodes associated with the circumference of the center bolt. The variation of Von-Mises stresses is shown in Table 7 under different loading conditions. The stresses are increased as the load increases.

Modal analysis is carried out to decide the natural frequencies and mode shapes of the leaf spring. Modal analysis is performed for various parametric combinations of the leaf spring. The parameters are camber, span, thickness, number of leaves. Here, camber varies from 80 to 110 mm, span varies from 1220 to 1420 mm, thickness varies from 7 to 10 mm and number of leaves varies from 9 to 12 keeping width is constant. Modal analysis need only boundary conditions, it is not associated with the loads apply, because natural frequencies are resulted from the free vibrations. The boundary conditions are same as in the case of static analysis.

**Table 7. Variation of Von-Mises stress with load**

| Load (N) | Von – Mises Stresses (N / $mm^2$) |
|---|---|
| 1000 | 50.095 |
| 2000 | 101.856 |
| 3000 | 150.428 |
| 4000 | 200.712 |
| 5000 | 254.640 |
| 6000 | 305.150 |
| 7000 | 356.535 |
| 8000 | 407.469 |
| 9000 | 458.124 |
| 10000 | 509.928 |
| 11000 | 560.270 |
| 12000 | 611.204 |
| 13000 | 662.064 |
| 14000 | 713.071 |
| 15000 | 764.005 |



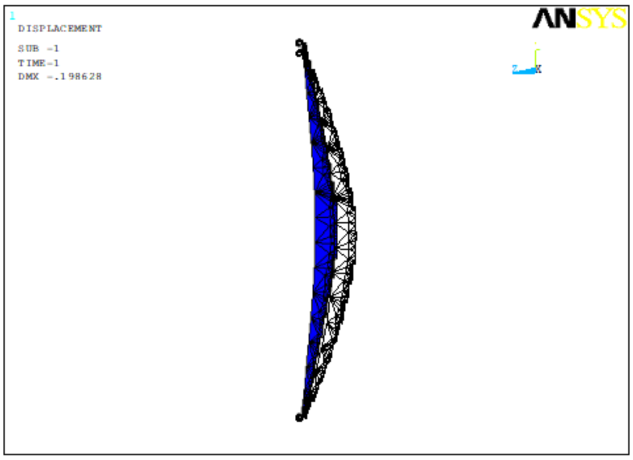




**Fig.7 Meshing, Boundary conditions and loading of leaf spring**   **Fig. 8 Deformed and undeformed shape of leaf spring**

## VII. RESULTS AND DISCUSSION

### A. Static Analysis

Static analysis is performed to decide the Von-Mises stress by using ANSYS software and are compared with bending stresses obtained via analytical approach at various loads. The Table 8 shows the assessment of stresses obtained from the computational and mathematical approaches. It is seen that the yield stress of the material is 1680 N/mm$^2$ . By considering the factor of safety 3 to 3.5, it is obvious that the allowable design stress is 480 to 560 N/mm$^2$ . So the corresponding loads are 8000 to 10000 N. Therefore it is concluded that the maximum safe pay load for the given specification of the leaf spring is 10000N.

From *Figure 8.1 and Figure 8.11*, it is obvious that maximum stress developed is at inner side of the eye sections i.e. the red color indicates maximum stress, because constraints applied at interior of the eyes. Since eyes are subjected to maximum stress, care must be taken in eye design and fabrication and material selection. The material must have good ductility, resilience and toughness to avoid sudden fracture.

**Table 8. Comparison between Theoretical and ANSYS for Von-Mises Stress**

| **Load (N)** | Von – Mises Stresses (N / mm$^2$) | |
|---|---|---|
| | Theoretical | ANSYS |
| 1000 | 48.502 | 50.095 |
| 2000 | 97.005 | 101.856 |
| 3000 | 145.075 | 150.428 |
| 4000 | 194.010 | 200.712 |
| 5000 | 242.512 | 254.640 |
| 6000 | 291.015 | 305.585 |
| 7000 | 339.517 | 356.565 |
| 8000 | 388.020 | 407.469 |
| 9000 | 436.520 | 458.124 |
| 10000 | 485.025 | 509.928 |
| 11000 | 533.527 | 560.270 |
| 12000 | 582.030 | 611.204 |
| 13000 | 630.532 | 662.264 |
| 14000 | 679.035 | 703.071 |
| 15000 | 727.537 | 764.005 |

From the analysis of theoretical and ANSYS, the allowable design stress is found in between the loads from 8000 to 10000 N, the near corresponding safe loads are given Table 9.

**Table 9. Comparison between Theoretical and ANSYS for allowable design stresses**

| **Load (N)** | Von – Mises Stresses (N / mm$^2$) | |
|---|---|---|
| | Theoretical | ANSYS |
| 9500 | 460.770 | 481.916 |
| 9700 | 470.470 | 494.565 |
| 9900 | 480.174 | 504.243 |

From Figure 9, 10 and 11, it is resulted that the maximum stress developed is at inner side of the eye sections i.e. the red color indicates maximum stress, because constraints applied at interior of the eyes. Since eyes are subjected to maximum stress, care must be taken in eye design, fabrication and material selection. The material must have good ductility, resilience and toughness to avoid sudden fracture. The theoretical and ANSYS results are almost same with a little variation. The ANSYS results are provided in the Figures 14 to 15.

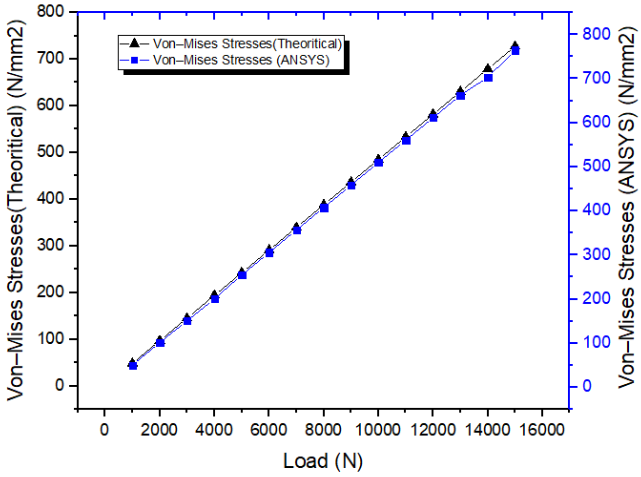



**Fig. 10 Load Vs Von – Mises Stresses (The & ANSYS)**

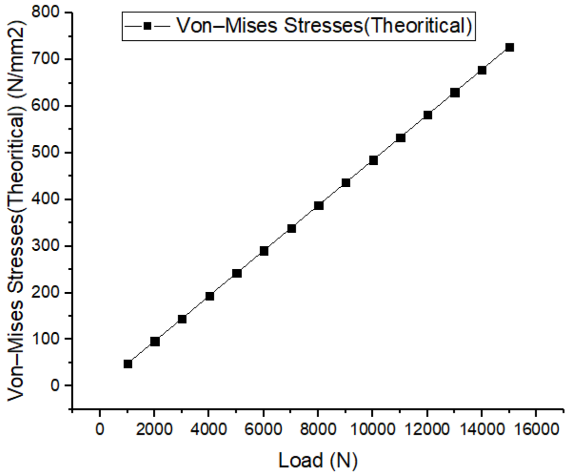



**Fig. 11 Load Vs Von – Mises Stresses (Theoritical)**

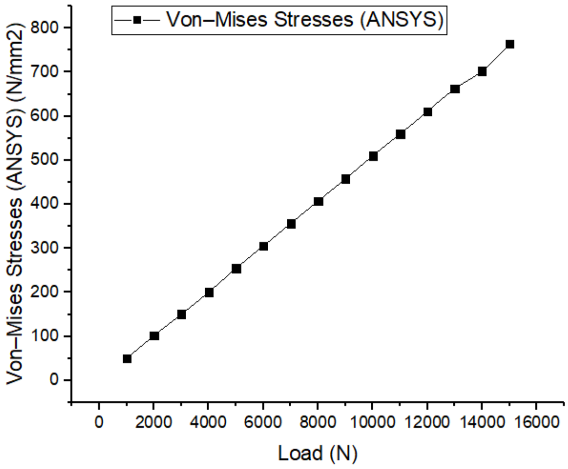



**Fig. 12 Load Vs Von – Mises Stresses (ANSYS)**

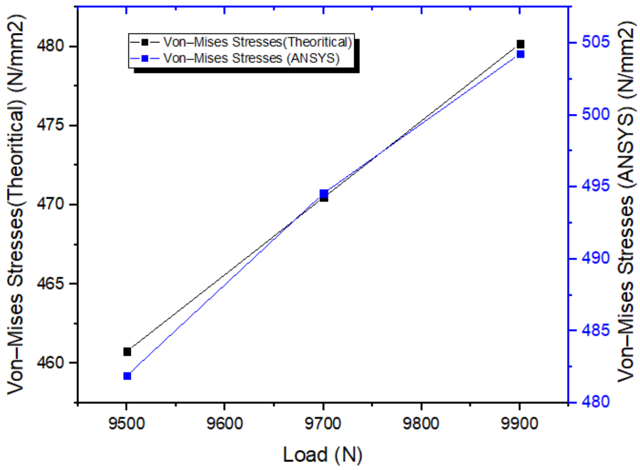



**Fig. 13 Safe design conditions – Load vs Stress**

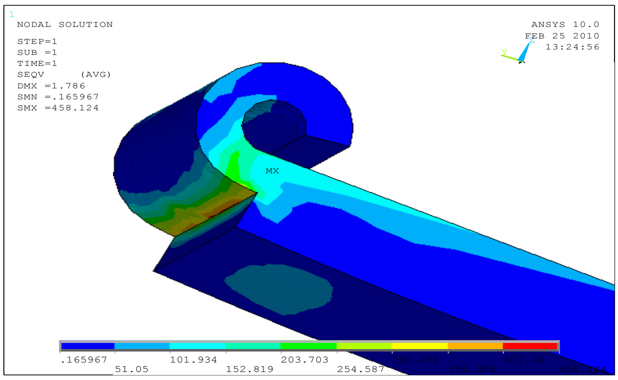



**Fig. 14 Von-mises Stress contour plot of Front eye of leaf spring**

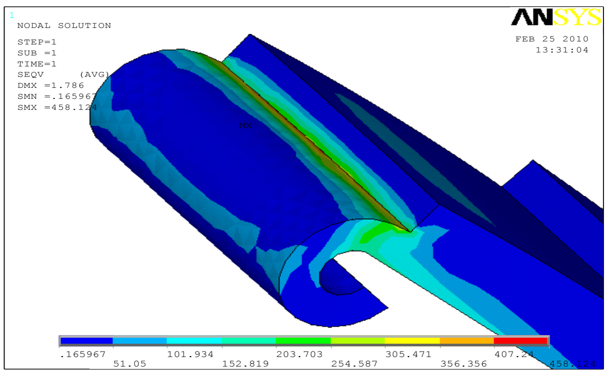



**Fig. 15 Von-mises Stress contour plot of Rear eye of leaf spring**

### B. Dynamic Analysis

The width is fixed for leaf spring and other parameters namely thickness, camber, span and numbers of leaves are varied. Ten modes are considered for analysis. Variations of natural frequencies with spring parameters are studied.

**(i) Variation of natural frequency with span**

The span is varied from 1120 mm to 1420 mm and corresponding natural frequencies are studied and presented in Table10. The other parameters Camber, thickness and no of leaves are constants and are 80 mm, 7 mm and 10nos respectively. When span increases, the spring becomes soft and hence the natural frequency decreases. Every three modes are in one set of range. There is a considerable gap between mode3 to mode4, mode6 to mode7 and mode9 to mode10. It is observed from the Fig. 16 that the frequency value rapidly decreases with the increase of span for mode10 compared to remaining modes.

**Table 10 variation of natural frequency with Span**

| Frequency (Hz) at | Span (mm) | | | |
|---|---|---|---|---|
| | 1120 mm | 1220 mm | 1320 mm | 1420 mm |
| Mode 1 | 2.464 | 2.362 | 2.038 | 1.741 |
| Mode 2 | 3.700 | 3.624 | 3.053 | 2.603 |
| Mode 3 | 7.168 | 6.874 | 5.916 | 5.042 |
| Mode 4 | 14.409 | 14.240 | 12.192 | 10.416 |
| Mode 5 | 15.553 | 15.412 | 14.862 | 12.995 |
| Mode 6 | 18.224 | 17.652 | 15.246 | 13.413 |
| Mode 7 | 26.208 | 25.596 | 23.181 | 20.292 |
| Mode 8 | 31.377 | 31.126 | 26.798 | 22.968 |
| Mode 9 | 31.690 | 31.149 | 27.889 | 24.651 |
| Mode 10 | 46.567 | 45.532 | 39.470 | 33.549 |

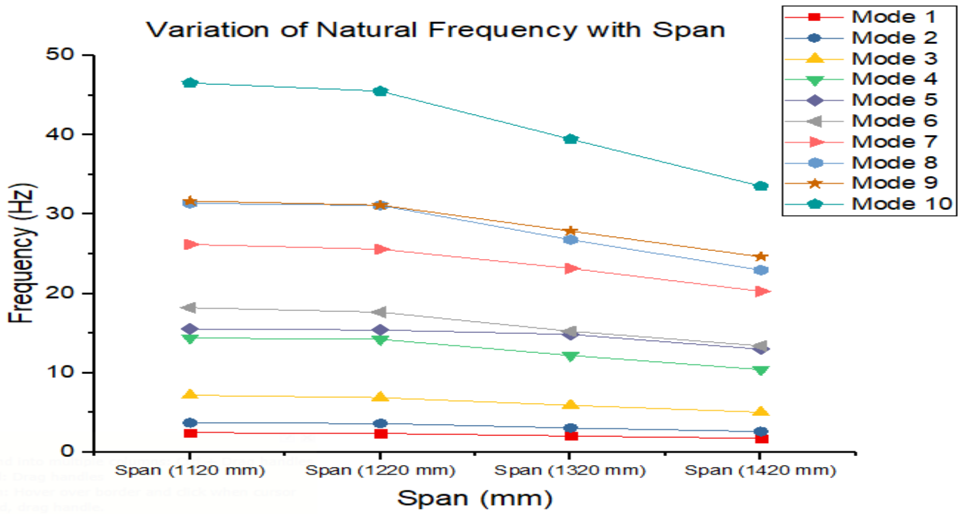



**Fig 16 Variation of natural frequency with span**

**(ii) Variation of natural frequency with camber**

The camber is varied from 80 mm to 110 mm and corresponding natural frequencies are studied and presented in Table11. The other parameters span, thickness and no of leaves are constants and are 1220 mm, 7 mm and 10nos respectively. When camber increases, the spring becomes stiff and hence the natural frequency increases. Every three modes are almost in one set of range. There is a considerable gap between mode3 to mode4, mode6 to mode 7 and mode 9 to mode 10. It is observed from the *Fig.17* that the increase of frequency value with the increase of camber is very high for mode10 compared to remaining modes.

**Table 11 variation of natural frequency with Camber**

| Frequency (Hz) at | Camber (mm) | | | |
|---|---|---|---|---|
| | 80 | 90 | 100 | 110 |
| Mode 1 | 2.362 | 2.344 | 2.344 | 2.414 |
| Mode 2 | 3.624 | 3.527 | 3.446 | 3.571 |
| Mode 3 | 6.874 | 6.791 | 6.760 | 7.063 |
| Mode 4 | 14.240 | 14.107 | 13.988 | 14.361 |
| Mode 5 | 15.412 | 16.006 | 16.642 | 15.395 |
| Mode 6 | 17.652 | 17.506 | 17.458 | 18.122 |
| Mode 7 | 25.596 | 25.625 | 25.741 | 27.007 |
| Mode 8 | 31.126 | 30.895 | 30.702 | 30.557 |
| Mode 9 | 31.149 | 31.215 | 31.391 | 31.667 |
| Mode 10 | 45.532 | 45.241 | 45.109 | 45.915 |

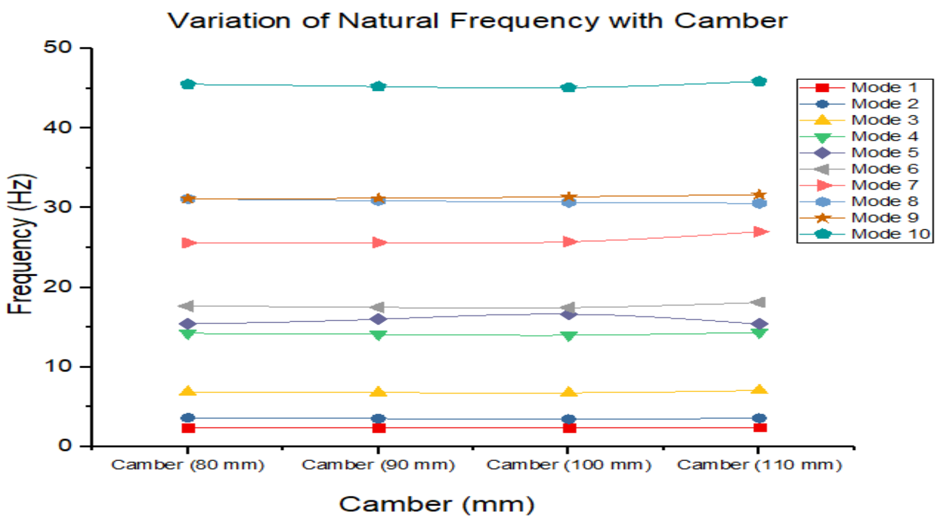



**Fig 17 Variation of natural frequency with camber**

**(iii) Variation of natural frequency with thickness**

The thickness is varied from 7 mm to 10 mm and corresponding natural frequencies are studied and presented in Table12. The other parameters span, camber and no of leaves are constants and are 1220 mm, 80 mm and 10 nos respectively. *Figure 18* shows the variation of natural frequency with thickness of the spring. When thickness increases the natural frequency also increases. Its natural frequency increases like variation of natural frequency with camber, but with thickness the natural frequency increasing rate is lesser than that of variation of natural frequency with camber. Every three modes are almost in one set of range. There is a considerable gap between mode3 to mode4, mode6 to mode7 and mode9 to mode10.It is observed from Fig. 18 that the increase of frequency value with the increase of thickness is very high for mode9 and mode10 compared to remaining modes.

**Table 12 variation of natural frequency with Thickness**

| Frequency (Hz) at | Thickness (mm) | | | |
|---|---|---|---|---|
| | 7 | 8 | 9 | 10 |
| Mode 1 | 2.362 | 2.744 | 2.945 | 3.270 |
| Mode 2 | 3.624 | 3.697 | 3.650 | 3.702 |
| Mode 3 | 6.874 | 7.950 | 8.502 | 9.403 |
| Mode 4 | 14.240 | 14.293 | 14.092 | 14.116 |
| Mode 5 | 15.412 | 15.710 | 15.656 | 15.736 |
| Mode 6 | 17.652 | 20.244 | 21.716 | 23.691 |
| Mode 7 | 25.596 | 26.669 | 26.678 | 27.275 |
| Mode 8 | 31.126 | 31.233 | 30.955 | 31.004 |
| Mode 9 | 31.149 | 34.630 | 37.249 | 40.714 |
| Mode 10 | 45.532 | 51.608 | 51.091 | 51.025 |

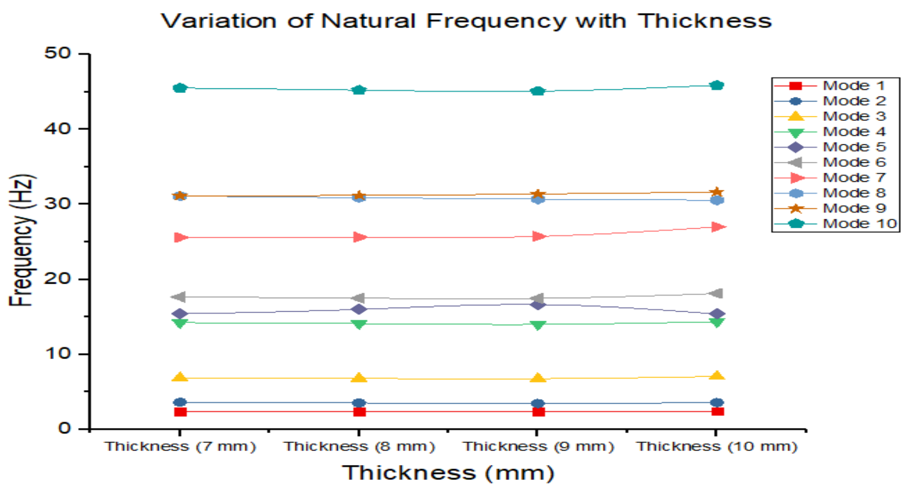



**Fig 18 Variation of natural frequency with Thickness**

**(iv) Variation of natural frequency with number of leaves**

Number of leaves is varied from 9 to 12 and corresponding natural frequencies are studied and presented in Table13. The other parameters span, camber and thickness are constants and are 1220 mm, 100 mm and 7 mm respectively. Figure 19 shows the variation of natural frequency with number of leaves of the spring. Even though the number of leaves increases there is no considerable increase in natural frequency, it is almost constant. It is observed from the Fig.19 every three modes are in gradual increment, there is considerable increase in natural frequency from mode3 to mode4, there is much increase in natural frequency from mode6 to mode7 and there is very much in increase in natural frequency from mode9 to mode10.

**Table 13 variation of natural frequency with Number of leaves**

| Frequency (Hz) at | Number of leaves | | | |
|---|---|---|---|---|
| | 9 | 10 | 11 | 12 |
| Mode 1 | 2.240 | 2.362 | 2.527 | 2.559 |
| Mode 2 | 3.571 | 3.624 | 3.440 | 3.285 |
| Mode 3 | 6.506 | 6.874 | 7.262 | 7.301 |
| Mode 4 | 14.202 | 14.240 | 14.006 | 13.720 |
| Mode 5 | 16.473 | 15.412 | 16.410 | 15.887 |
| Mode 6 | 17.044 | 17.652 | 18.873 | 19.360 |
| Mode 7 | 25.060 | 25.596 | 26.346 | 26.188 |
| Mode 8 | 30.567 | 31.126 | 30.789 | 30.446 |
| Mode 9 | 30.906 | 31.149 | 33.002 | 33.751 |
| Mode 10 | 42.669 | 45.532 | 48.544 | 50.096 |

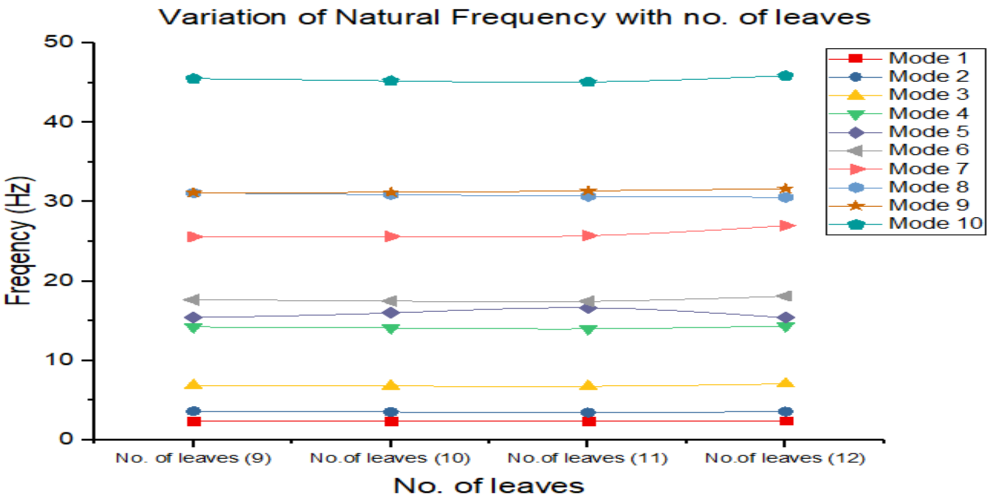



**Fig 19 Variation of natural frequency with No. of leaves**

**C. Mode shapes**

The mode shapes for modes 1,3 & 10 and for different parameters like Camber, Span, Thickness of leaves and number of leaves are presented in the following Figures 20 to 28.

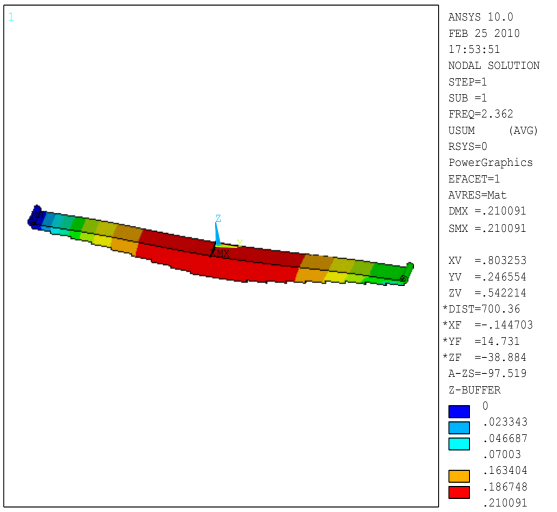



**Fig. 20 Mode 1 (Camber 80 mm, Span 1220 mm)**

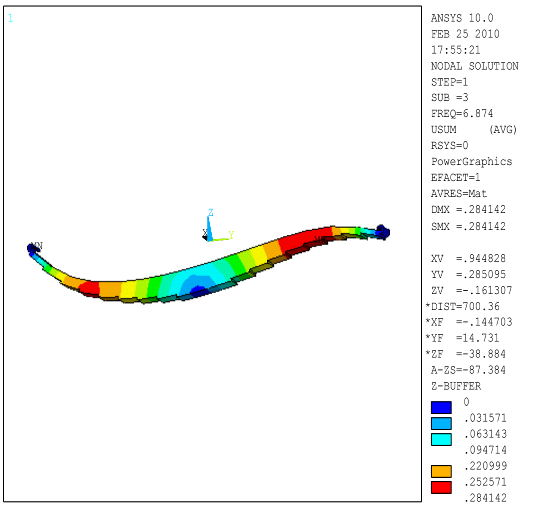



**Fig. 21 Mode 3 (Camber 80 mm, Span 1220 mm)**

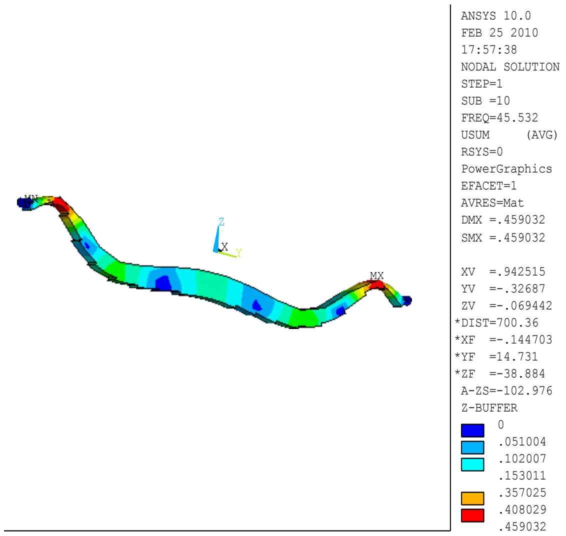



Fig. 22 Mode 10 (Camber 80 mm, Span 1220 mm)

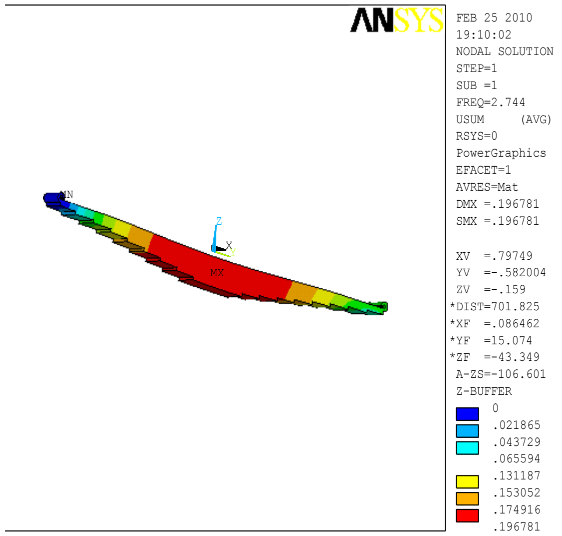



Fig. 23 Mode 1 (Thickness 8 mm)

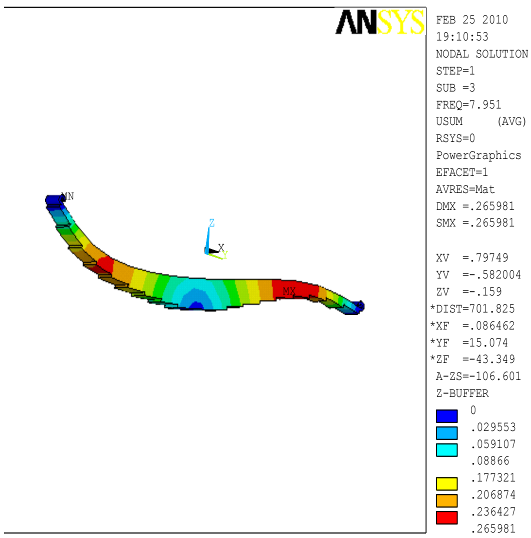



Fig. 24 Mode 3 (Thickness 8 mm)

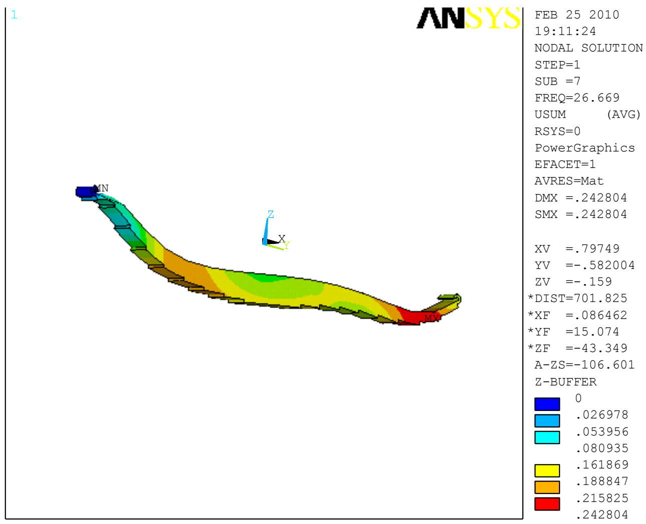
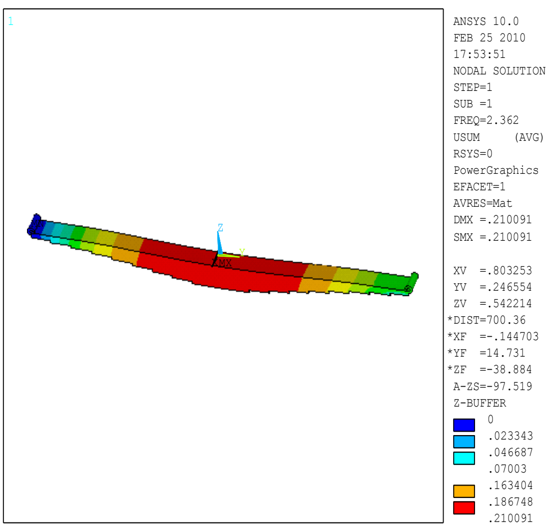



Fig. 25 Mode 7 (Thickness 8 mm)



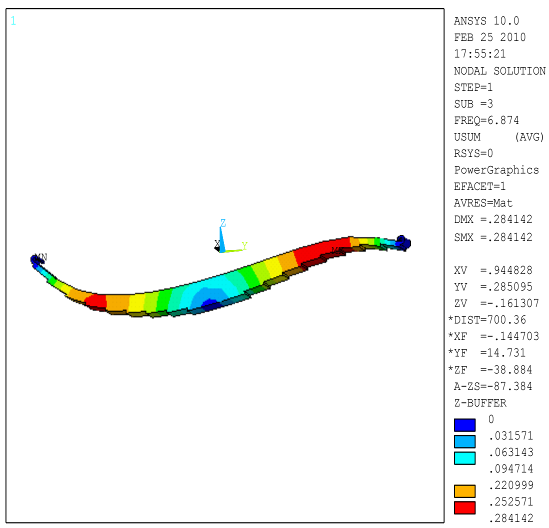




Fig. 26 Mode 1 (Number of leaves 10)

Fig. 27 Mode 3 (Number of leaves 10)

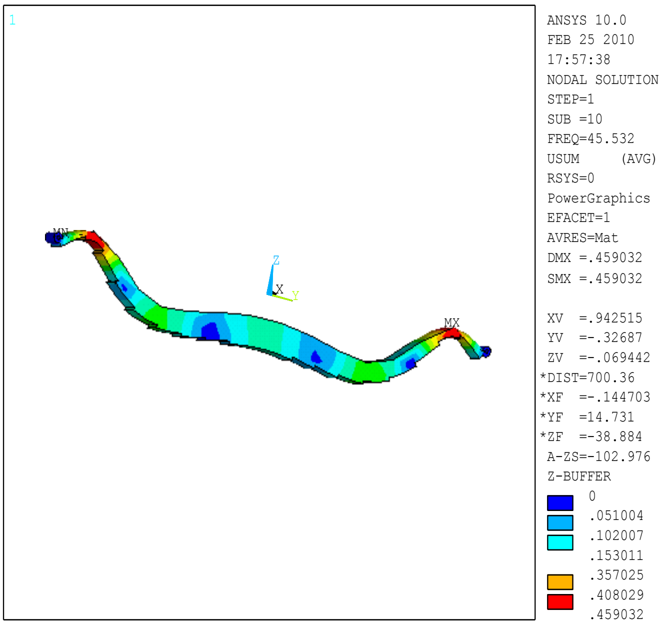



**Fig. 28 Mode 10 ( Number of leaves 10)**

### D. Variation of Exciting Frequency with Vehicle Speed

The variation of exciting frequency is studied with varying vehicle speeds for assumed width of road Irregularity. At low speeds the wheel of the vehicle passes over road irregularities and moves up and down to the same extent and the frequency induced is less. . If the speed increases and the change in the profile of the road irregularity are sudden, then the movement of the body and the rise of the axles which are attached to the leaf spring are opposed by the value of their own inertia. Hence, the frequency induced also increases. The exciting frequency is very high for the lower value of road irregularity width, because of sudden width.

It is noted that the some of the excitation frequencies are very close to natural frequencies of the leaf spring, but they are not exactly matched, hence no resonance will takes place.

**Table 14. Variation of Exciting Frequency with Vehicle Speed**

| Speed (Kmph) | Frequency Hz (at WRI = 1m) | Frequency Hz (at WRI = 2m) | Frequency Hz (at WRI = 3m) | Frequency Hz (at WRI = 4m) | Frequency Hz (at WRI = 5m) |
|---|---|---|---|---|---|
| 20 | 5.5500 | 2.77 | 1.8518 | 1.3888 | 1.11111 |
| 40 | 11.1111 | 5.54 | 3.7037 | 2.7777 | 2.22222 |
| 60 | 16.6666 | 8.31 | 5.5555 | 4.1664 | 3.33333 |
| 80 | 22.2222 | 11.08 | 7.4074 | 5.5552 | 4.44444 |
| 100 | 27.7777 | 13.85 | 9.2593 | 6.9440 | 5.55555 |
| 120 | 33.3333 | 16.66 | 11.1111 | 8.3333 | 6.66666 |
| 140 | 38.8890 | 19.44 | 12.9630 | 9.7222 | 7.77777 |

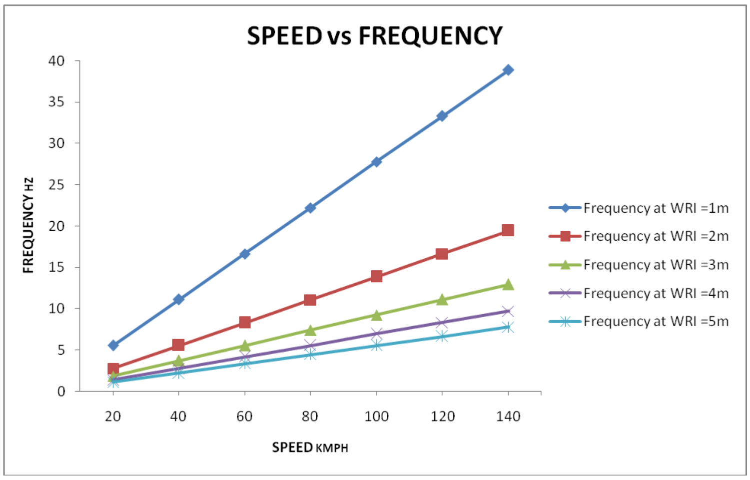



**Fig 8.17 variation of Excitation frequency with vehicle speed (WRI = width of road irregularity in meters)**

## VIII. CONCLUSIONS AND FUTURE SCOPE OF WORK

It is necessary to estimate the life of a vehicle when it is subjected to varying loading conditions. The natural frequency, exiting frequencies may cause the vehicle damaged. This paper mainly focuses on the payload conditions on leaf spring which offers resistance against the vibration. The bending stress, Von-Mises stresses are computed at different loads with varying parameters such as span, camber, thickness and number of leaves of the leaf spring. The effect of these parameters is studied to get the optimal conditions for safe design of leaf spring. The following conclusions are made.

1. The Leaf spring has been modeled using solid tetrahedron 10 node element.
2. The maximum safe load is 9900 N is obtained for the given specification of the leaf spring from the static analysis.
3. In model analysis, the leaf spring width is kept as constant and variation of natural frequency with leaf thickness, span, camber and numbers of leafs are studied.
4. It is observed from the present work
    a. The natural frequency increases with the increase of thickness, number of leaves as well as camber, and decreases with decrease of thickness of leaves as well as camber.
    b. The natural frequency decreases with increase of span, and increases with decrease of span.
    c. The natural frequency almost constant with number of leaves.
5. The natural frequencies of various parametric combinations are compared with the excitation frequency for different road irregularities.
6. This study concludes that it is advisable to operate the vehicle such that its excitation frequency does not match the natural frequencies i.e. the excitation frequency should fall between any two natural frequencies of the leaf spring.
7. Sensors and microprocessors can be used to achieve the optimum speed for comfortable, low vibration journey.
8. In this work no contact elements are considered only nodal coupling has taken, instead of nodal coupling contact elements can be considered.
9. The composite material may be considered instead of steel so that the durability of the vehicle may be enhanced with low maintenance.

## References

[1] Jonnala Subba Reddy, M. Bhavani, J. Venkata Somi Reddy, "Simulation of stress distribution in leaf spring under variable parametric and loading conditions," International Journal of Engineering Research & Technology, vol. 7, Issue 04, April 2018, pp. 115-124.

[2] M.Venkateshan, D.Helmen Devraj, Design and analysis of leaf spring in light vehicles, IJMER 2249-6645 Vol.2, Issue.1,pp.213-218, Jan-Feb2012.

[3] U. S. Ramakant & K. Sowjanya, Design and analysis of automotive multi leaf springs using composite material, IJMPERD 2249-6890 Vol. 3, Issue 1,pp.155-162, March 2013

[4] Manas Patnaik, NarendraYadav, Study of a Parabolic Leaf Spring by Finite Element Method & Design of Experiments, IJMER 2249-6645, Vol.2, 1920-1922, July-Aug 2012

[5] Rakesh Hota, Kshitij Kumar, Ganni Gowtham andAvinash Kumar Kotni. Experimental Investigation of Fiberglass Reinforced Mono-Composite Leaf Spring, International Journal of Design and manufacturing Technology, 4(1), 2013, pp. 30-42.

[6] Prof. N.V. Hargude, Mr. J.G. Herekar and Prof. P.P. Awate. Analysis of Composite Mono Leaf Spring, International Journal of Advanced Research in Engineering and Technology, 5(5), 2014, pp. 09-16

[7] Senthilkumar Mouleeswaran (2012), "Design, Manufacturing and Testing of Polymer Composite Multi-Leaf Spring for Light Passenger Automobiles—A Review", Materials Science and Technology, Sabar Hutagalung (Ed.), ISBN: 978-953-51-0193-2, InTech.

[8] Shahriar Tavakkoli, Farhang, Daved S.Lohweder,(2001) "*Practical prediction of leaf spring , Loads using MSC/NASTRAN & MDI/ADAMS".*

[9] Tirupathi R. Chandrupatla & Ashok D.Belegundu, "Introduction to Finite Elements inEngineering". Third Edition-Pearson Education Pvt.. Ltd-2002.

[10] M. Patunkar"Modeling And Analysis of Composite Leaf Spring Load Condition By Using FEA",(IJMIE) International Journal of Mechanical & Industrial Engineering, Volume 1 Issue 1- 2011.