TechS Vidya e-Journal of Research
ISSN 2322 - 0791
Vol. 3 (2014-15) pp. 4-13.

# Design and analysis of leaf springs using the FEA approach

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**Abstract**: The aim of this paper is to represent a general study the design and analysis of leaf spring. The suspension system in a vehicle significantly affects the behavior of vehicle. Leaf springs are subjected to millions of varying stress cycles loading to fatigue failure. Leaf springs are special kind of springs used in automobile suspension systems. The main function of leaf spring is not only to support vertical load but also to isolate road induced vibrations. The present work attempts to linear Static analysis determines the safe stress and corresponding pay load of the leaf spring and analyze the safe load of the leaf spring. Which will indicate the speed at which a comfortable speed and safe drive is possible. A typical leaf spring configuration of TATA-407 light commercial vehicle is chosen for study. Finite element analysis has been carried out to determine the safe stresses and pay loads and done the simulation also.

*Keywords*: fatigue failure, linear static analysis, safe load

## 1 Introduction

The mission of a vehicle suspension is to maximize the friction between the tires and the road surface, to provide steering stability with good handling and to ensure the comfort. If a road were perfectly flat, with no irregularities, suspensions wouldn't be necessary. But roads are far from flat. Even freshly paved highways have slight imperfections that can interact with the wheels. It's these imperfections that apply forces to the wheels. Suspension is the term given to the system of springs, shock absorbers and linkages that connects

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Published on 13 February 2015.

a vehicle to its wheels and allows relative motion between the two. It serves a dual purpose - contributing to the vehicle's road holding, handling and keeping vehicle occupants comfortable. According to Newton's laws of motion, all forces have both magnitude and direction. A knock in the road causes the wheel to move up and down perpendicular to the road surface. the vehicle wheel experiences a vertical acceleration as it passes over an imperfection.

## 2 Literature survey

Shiva Shankar and Vijayarangan manufactured a composite mono leaf spring with an integral eye and tested under static load conditions (see [2]). Also fatigue life prediction was also done to ensure a reliable number of life cycles of a leaf spring. Niklas Philipson and Modelan (see [3]) modeled a leaf spring in conventional way and simulated for the kinematic and dynamic comparatives. Zhi'an Yang and et al. (see [4]) studied the cyclic creep and cyclic deformation. Efforts were taken for Finite Element Analysis of multi leaf springs. These springs were simulated and analyzed by using ANSYS. C.K. Clarke and G.E. Borowski evaluated the failure of leaf Spring at different static load conditions (see [6]) and J.J. Fuentes et al. studied the effect of premature fracture in automobile leaf springs (see [7]). Mouleeswaran et. al. (see [8]) describes static and fatigue analysis of steel leaf springs and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. The dimensions of existing conventional steel leaf springs of a light commercial vehicle are taken and are verified by design calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. H.A. Al-Qureshi (see [9]) has described a single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf steel spring, was designed, fabricated and tested. J.J.Fuentes et. al. in this work (see [10]), the origin of premature failure analysis procedures, including examining the leaf spring history, visual inspection of fractured specimens, characterization of various properties and simulation tests on real components, were used.

The present work attempts to find the maximum pay load of the vehicle by performing static analysis using ANSYS software and the obtained results are compared with the mathematical calculations and the maximum bending stress and the corresponding pay load is determined by considering the factor of safety.

## 3 Methodology

First to find the 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

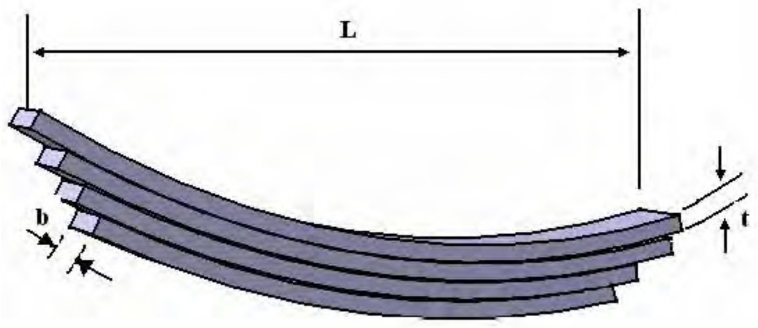

Figure 1: Notations

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.

We use the following notations (see Figure 1):

$t$ = thickness of plate
$b$ = width of plate
$L$ = length of plate, or distance of the load $W$ from the cantilever end

The bending stress $f$ of a leaf spring can be calculated by

$$f = \frac{6WL}{bt^2}.$$

The maximum deflection $\delta$ is given by

$$\delta = \frac{4WL^3}{Ebt^3}.$$

Combining the two we get

$$\delta = \frac{2fL^2}{3Et}. \tag{1}$$

Eq. (1) gives the bending stress of a leaf spring of uniform cross-section and is given in Table 1 at various loads. The stress at such a spring is maximum at the support.

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.

| **Load (Newton)** | **Bending stress N/mm$^2$** |
|---:|---:|
| 1000 | 145.507 |
| 2000 | 291.015 |
| 3000 | 436.522 |
| 4000 | 582.030 |
| 5000 | 727.540 |
| 6000 | 873.045 |
| 7000 | 1018.550 |
| 8000 | 1164.060 |
| 9000 | 1309.570 |
| 10000 | 1455.076 |
| 11000 | 1600.583 |
| 12000 | 1746.091 |
| 13000 | 1891.598 |
| 14000 | 2037.106 |
| 15000 | 2182.613 |

Table 1: Load vs. bending stress

## Modeling procedure for leaf spring

1. First create the key point 100 at origin, that is, at $(x, y, z) = (0, 0, 0)$.
2. Create another key point 200 at some arbitrary distance in $Z$-direction, say, $x, y, z = (0, 0, 200)$.
3. Join the above two key points 100 and 200 to get the reference axis.
4. By using data from mathematical analysis, create the key point 1 with a distance of radius of curvature $R_1$ in the vertically down-ward direction, that is, $x, y, z = (0, -R_1, 0)$.
5. Similarly key points 2 and 3 correspond to $R_2$, that is, $x, y, z = (0, -R_2, 0)$ and key points 4 and 5 corresponds to $R_3$, that is, $x, y, z = (0, -R_3, 0)$.
6. Key point 20 corresponds to $R_{11}$, that is, $x, y, z = (0, -R_{11}, 0)$.
7. Join the pair of key points sequentially as follows: Key points 1 and 2, 2 and 3, 3 and 4...and 19 and 20.

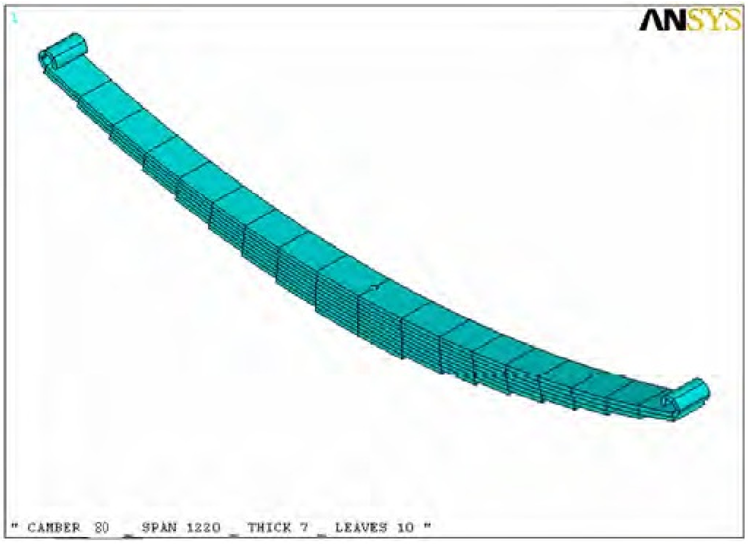

Figure 2: Full model of leaf spring

8. Then line 1 is formed by the key points 1 and 2, line 2 by the key points 2 and 3, and line 10 by the key points 19 and 20.
9. Extrude the above lines with respect to reference axis stated in Step 3 as follows:
   - Extrude line 1 with an angle $\Phi_1$, and get area 1.
   - Extrude line 2 with an angle $\Phi_2$, and get area2.
   - Continue the process.
   - Extrude line 10 with an angle $\Phi_{10}$ and get area 10.
10. After extruding all the lines, the semi-area of the spring without eye will form on $XY$-plane with significant degeneracy.
11. To avoid degeneracy, extend the right side line of smallest area, that is, area 10 to some extent such that it crosses the top most area, that is, area 1. Now divide area by line. For this, select the areas left to extended line 1 and divide with that line. Similarly, extend the right side line of second smallest area, that is, area 9 to some extent such that it cross the top most area, that is, area 1. Again divide area by line. For this select the areas left to extended line 2 and divide with that line.
12. The above process is to be done up to extension of line of area 9 and divide area by extension line 9.
13. Now perfect half area of leaf spring without eye will form.

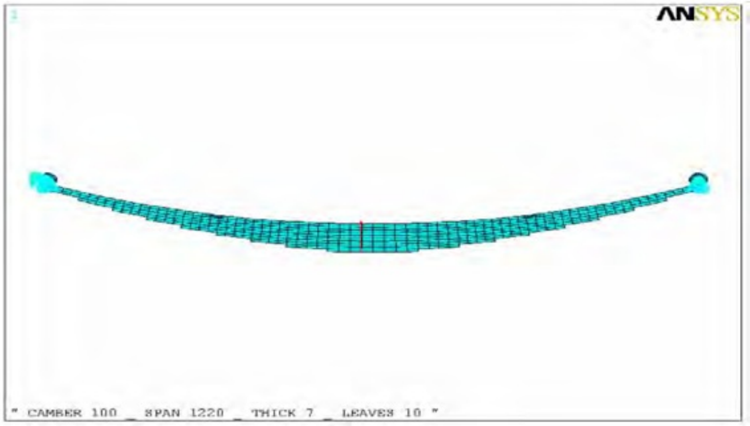

Figure 3: Meshed model of leaf spring

14. **Eye construction:**

    Extend the right side line of top most area, that is, area 1 to the length equal to the radius of eye. Delete lines only, so that key point of that line will remain. Shift the origin to that key point. Create another key point say some key point300 in $Z$-direction. Join the above two key points to get reference axis to rotate the right side line of area 1. Extrude the line with respect to reference axis to an angle 2750 to 2800. Delete all reference lines. So half area of leaf spring with eye is formed.

15. To get the full area of the leaf spring. Shift the origin to the top left most area key point, that is, key point 1. Reflect the entire area with respect to $YZ$plane.

16. To get the solid model of the leaf spring, extrude the area by $Z$-offset to a length equal to the width of the leaf spring.

17. To make a cylindrical hole at centre of the leaf spring to provide bolting for all the leaves, so that all the leaves are in perfect alignment: Create centre key point of the leaf spring on the top view, that is, $XY$-plane, by using key points between key points' command. Shift the origin to that key point. Choose the proper work plane by using work plane Create a cylinder along Z-axis in vertically downward direction. Subtract the cylinder from the solid leaf spring. So that leaf spring with hole to provide bolt will obtain.

## 4 Meshed view

The load is 9000 N, and the number of associated nodes is 12. So the load on each node is 750 N. Meshing involves division of the entire model into small pieces called elements.

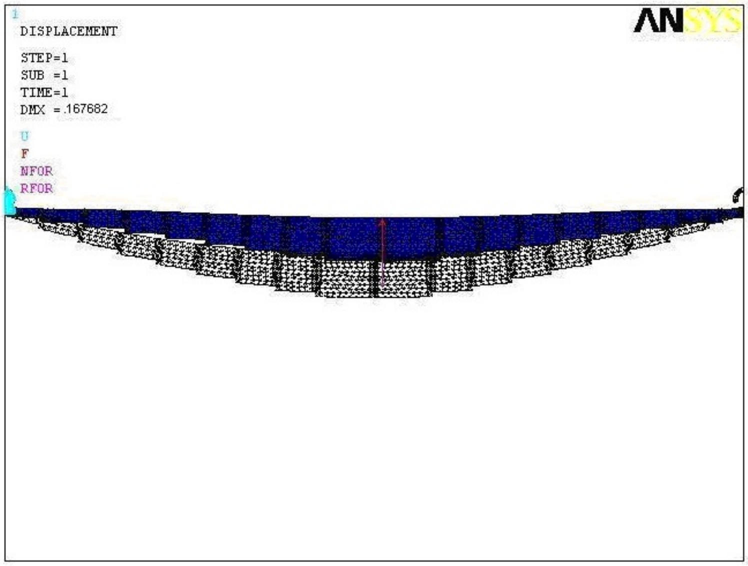

Figure 4: Deformed and non-deformed shapes of leaf spring

This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that the shape of the object will not alter. To mesh the leaf spring, the element type must be decided first. Here, the element type is solid 72. The element edge length is taken as 15 and is refined the area of centre bolt to 2. Figure 3 shows the meshed model of the leaf spring.

# 5 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 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 eyes of the leaf spring have 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 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 $UX$, $UY$, $UZ$, $ROTX$, $ROTY$ and the nodes of the rear eye are constrained as $UY$, $UZ$, $ROTX$, $ROTY$.

| **Load (Newton)** | **Von Mise's stress N/mm$^2$** |
|---:|---:|
| 1000 | 139.628 |
| 2000 | 282.615 |
| 3000 | 426.152 |
| 4000 | 568.830 |
| 5000 | 712.642 |
| 6000 | 852.345 |
| 7000 | 993.515 |
| 8000 | 1136.106 |
| 9000 | 1277.672 |
| 10000 | 1420.076 |
| 11000 | 1458.076 |
| 12000 | 1602.463 |
| 13000 | 1746.091 |
| 14000 | 1891.599 |
| 15000 | 2037.106 |

Table 2: Load vs. von Mise's stress

## 6 Results and conclusions

### Results

Figure 4 shows the deformed and non-deformed shapes of a leaf spring. Table 2 gives the von Mise's stress at various loads. From the theoretical and the ANSYS, the allowable design stress is found between the corresponding loads 6000 to 8000N. The near corresponding safe loads are given in Table 3.

### Conclusion

In the present work, leaf spring is modeled and static analysis is carried out 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.

| Load | Von Mise's stress (N/mm$^2$) | |
|---|---|---|
| | **Theoretical** | **ANSYS** |
| 7500 | 1091.310 | 1072.133 |
| 7600 | 1105.857 | 1084.372 |
| 7700 | 1120.408 | 1097.681 |

Table 3: Theoretical vs. ANSYS

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