

Optimization of Mono Leaf Spring by Parabolic Variation of Thickness along the Length

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Abstract- While considering the optimization in the geometry of the leaf spring, it can be said that the design of leaf spring is quite thickness sensitive due to its relative dimensions & the loading direction. Hence stress analysis of a mono leaf spring is done by F.E.M. before and after changing the variation of its thickness along the length. The variation of thickness considered initially is linear. After careful study it was judged that if the thickness is varied parabolically along the length of the leaf spring, better results can be obtained. Hence the values of stress at different points along the length (average values at various cross sections) for both geometries are compared graphically. In short the stress variation along the length for both geometries is plotted on graph and comparison is visualized by overlapping of graphs. An improvement in the distribution of stress along the length improves the utilization of material & thus mass of the leaf spring can be reduced. Parabolic variation of thickness along the length also permits decrease in width to thickness ratio, resulting in reduction of material required, without reduction in deflection obtained (in fact deflection increases). This is also revealed from the Finite element analysis and the comparison of deflection obtained in case of both the geometries at maximum as well as minimum load.

Index Terms--: parabolic, leaf spring, thickness, deflection, stress.

I. INTRODUCTION

Leaf spring suspension system is the simplest, cheapest and the most sturdy suspension system. Moreover the leaf spring itself acts as a link of the suspension mechanism. In addition to heavy duty vehicles, leaf springs are still used in light carriers and vehicles like Maruti Omni. The author recommends the use of mono leaf spring in cars also as it was being used in Maruti 800 car. This is due to the better resistance offered by it to cornering & braking forces. These advantages of leaf spring can be realized better by highly improved & advanced design. For example in the present work the geometry of the leaf spring is improved after a careful study. This study reveals that the design of leaf spring is quite thickness sensitive. This is obvious due to its shape, loading direction & relative dimensions. An engineering perception reveals that the variation of the thickness along the length of the leaf spring can be an important parameter in the leaf spring design. Other important parameter being the width to thickness ratio (W/T). Decrease in W/T ratio decreases the material required for the same vertical load carrying capacity. But at the same time this increases the stiffness and required deflection in the vertical direction may not be obtained. Deflection/stiffness is also equally important in spring design since a certain minimum required amount of deflection at a particular load is always necessary in springs, although in design of other mechanical components, deflection is undesirable within the working load range. Secondly decrease in W/T ratio also reduces the ability of the suspension to resist the cornering load. Hence in the present work the thickness and its variation along the length is given due consideration.

FINITE ELEMENT ANALYSIS OF LEAF SPRING

Pro-E software is used for modeling and Abacus software for Analysis of Leaf spring.

The finite element analysis of leaf spring is to be subdivided in following steps-

1. Modeling,
2. Meshing,
3. Loads and restraints,
4. Analysis

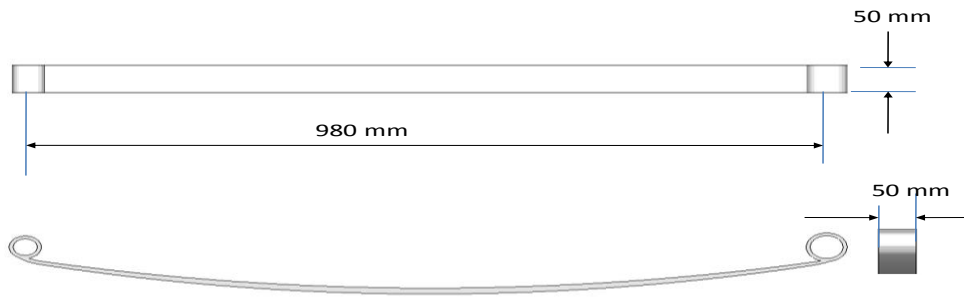


Fig.1 Geometry of Leaf Spring in AutoCAD

MODELING AND MESH GENERATION OF LEAF SPRING.

By using the overall dimensions and geometry leaf spring is modeled in Pro-E software. Leaf spring is modeled in CAD software PRO-E

The mesh generation consists of forming a collection of nodes and elements which form an acceptable discretization of the structure to be analyzed. Such a discretization must conform to the boundaries of the component and the interfaces between different regions. The shapes of the elements must not be too irregular and should, as much as possible, resemble the standard elements (triangles or tetrahedral, square or cubes, etc).

The nodes are defined by their coordinates while the elements are characterized by their type and a list of their nodes. Certain formulations involve boundary integrals. In this case the designer must define not only interior finite element, but also boundary finite elements on the corresponding boundaries.

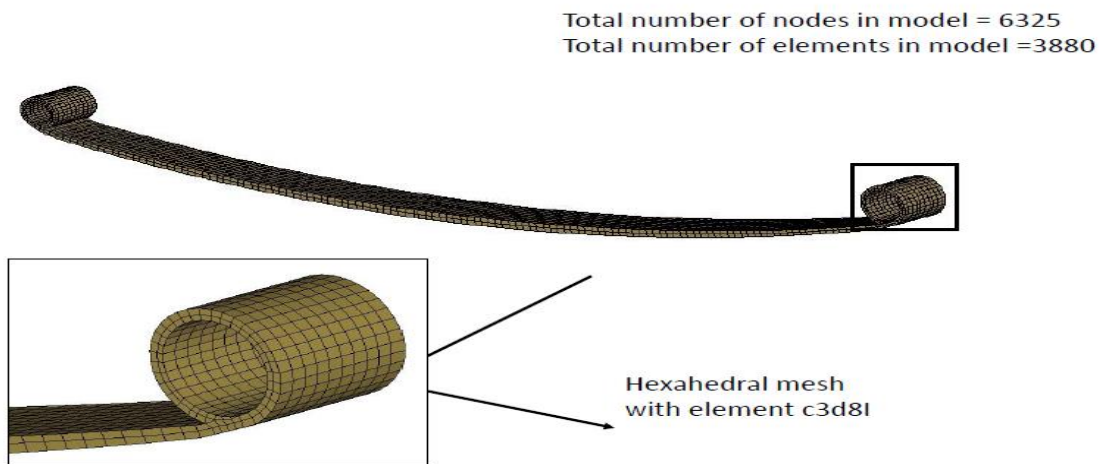


Fig. 2 Finite Element Modeling and Meshing

LOADING AND BOUNDARY CONDITIONS

This leaf spring is not clamped at the center but at a distance of 425 mm from the centre of small eye since it is a non-symmetrical leaf spring. Larger eye end (right end) acts as a fixed hinge while smaller eye is shackled and acts as a movable hinge in order to accommodate the change in distance between eye centers. Certain boundary conditions are required to be approximated due to limitations of F.E.M.

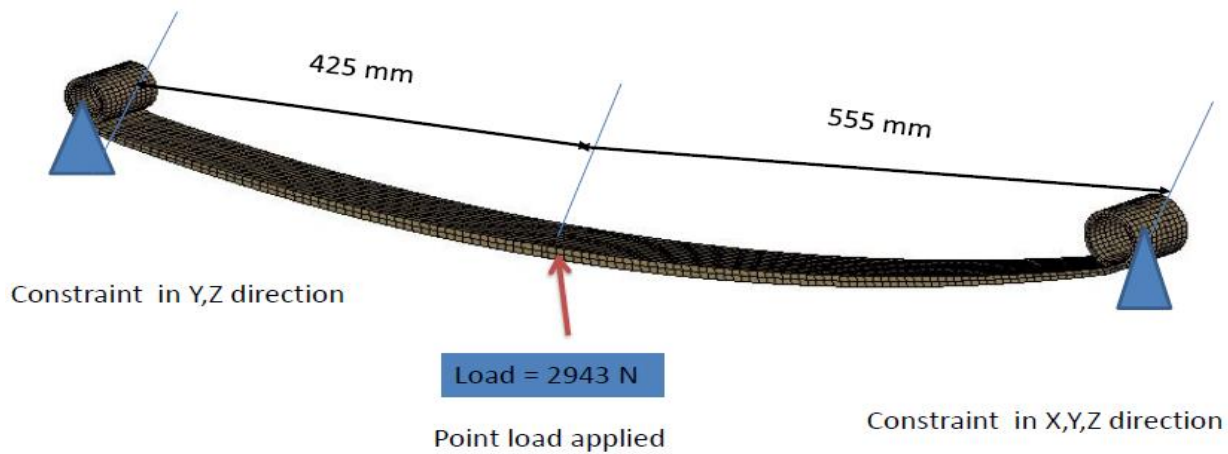


Fig. 3. Loading and Boundary Conditions

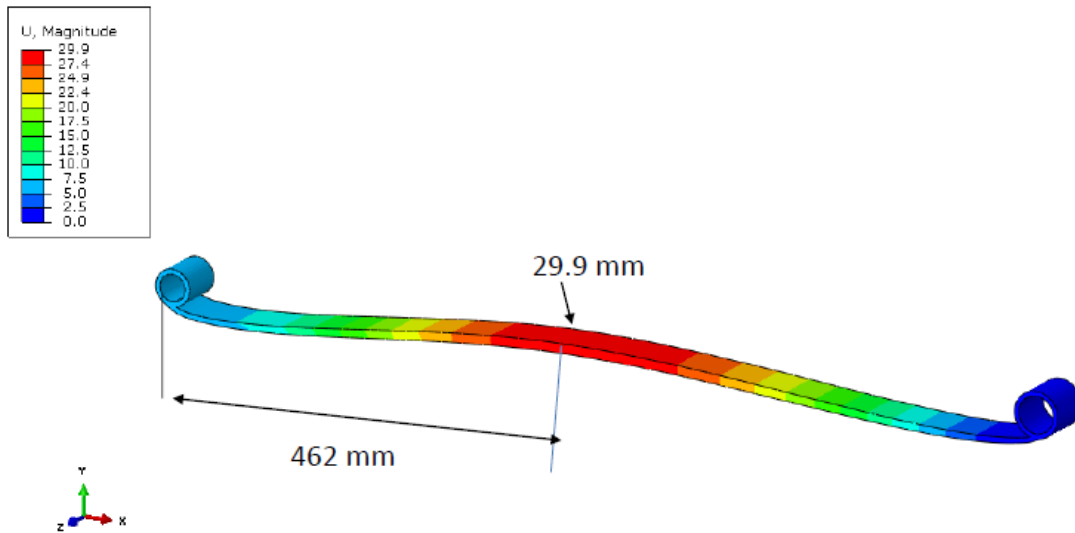
Material Properties of Leaf Springs

*MATERIAL, NAME = steel *ELASTIC, TYPE = ISOTROPIC 210000.0, 0.29 , 0.0

Where- Modulus of elasticity = 210000 MPa, Poison's ratio = 0.29

Analysis Methodology

- Finite element model is prepared on CAD geometry.
- Hyper mesh software used to create mesh.
- Hexahedral mesh done on leaf spring geometry.
- Then deck is prepared
- Deck preparation steps –
 - 1) Apply material properties.
 - 2) Apply boundary conditions.
 - 3) Apply load.
 - 4) Export deck as *.inp file.
- Submit run in Abacus and obtain results odb file.
- Post process the results
- Plot deformation animation
- Plot displacement
- Plot Principal stresses.



Load case 1. Point load of 2943 N applied

Fig. 4. Deformation shape max displacement=29.9mm

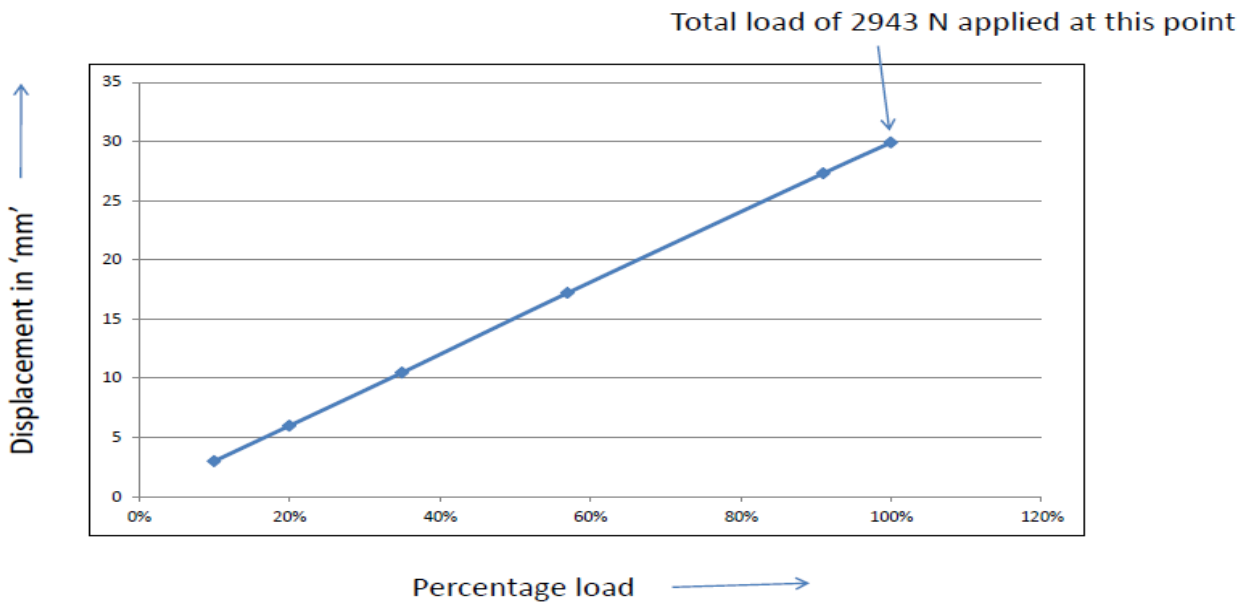
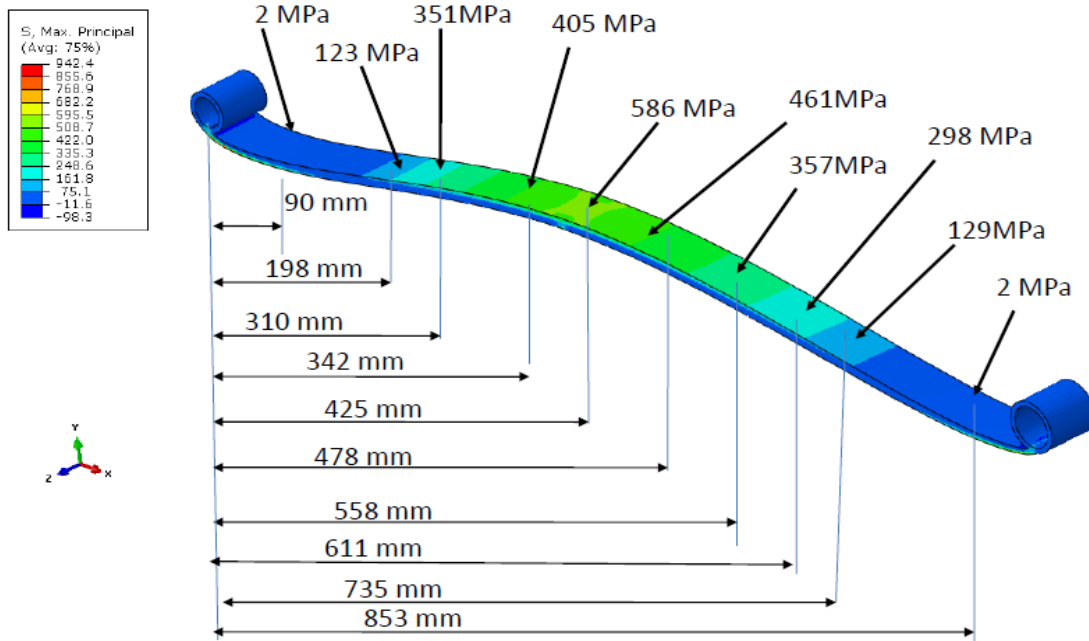


Fig. 5. Graph of Displacement v/s Percentage Load



Point load of 2943 N applied Yield strength= 1158 MPa

Fig. 6. Stress Contour Plot along the Length

Table 1. Stress Variation Table

Sr. no.	Distance of point From Left end in mm	Stress value at the point in MPa	Thickness of leaf At the point in mm
1	90	2	6.9
2	198	123	8.5
3	310	351	9.5
4	342	405	9.7
5	425	586	10.2
6	478	461	10.2
7	558	357	10
8	611	298	9.9
9	735	129	8.9
10	853	2	7.4

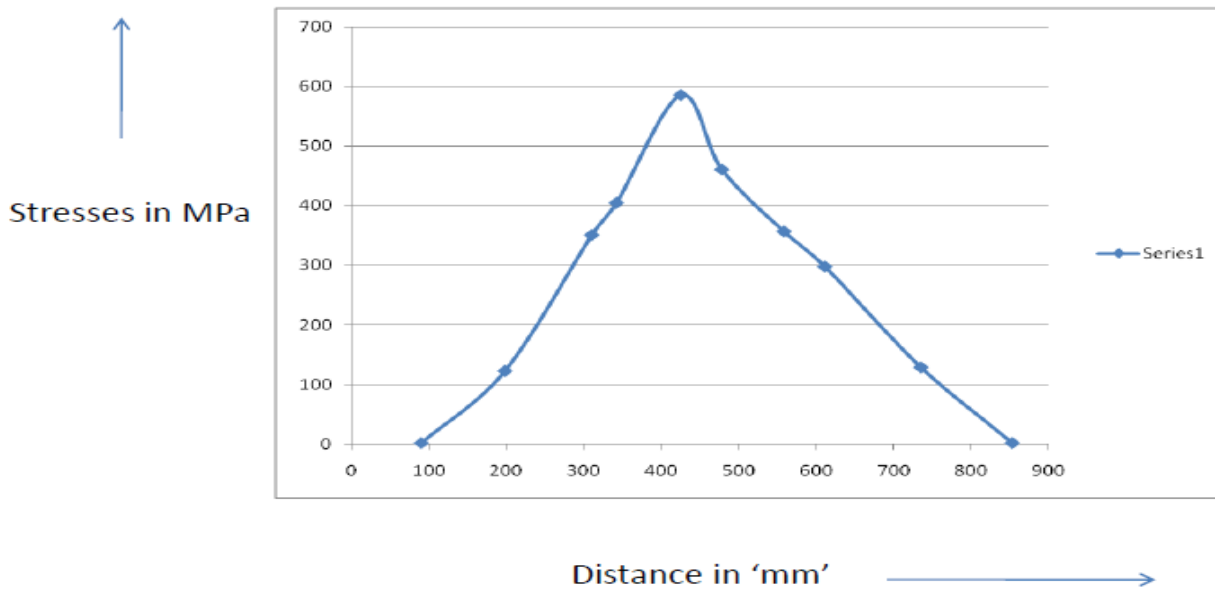


Fig. 7. Stress Distribution along the Length

OPTIMIZATION OF LEAF SPRING (STEEL)

OPTIMIZATION THEORY

As discussed earlier the design of leaf spring is very much sensitive to the thickness of the leaf spring. It means that the values of stiffness or deflection & corresponding stress at various points have maximum dependence on the thickness at that point. In other words a small variation in the thickness gives rise to a large variation in the stress values at a certain value of deflection or applied load. This is due to the large difference between the values of width (50mm) and thickness(10mm). Hence small variation in thickness affects the design a lot. Moreover the variation of thickness along the length also plays an important role in the design perfection. The optimization thus is based on the values of thickness and their variation along the length of the leaf spring. Careful study of the theory of leaf spring reveals that the parabolic variation in the thickness gives optimum design.

Table 2. Thickness Values for Optimization

Sr.no	Distance from small eye centre (left end) in mm	Thickness in mm
1	000	5.00
2	025	5.00
3	050	5.00
4	075	5.00
5	100	5.34
6	125	5.97
7	150	6.53
8	175	7.06
9	200	7.55
10	225	8.00
11	250	8.44
12	275	8.85
13	300	9.24
14	325	9.62
15	350	9.98

16	375	10.33
17	400	10.67
18	425	11.00
19	450	10.75
20	475	10.49
21	500	10.23
22	525	10.70
23	550	9.68
24	575	9.40
25	600	9.10
26	625	8.80
27	650	8.48
28	675	8.15
29	700	7.81
30	725	7.46
31	750	7.08
32	775	6.69
33	800	6.26
34	825	5.81
35	850	5.32
36	875	5.00
37	900	5.00
38	925	5.00
39	950	5.00
40	975	5.00

Width of leaf spring = 41 mm.

Point of application of load at 425 mm from left end (centre of small eye) as before.

Thickness at this point = 11 mm (given in table also)

Parabolic reduction in thickness is stopped at 5 mm value so that the spring can resist other forces like cornering and breaking forces also.

No change in other parameters including material properties, length, etc.

Finite element analysis of leaf spring is done in Abacus software with above dimensions to obtain values of stress all along the length of the leaf spring. Deflection of leaf spring is also obtained. These results are then compared with the FEA results before optimization.

The results of FEA of leaf spring after optimization are as given below.

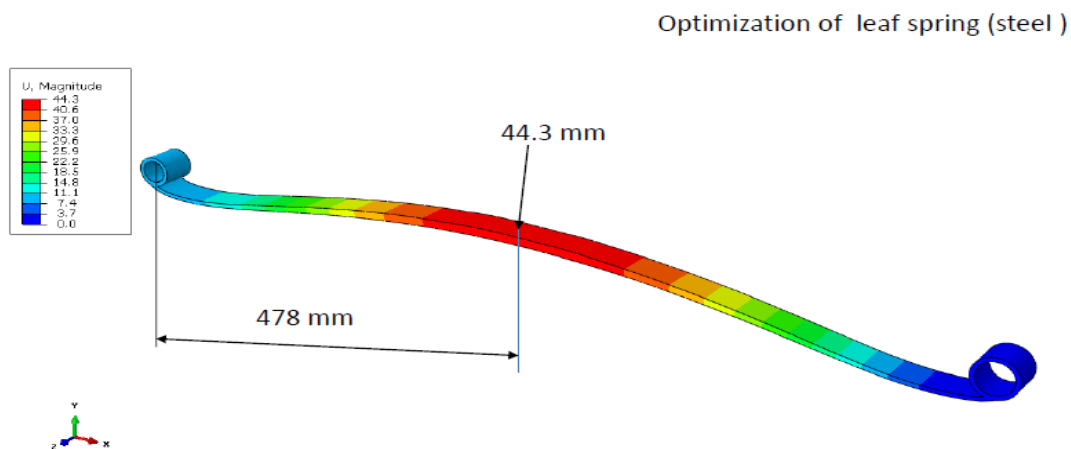


Fig. 8. Deformation shape- maximum displacement = 44.3mm

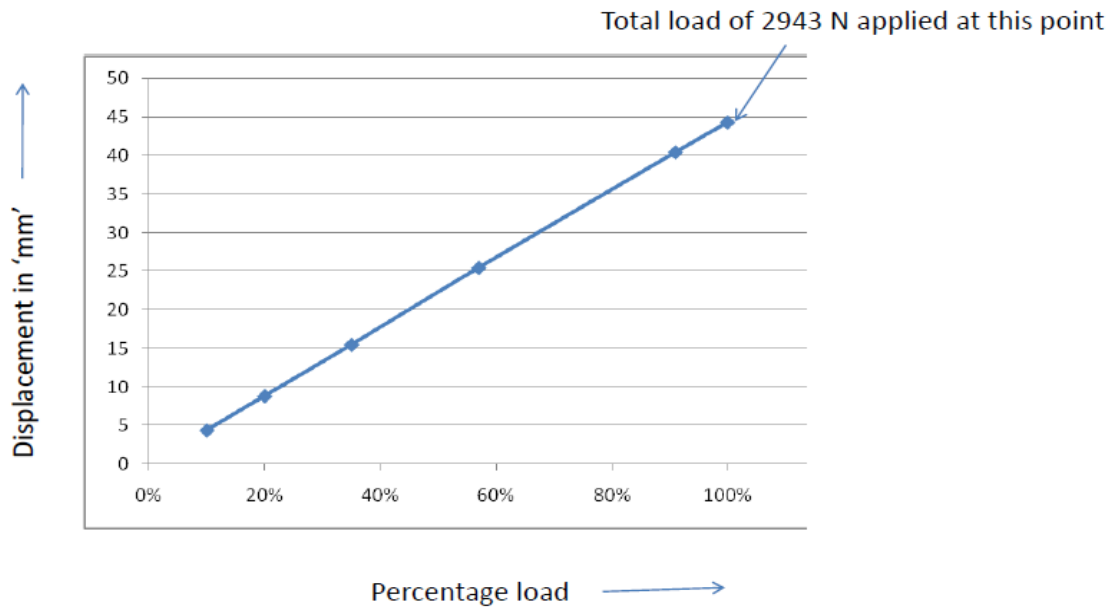


Fig. 9. Graph of Displacement vs. Percentage Load

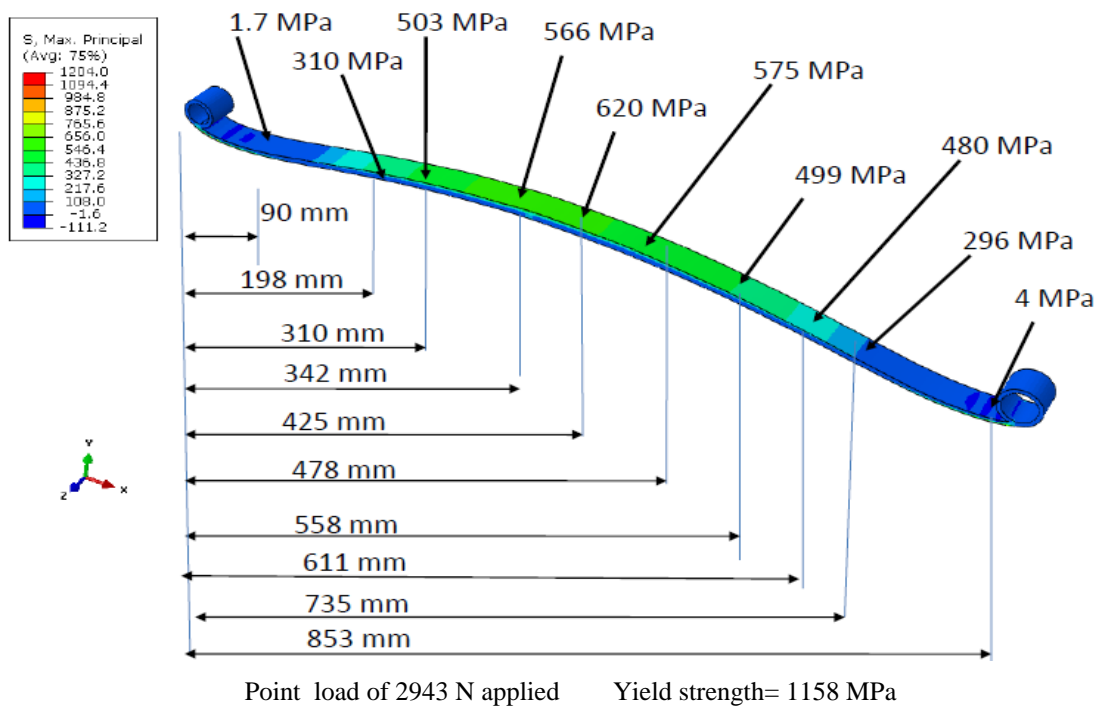


Fig. 10. Stress Contour Plot Along Length

Table 3. Stress Comparison Before and After Optimization

Sr. no.	Distance of point from left end in mm	Thickness of leaf at the point in mm (Design before optimization)	Thickness of leaf at the point in mm (Optimized design)	Stress value at the point in MPa (Design before optimization)	Stress value at the point in MPa (Optimized Design)
1	90	6.9	5.1	2	1.7
2	198	8.5	7.55	123	310
3	310	9.5	9.6	351	503
4	342	9.7	9.8	405	566
5	425	10.2	11	586	620
6	478	10.2	10.4	461	575
7	558	10	9.8	357	499
8	611	9.9	8.8	298	480
9	735	8.9	7.2	129	296
10	853	7.4	5.2	2	4

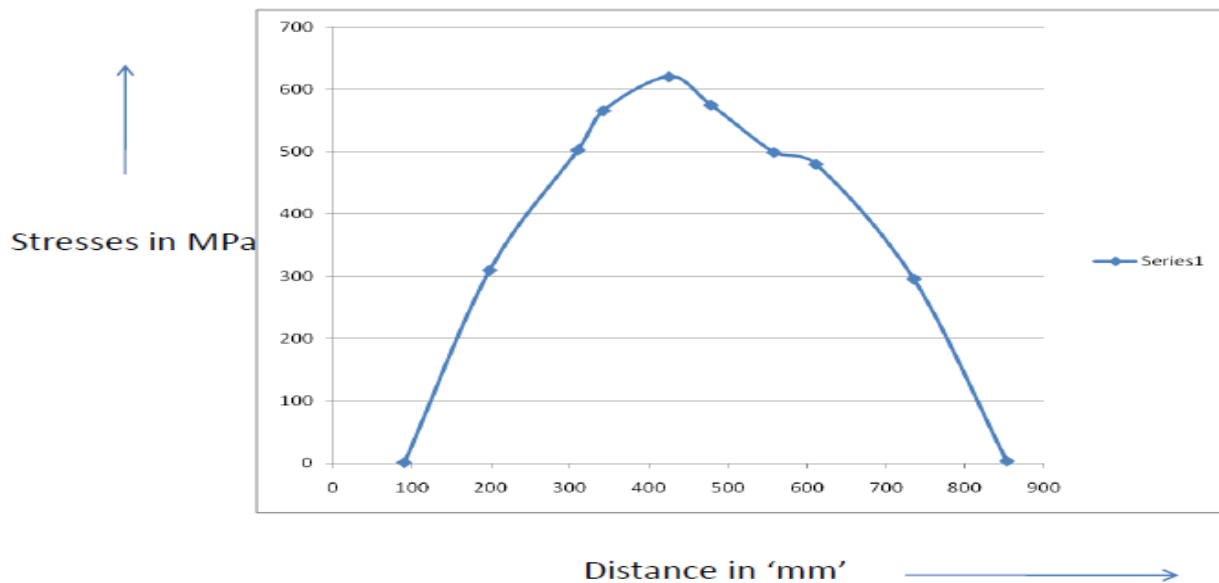


Fig. 11 Stress distribution after optimization

The stress distribution before and after optimization along the length of the leaf spring can be compared easily by plotting both the curves on a single graph (with the same scale).

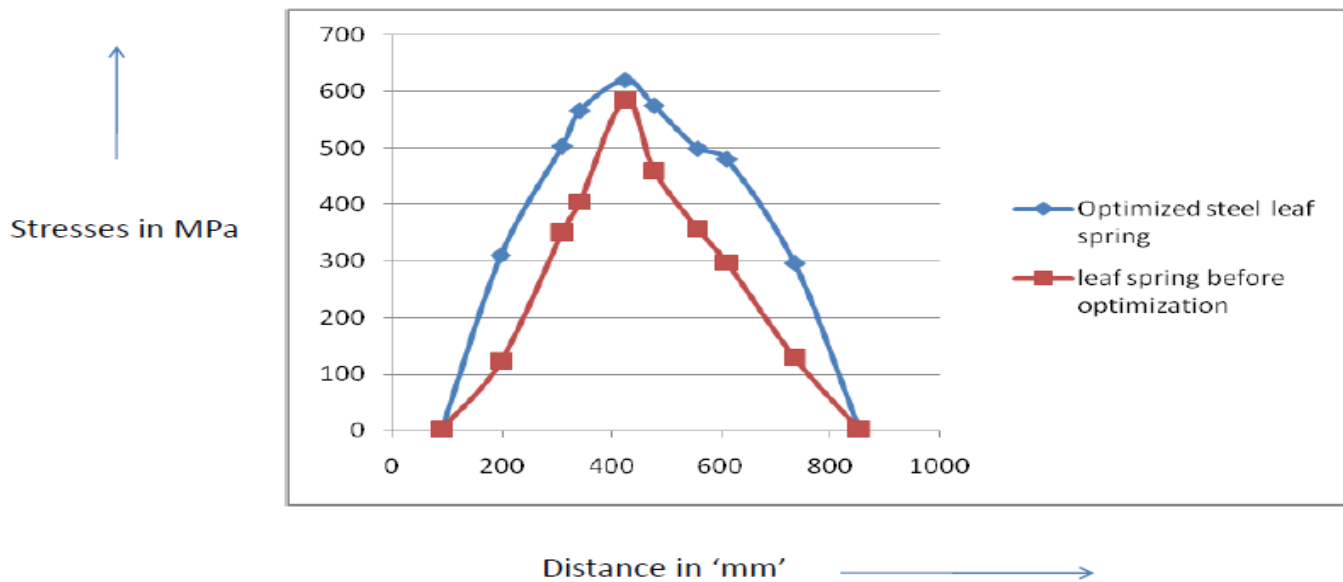


Fig. 12 Graphical comparison of stress distribution

Table 4 - Results of Optimization of Spring

Sr. no.	Parameter	Value before optimization	Value after optimization	Percentage Improvement
1	Maximum stress value in mpa	586	620	- 5.80
2	Volume Of springs in mm ³	484975	363742	25.00
3	Mass of springs in kg	3.789	2.837	25.00
4	Maximum deflection (deflection at max load).	29.9	44.3	48.16
5	Minimum deflection (deflection at min. load)	16.5	24.5	48.48

RESULTS AND DISCUSSION

The uniformity in stress distribution could have been more pronounced if parabolic reduction in thickness would be continued at the ends. But this cannot be done since the suspension system is required to resist other forces like cornering & breaking forces also. Nevertheless considerable improvement in certain parameters mentioned in conclusion bellow is obtained by parabolic variation in thickness along the length of the leaf spring.

CONCLUSION

Material saving up to 25% can be achieved by parabolic variation in thickness along the length of the leaf spring. In other words distribution of stress of leaf spring can be improved (it becomes more uniform) after optimization. Utilization of material is improved due to optimization. Riding comfort of passengers is improved due to reduction in unsprung mass of the vehicle. More deflection can be obtained after optimization thus increasing the riding comfort further.

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