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Design and Analysis of Leaf Spring of Tanker Trailer Suspension System

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Abstract: **The component chosen for analysis is a leaf spring which is an automotive component used to absorb vibrations induced during the motion of the vehicle. The function of Leaf spring is to distort when loaded and to recover its original shape when the load is removed. Leaf springs are long and narrow plates attached to the frame of trailer that rest above or below the trailers axle. The work is carried out on a semi elliptical Leaf spring having 8 Leaves. The number of leaves vary as per load capacity.**

The objective of this present work is to estimate the stresses and deflections calculated by hand calculation and this is compared with the FEA result. The FEA model of the Leaf spring has been generated in CATIA V5 R17 and imported in ANSYS 14.5 for Finite Element Analysis. Which are most popular CAE tools. The design constrains are stresses and deflections. The strength validation is done using the FEA software.

Keywords: **Analysis Is A Leaf Spring, Generated In CATIA V5 R17 And Imported In ANSYS 14.5.**

1. INTRODUCTION

Leaf springs are crucial suspension elements used on light passenger vehicle load necessary to minimize the vertical vibrations impacts and bumps due to road irregularities and to create a comfortable ride. Leaf springs are widely used for automobile and rail road suspensions. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly so increasing the energy storage capabilities of a leaf spring and ensures a more compliant suspension system. Three dimensional finite element analysis of the leaf spring consists of a computer model or design that is stressed and analyzed for specific results. A company that is able to verify a proposed design will be able to perform to the clients specifications prior to manufacturing or construction. According to the study made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for the leaf spring.

2. LEAF SPRING

2.1 Basics:

A spring is defined as an elastic body whose function is to distort when loaded and to recover its original shape when the load is removed. Leaf sprigs are crucial suspension elements used on light passenger vehicle necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and to create a comfortable ride. Leaf springs are widely used for automobile and rail road suspensions. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly so increasing the energy storage capabilities of a leaf spring and ensures a more compliant suspension system.

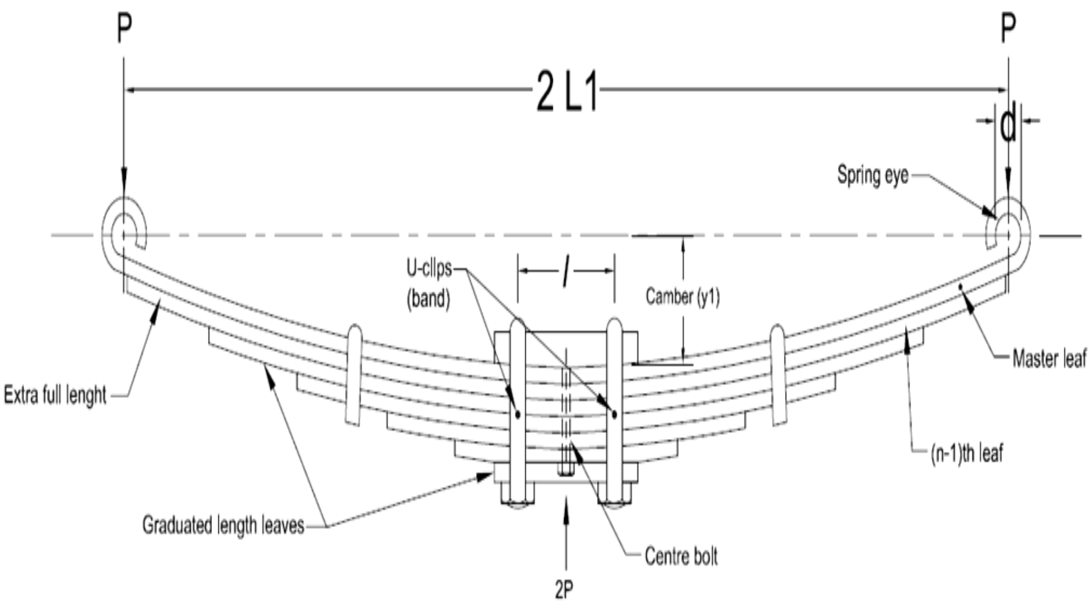

Figure 1:Semi-elliptical Leaf Spring

Functions of leaf spring:

Functions of leaf spring are to absorb road shocks, carry lateral load and in some cases to take the brake torque and driving torque in vehicles. It also functions as a structural member.

Extra full length leaves:

The longest leaves below master leaves .The extra full length leaves are stacked between master leaf and graduated leaves.

Graduated leaves:

The other leaves below extra full length leaves. In order to prevent digging in the adjacent leaves the ends of the graduated leaves are trimmed in various forms.

Rebound Clips:

Rebound clips are provided to keep the leaves are Extra full length leaf & graduated leaf in allignment and prevent lateral shifting of the leaves during operation.

Camber:

The amount of curvature given to the leaf and observed from the main leaf up to the point just below the centre of the either of the end eyes of the spring.

Spring eye:

There are two different leaf spring based on the spring’s ends, double-eye leaf springs and open-eye leaf springs. On double-eye leaf springs the top plate is the longest and has both ends curved like a circle. The ends of the double-eye leaf springs make two holes, which can be connected to the bottom of a trailer's frame. Open-eye leaf springs have only one hole. The other end of an open eye leaf spring usually has a hook end or a flat end.

2.2 Materials for Leaf Spring:

The basic requirements of a leaf spring steel is that the selected grade of steel must have sufficient harden ability for the size involved to ensure a full martenstic structure throughout the entire leaf section. In general terms higher alloy content is mandatory to ensure adequate harden ability when the thick leaf sections are used. The material used for the experimental work is 55Si2Mn90. The other designation of this material is shown in Table. And its chemical compositions are shown below in Table.The material used for leaf spring is usually a plain carbon steel having 0.90 to 1.0% carbon.

Table 1: International Standard of Material

International Standard	Equivalent Grade			
	IS	DIN	BS	AISI
EN45	55si2Mn90	55si7	250A53	9255

Table 2: Composition of Material

Grade	C%	Si%	Mn%	Cr%	Mo%	P%	S%
55si2MN90	0.55	1.74	0.87	0.1	0.02	0.05	0.05

Table 3: Physical properties of materials used for leaf spring

Material	Condition	Ultimate tensile strength (MPa)	Tensile yield strength (MPa)	% minimum elongation l=5.65√(area of cross section)	Brinell hardness number
50 Cr 1	Hardened & tempered	1680-2200	1540-1750	-	461-601
50 Cr 1 V 23	Hardened & tempered	1900-2200	1680-1890	4	534-601
55 Si 2 Mn90	Hardened & tempered	1820-2060	1680-1920	6	534-601

3. GENERAL ARRANGEMENT OF DRAWING

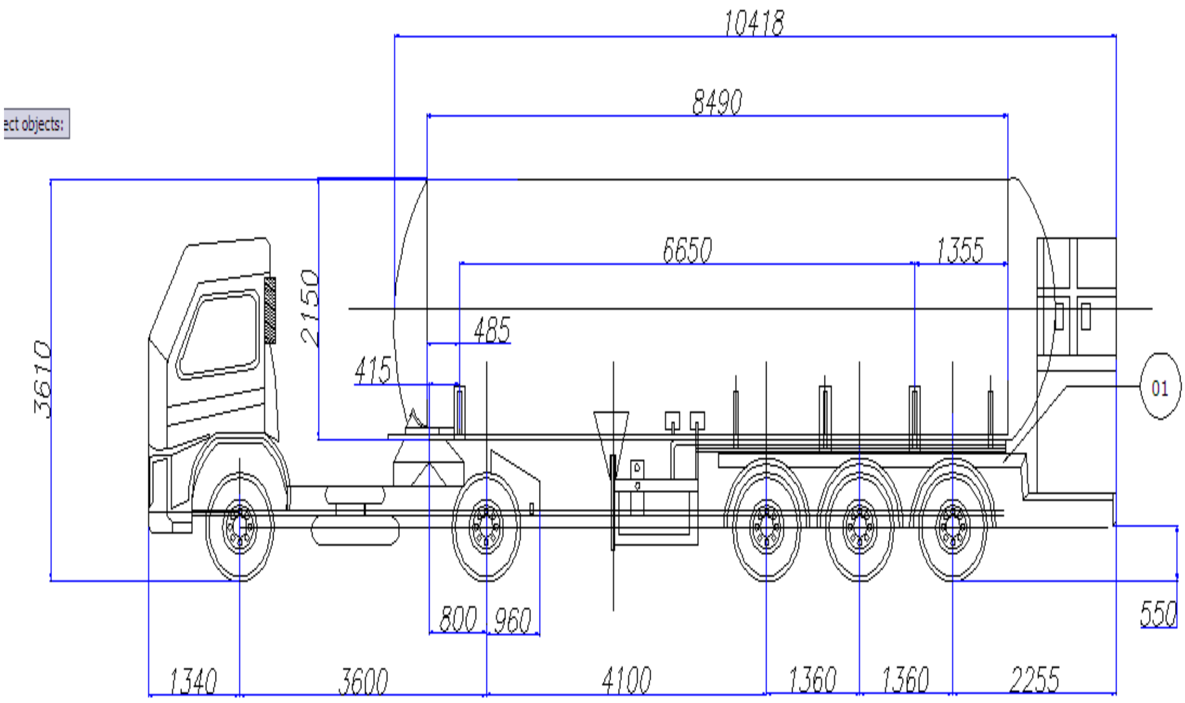

Figure 2: TATA LPS 4018 Tanker trailer

The above figure is Tata LPS 4018 Tanker trailer. The trailer shown is heavy commercial vehicle with the capacity of 5675cc. The trolley on the truck has a tri axle arrangement at the back. The dimensions of the height, width and length are also shown in the figure and are all measured in mm. The suspension used in the trailer is semi elliptical leaf spring both at the front and rear end. In addition at the front end hydraulic double acting telescopic shock absorber. In addition it also has a Anti roll bar at the front axle. The vehicle is used to supply gas tanks, petrol tanks, etc. The semi elliptical leaf spring which contains the number of leaves such as master leaf, graduated leaves and extra full length leaves. The number of leaves vary as per load capacity. I selected this vehicle for the project and design the vehicle for 12ton capacity. I selected 8 leaves for the design, 1 master leaf , 2 extra full length leaves , 5 graduated leaves. 1 master leaf with length 1176mm and extra full length leaves with 795mm and graduated leaves with 680mm, 564mm, 449mm, 334mm, 219mm respectively. The width of all leaf springs is 75mm and thickness is 13mm with material 55Si2Mn90.

3.1 Specification of tri-axle trailer:

1	Class of vehicle	Cryo Tanker Trailer
2	Type	Tanker Trailer, Tri-axle
3	Prime Mover Used	TATA LPS4018 Tractor
4	Unladden weight of the trailer	59939.1 N
5	Payload	235440 N
6	Gross vehicle weight of the trailer	295379.1 N
7	Under carriage & 3 axle	38259 N
8	Overall length of trailer	10.418 m
9	Overall width of trailer	2.495 m
10	Overall Height of trailer	1.270 m
11	Overall length of tanker trailer combination	14.015
12	Cross bearers	C Section 125x65 mm
13	Wheel base	6.260 m
14	Axle	3 no. 150mmx150mm Round beam of axle, 16 mm wall thickness
15	Leaf spring	75x13mm flat:940mm eye
16	Tyres	10.00x20, 16R, 12 nos.

4. METHODOLOGY

4.1Design of leaf Spring:

4.1.1 Design Input:

Axle load carrying capacity = 12 T
= 12000 kg
Load on spring (2P) = 6000 kg
Load on spring at one side (P) = 3000 kg
Length of Span ($2L_1$) = 876 mm
Length of half Span (L_1) = 438 mm
Ineffective length (l) = 104 mm
Length of hanger (l_1) = 150 mm
Width of the leaves (b) = 75
Thickness of leaves (t) = 13
Number of leaves in the spring ($n_e + n_g = n$) = 8
Number of graduated leaves including master = 6 leaf (n_g)
Number of extra full length leaves (ne) = 2
Modulus of elasticity (E) = 2×10^4 kg/mm^2

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4.1.2 Leaf spring Result:

Sr. No.	***Parameters***	***Case-1 (8×75×13), 876mm 12 ton axle capacity***
1	Axle load carrying capacity, kg	12000 kg
2	Load on spring(2P),kg	6000 kg
3	Load on spring at one side (P),kg	3000 kg
4	Length of span(2L1),mm	876 mm
5	Ineffective length(l), mm	104 mm
6	Total no. of leaves(n)	8
7	No. of extra full length leaves(n)	2
8	No. of graduated leaves (n) including master leaf	6
9	Width of leaves(b), mm	75 mm
10	Thickness of leaves (t),mm	13 mm
11	Effective length (2L),mm	806.67mm
12	Bending stress in leaf spring(σb),	kg/mm²71.53 kg/mm²
13	Deflection in leaf spring (y), mm	44.68 mm
14	Initial gap (C), mm	14.89 mm
15	Initial load (Pi), kg	500 kg
16	Radius of curvature (R),mm	2434.8 mm
17	Material (55Si2Mn90):	
	a. Ultimate tensile strength, kg/mm²	185.52-209.98 kg/mm²
18	b. Tensile yield strength, kg/mm²	171.25-195.71kg/mm²
19	Factor of safety on yield	2.73
20	Deflection limit (2L1/y)	19.6

4.1.3 Analytical results by applying various loads:

The below shown results are hand calculated by considering 12tons load on axle and the load of 3tons is distributed towards the spring. The 3tons load has given the deflection 44.68mm by hand calculation and stress of 710.70x10^{6}N/m^{2}. The value of stress obtained in analytical result is less than the safe working stress which is 875x10^{6}N/m^{2}.

Table 4 : Analytical result for deflection and stress

Sr.no	Load(N)	Deflection(mm)	Stress(N/m^{2})
1	5000	7.59	108.22 x10^{06}
2	10000	15.18	216.45 x10^{06}
3	15000	22.77	324.68 x10^{06}
4	20000	30.36	432.91 x10^{06}
5	25000	37.95	541.14 x10^{06}
6	30000	41.55	649.37 x10^{06}
7	32833	44.68	710.70 x10^{06}

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The below shown graph are according to the above table:-

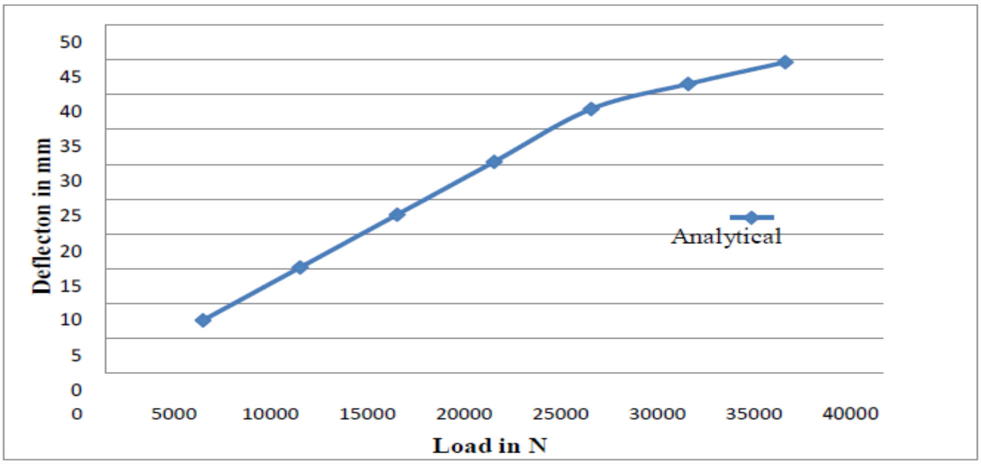

Figure 3 : Variation in deflection with load for leaf spring

The above graph shown is load vs deflection graph. By applying various loads the deflection varies at different points. At 32833N the deflection is 44.68mm.

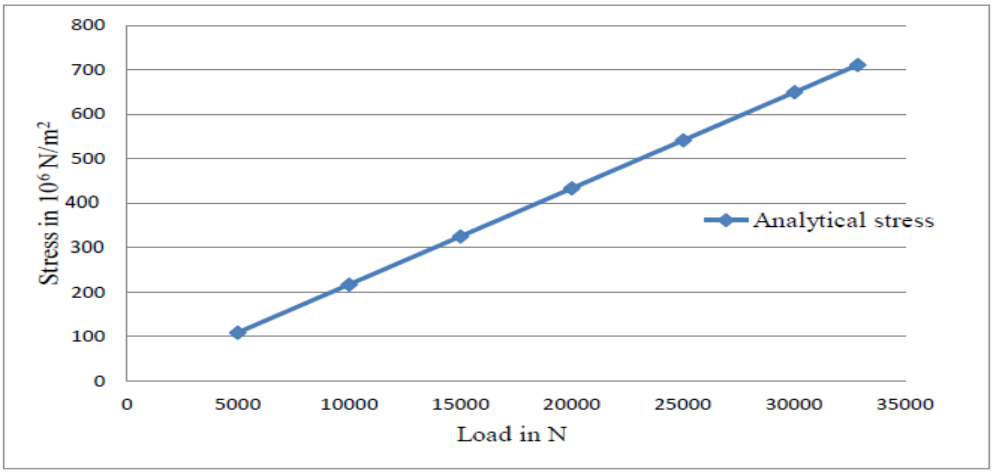

Figure 4: Variation in stresses with load for leaf spring

The above shown graph shows that when the value of load increases on the spring, stress also increases proportionally with the load.

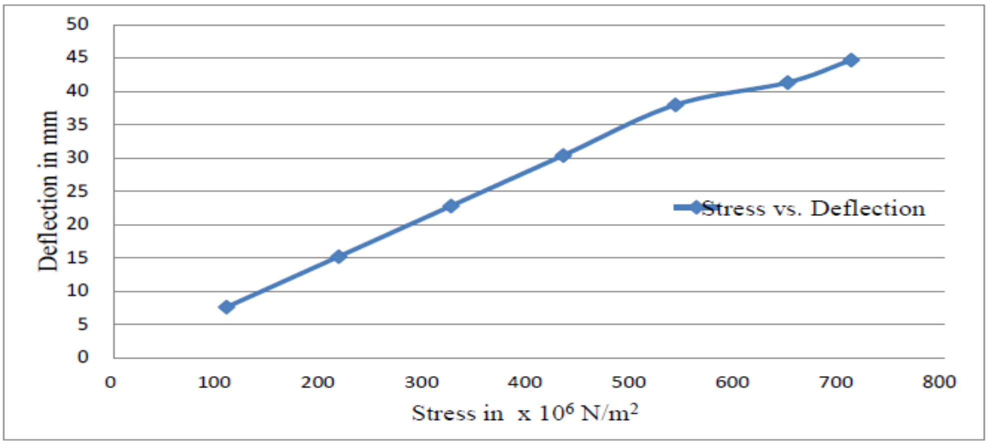

Figure 5: Stress vs. Deflection

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The above shown figure shows that as the stress increases the deflection increases till the point the deflection reaches 30-40mm and then it increases gradually.

4.2 Finite Element Analysis:

In finite element analysis 3D model of leaf spring is developed in CATIA v5. After modeling of leaf spring then give the actual supporting boundary condition in ANSYS 14.5 i.e. fixed support in front side, displacement in the rear side and in center 32833N force is applied. In fixed support there is no any degree of freedom i.e. zero displacement at any direction. In rear side only z-axis displacement is allowed. This condition is real in TATA LPS-4018 Leaf spring. After giving the boundary condition meshing of leaf spring is done by obtaining the nodes 46588 and element 7864. The results of the solution are available at the node of the elements. Finite element analysis can display them in graphical form to analyse them, to make design decisions and recommendations. Conventional analytical method for solving stress and strain becomes very complex. In such cases finite element modeling becomes very convenient.

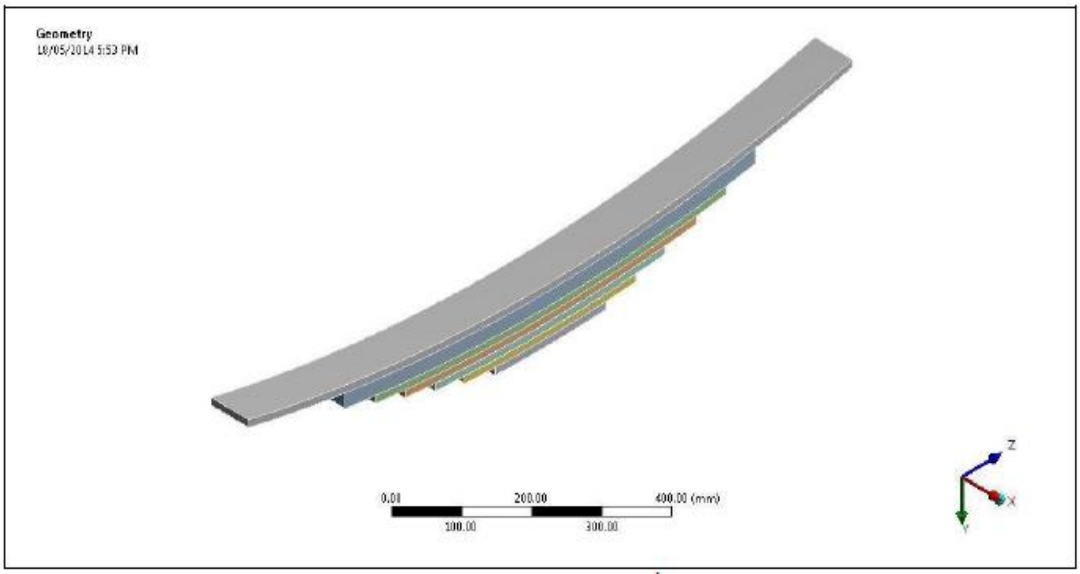

Figure 6: Model of the leaf spring

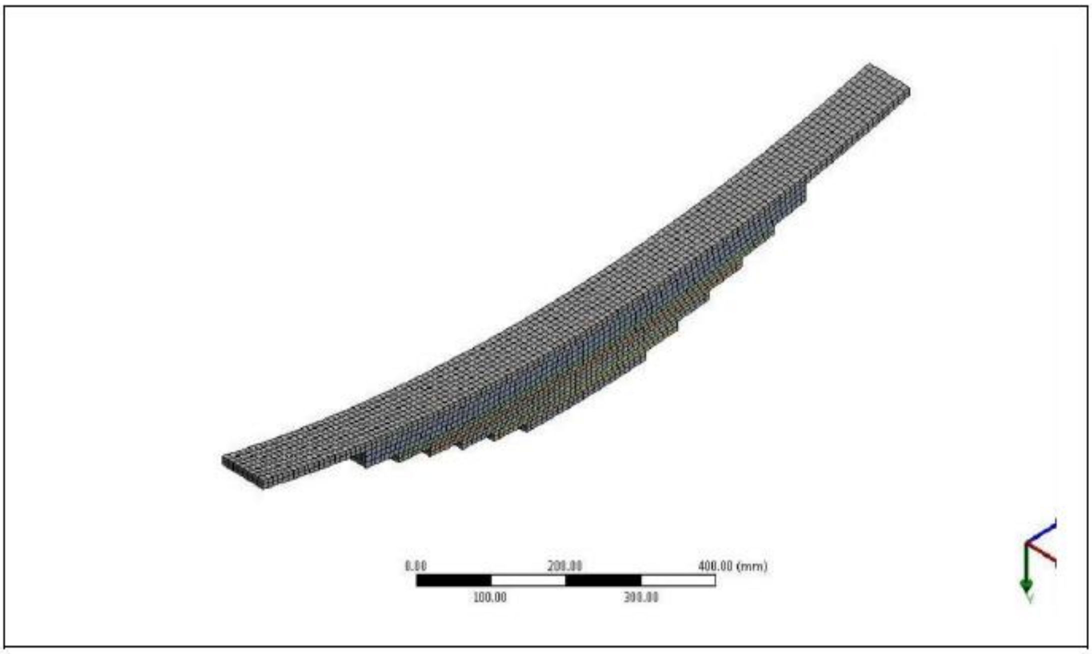

Figure 7: Meshing of the leaf spring

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After giving all boundary condition and load i.e. 32833N which is applied to the leaf spring and calculated by considering 12 Ton capacity load vehicle. Also applying all material properties of 55Si2Mn90 i.e. Young's Modulus (E), Poisson's Ratio , Tensile strength ultimate, tensile strength yield, Density, thermal expansion.

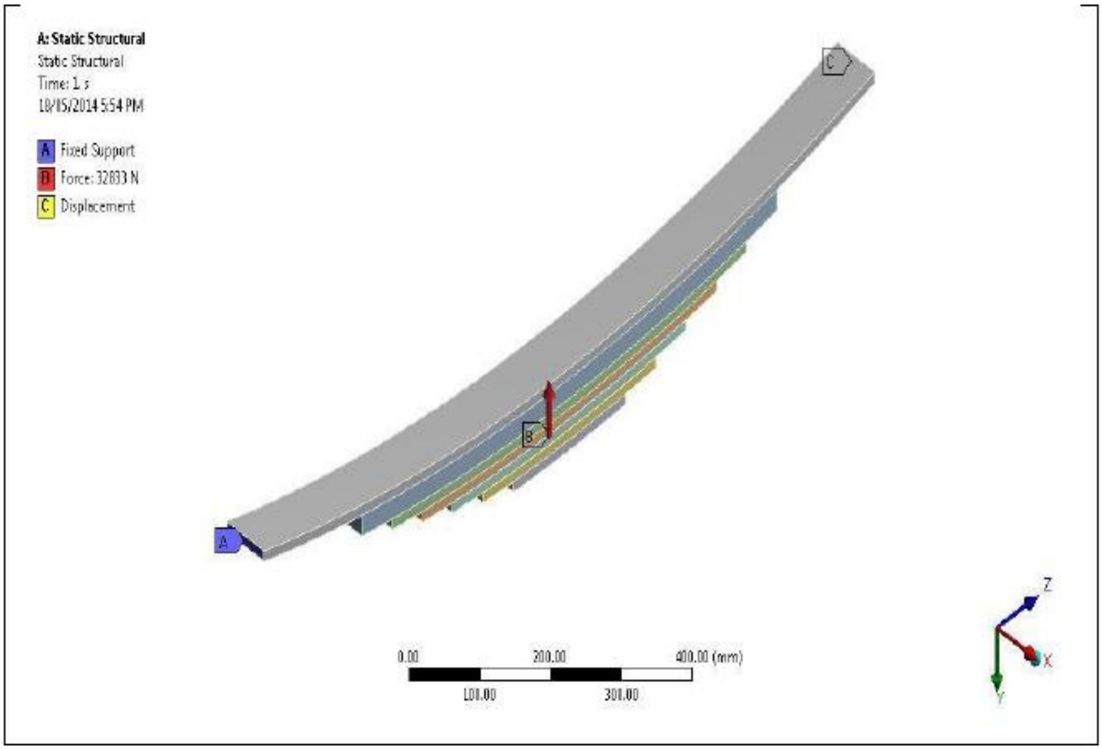

Figure 8: Boundary conditions applied on leaf spring model

In still leaf spring total deformation is found 46.104mm and equivalent (von-mises) stress 1361.3mpa. The von- mises stress and total deformation is shown below.

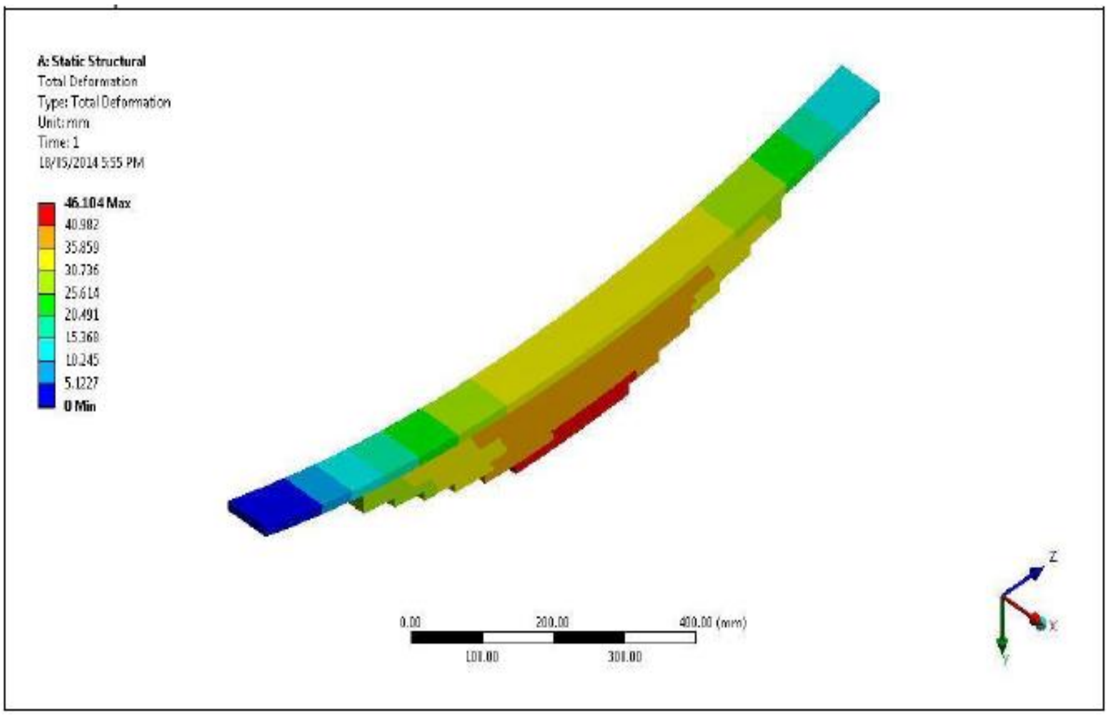

Figure 9: Total deformation of the leaf spring

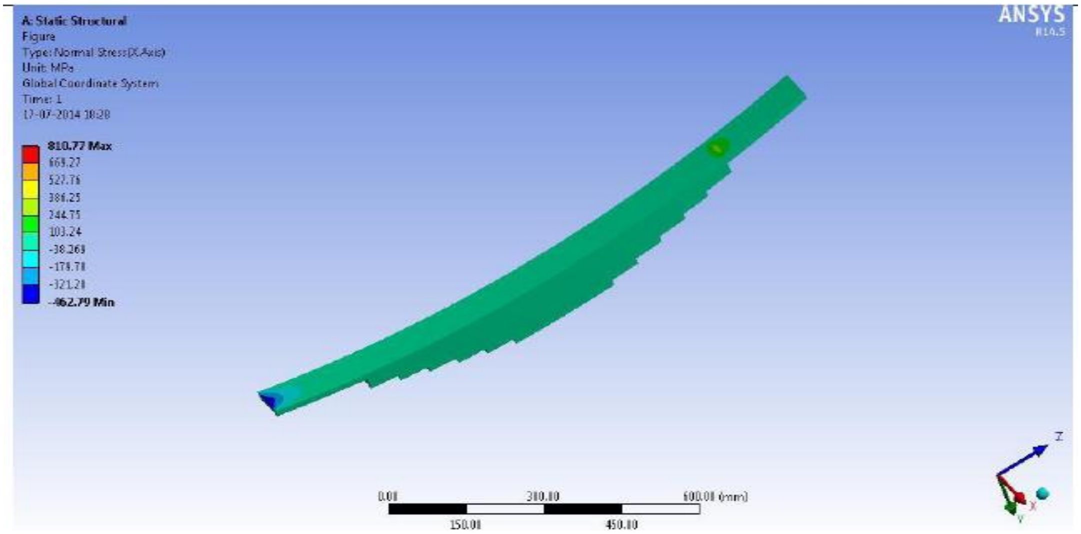

Figure 10:Normal stress of the leaf spring

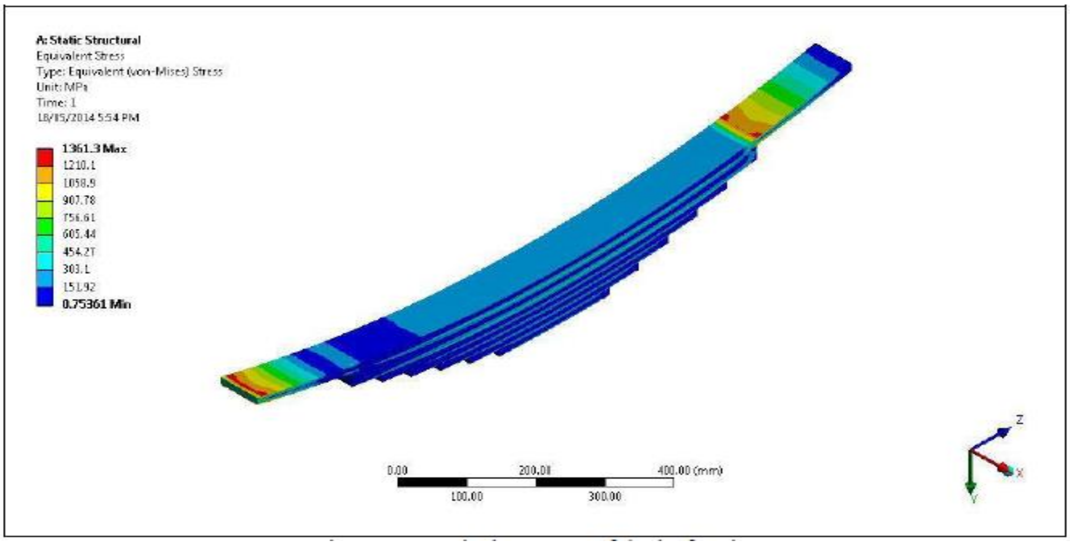

Figure 11: Equivalent stress of the leaf spring

4.2.1 FEA results by applying various loads:

The below shown results are calculated using finite element method by Ansys14.5. By considering 12tons load in axle and the load of 3tons is distributed towards the spring.

Table 5: FEA Result for Deflection and Stress

Sr.no	Load(N)	Deflection(mm)	Stress(N/m^2)
1	5000	7.02	123.46 x10^{06}
2	10000	14.04	246.93x10^{06}
3	15000	21.06	370.40 x10^{06}
4	20000	28.083	493.87 x10^{06}
5	25000	35.104	617.34x10^{06}
6	30000	42.125	740.81x10^{06}
7	32833	46.104	810.77 x10^{06}

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The below shown graph are according to the above table:-

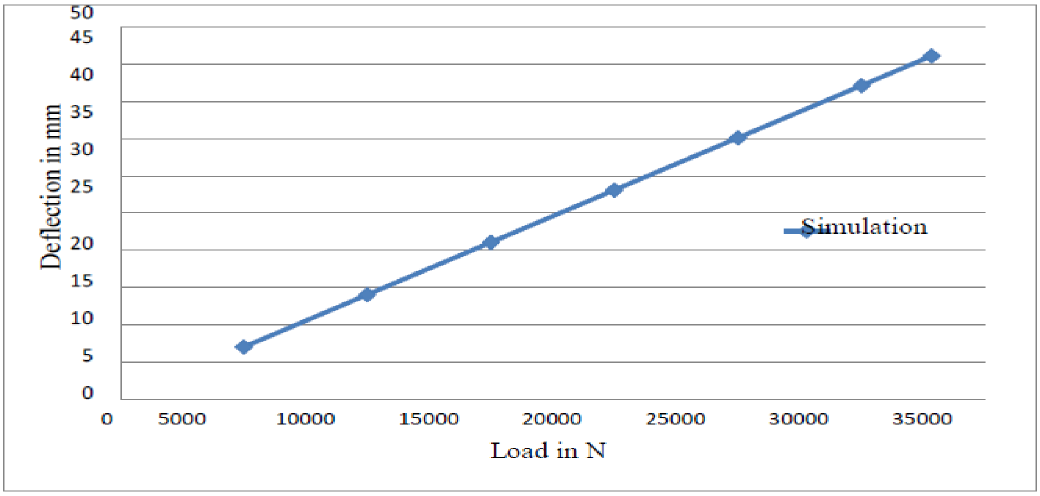

Figure 12: Variation in deflection with load for leaf spring

The above graph shows that the result obtained by hand calculation and FEA shows the same result. According to FEA the deflection is 46.10mm.

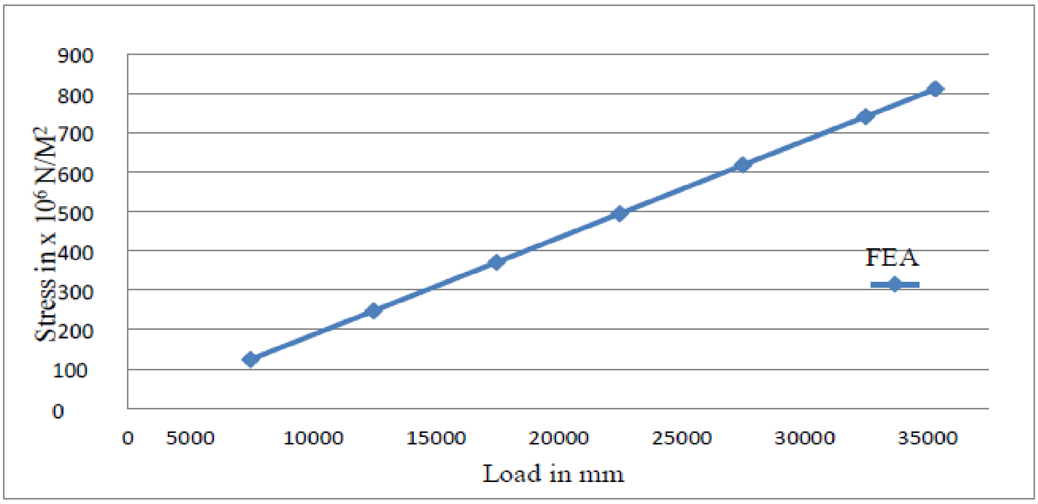

Figure 13: Variation in stress with load for leaf spring

The above graph shows that the result obtained by hand calculation and FEA shows the same result. The graph is made considering allowable value of safe working stress.

4.3 Experimentation:

In the experimental analysis steel leaf spring are taken. The deflection or the bending stress of the spring is taken on the universal testing machine. A universal testing machine (UTM) is used to calculate various stresses, strength and deflection of the material.

The first step is to purchase the leaf spring from the manufacturer as per dimensions. Then get it coupled as per the actual situation used in vehicle while assembling. After purchasing the leaf spring, it is put on the Universal testing machine where the rear end of the spring is fixed, the front end is kept free and the load of 32.83kN is applied at the centre of the leaf spring. The way leaf spring is used or fitted in the actual vehicle, the same boundary conditions are applied while experimentation. Then the results are being noted. The deflection is calculated using digital vernier caliper and the stress is also shown by the UTM machine. The figure shown below is the leaf spring on the universal testing machine used in the experimentation. Following figure shows the deflection value using vernier calliper:

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Figure 14: Setup of Leaf spring on the UTM

Figure 15: Deflection in the leaf spring

4.3.1 Experimental Result:

The table shown below contains the deflection and stress calculated by applying various load on the spring by using universal testing machine.

Table 6: Experimental Results for Deflection and Stress

Sr.no	Load(N)	Deflection(mm)	Stress(N/m^2)
1	5000	2.3	100.64x10^{06}
2	10000	5	186.29x10^{06}
3	15000	12.07	369.94x10^{06}
4	20000	19.15	498.59x10^{06}
5	25000	26.190	657.24x10^{06}
6	30000	37.22	810.88x10^{06}
7	32833	39.65	884.18x10^{06}

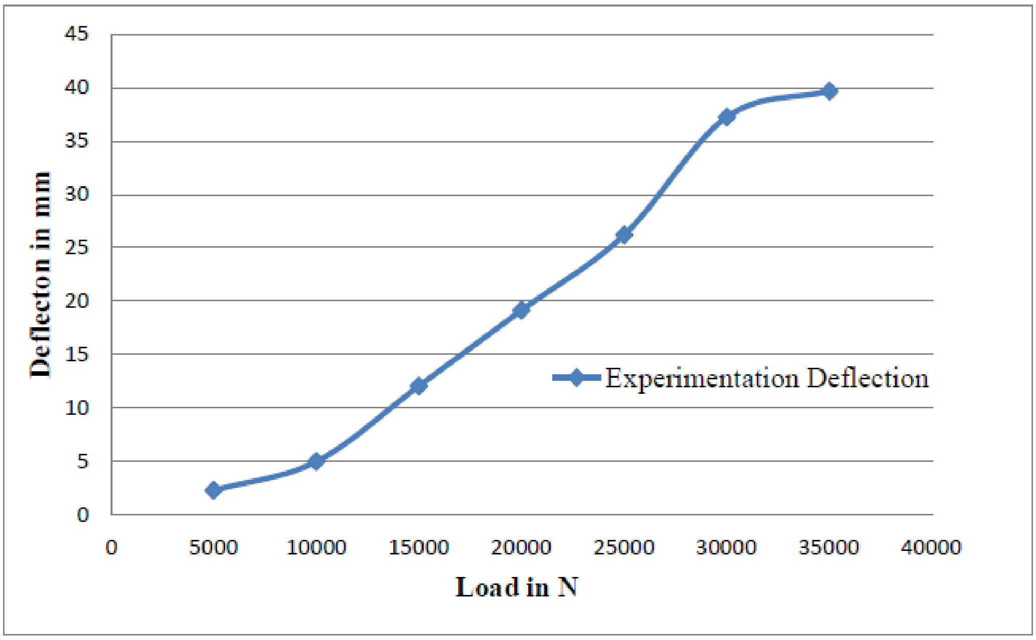

Figure 16: Load vs. Deflection

The above graph is shown by the experimental results. After applying the load on the leaf spring the leaf spring gives the deflection of 39.65mm. The reading of the digital vernier calliper is shown in the figure 30. The deflection shown at the intermediate stage of applying load is less and increases at the certain load of 10-15kN.

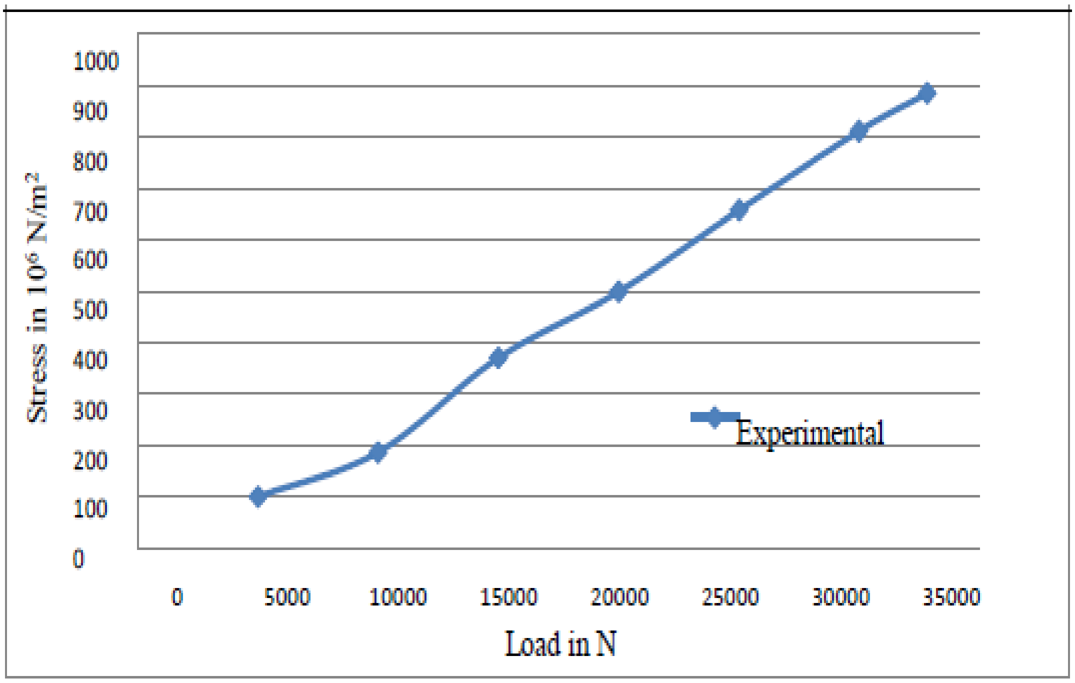

Figure 17: Load vs. Stress

The stress found in the graph is calculated by using the experimental result. The maximum stress is obtained 884.18 x 106N/m2 which is comparatively similar to the safe working stress of the material which is 875mpa.

5. RESULT AND DISCUSSION

Though the detailed results are presented in earlier, here an attempt is made to show compare the result obtained analytically by FEA and experimentation. For comparison of stress safe working stress and ultimate stress is considered.

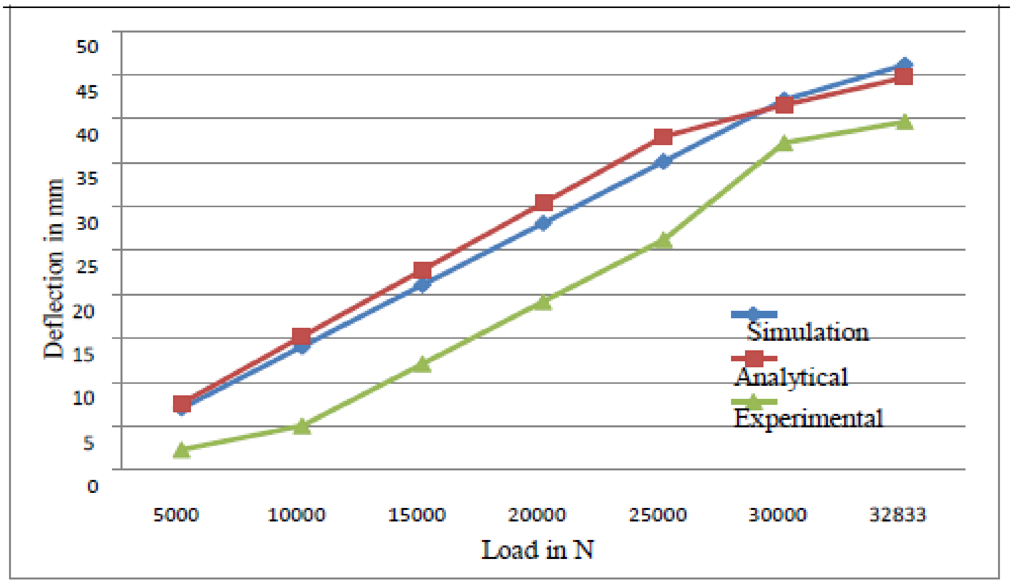

Figure 18: Comparison of Simulation, Analytical and Experimental Deflection

The deflections are evaluated at various loads varying from 5000N to 32833N. The results are given in the above tables and it is observed that the experimental deflection as compared to analytical and FEA deflection is less and maximum deflection is shown by finite element analysis. The results shown by experimentation are near to the values of the result shown by analytical and FEA. The deflection by simulation is 46.10, by analytical it is 44.68 and by experimental 39.65mm. The below shown graph shows the stress value which is calculated by formula and analytical methods are allowable values. The value obtained of von mises stress by using FEA is 1361.3mpa which is less than the ultimate tensile stress of the material-1750mpa and the stress obtained by other methods is less than the value of safe working stress. Safe working stress is calculated as 875mpa.

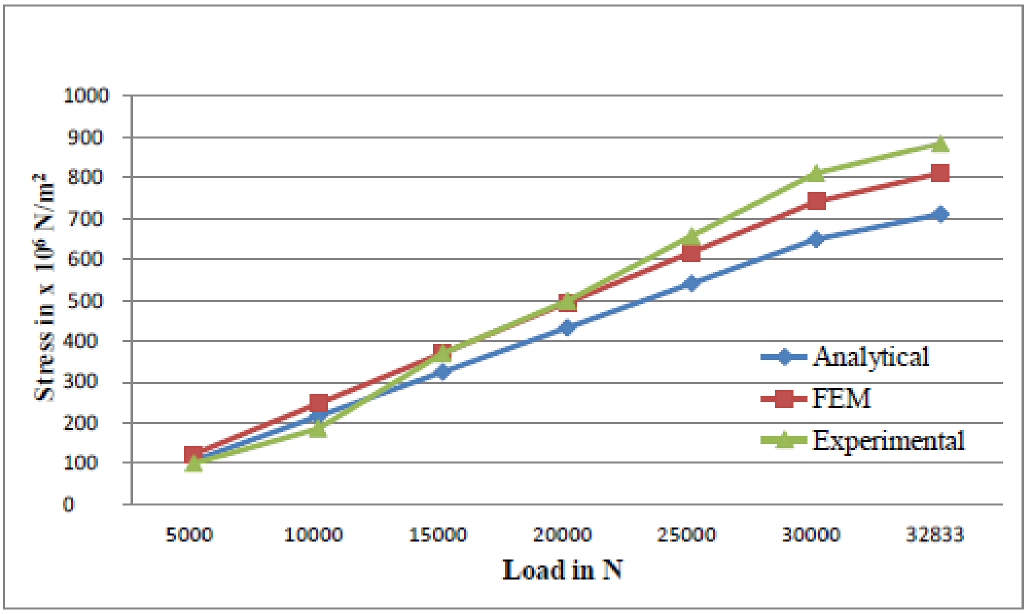

Figure 19: Comparison of Simulation, Analytical and Experimental Stress

5.1 Validation of Result:

Comparing the results by Hand calculation, FEA and Experimental shows that by hand calculation the stress is 710.70 x 10^6 which is similar to the safe stress of the given material is 875 x 10^6. The deflection calculated by hand calculation is 44.68 while that of FEA is 46.104, which shows that the deflection is similar to each other. The comparison in the graphs is shown above. The percentage variation of deflection considering FEA and hand calculation is 4%, FEA and experimental is 14%. The percentage variation of stress considering FEA and hand calculation is 12.35% while that of FEA and experimental is 9%.

Table 7: Deflection and stress result

Methodology	**Deflection in mm**	**Stress in N/m^2**
Hand Calculation	44.68	710.70 x 10^6
FEA	46.104	810.77 x 10^6
Experimental	39.65	884.18 x 10^6

6. CONCLUSION

The automobile chassis is mounted on the axles in form of springs. This is done to isolate the vehicle body from the road shocks which may be in the form of bounce, pitch, roll, etc. These tendencies give rise to an uncomfortable ride and also cause additional stress in the automobile frame and body. All the part which performs the function of isolating the automobile from the road shocks are collectively called a suspension system.

Leaf spring is a device which is used in suspension system to safeguard the vehicle and the occupants. For safe and comfortable riding i.e, to prevent the road shocks from being transmitted to the vehicle components and to safeguard the occupants from road shocks it is necessary to determine the maximum safe stress and deflection. Therefore in the present work, leaf spring is designed by using 32833N load. By considering this load the leaf spring is designed , modelling of leaf spring is created using CATIA V5 and analysis is done using ANSYS 14.5 workbench and it is concluded that for the given specifications of the leaf spring, the stress is found below its safe working stress of material which is used for the leaf spring. And 1361.3mpa von mises stress is also below its ultimate tensile stress. The deflection found by using all methods is nearly same and the maximum deflection is 46.10mm.

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