

Stress Analysis of a Leaf Spring Suspension System with the Combination of Helical Springs

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ABSTRACT:- This research article deals with a modified version of leaf spring suspension system introduced for the optimization of existing leaf spring suspension system design, by the combination of two helical springs with the master leaf. To furnish this end, a semi-elliptical type mono leaf spring of light-weighted mini truck is considered for design and modelling work. On both the sides of this mono leaf, a helical spring is designed and modelled at equal distances from the center of the leaf. All the modelling and analysis work is performed in CATIA- V5R20. Stress analysis results at various loading conditions are obtained by both theoretical and FEA methods, separately for typical mono leaf spring model and proposed model with helical springs. Results show an average 8.3% stress reduction for any of the loading conditions, by the utilization of helical springs with the combination of the master leaf. The proposed work has some certain benefits which could transform the existing leaf spring design into a more optimized, stable and flexible one for the overall better performance and comfort to passengers.

KEYWORDS

Leaf spring, helical spring, FEA, stresses, CATIA

INTRODUCTION

Springs are key elements of any suspension system and first line of its defense. Leaf springs and helical springs both are two basic types of suspension springs. Leaf springs, especially the longitudinal laminated type are reliable and persistent element in automotive suspension system [1], and helical springs are also one of the mechanical elements used in several industrial applications and automobile vehicles to satisfy the desired functions [2]. Generally, helical springs are made of an elastic material formed into the coil shape which returns to its initial length when unloaded [3]. Leaf springs are commonly formed by stacking leafs or plates of steel in progressively longer lengths on top of each other, so that the spring is thick in the middle portion to resist bending and thin at the ends where it attaches to the body [4]. Increasing the energy storage capability of a leaf spring ensures a more compliant suspension system [5]

Both the springs as a suspension element have their specific benefits and some limitations.

So, a leaf spring can be used in conjunction with helical spring to enhance the spring rate adjustability function for chassis set up balance and for overall better performance of the suspension system. The first automotive helical spring was on the model-T (Ford) in 1910, where the suspension system was a combination of leaf spring and helical spring. The design of this leaf and helical spring suspension was totally different from the model presented in this work. Taking consideration of these above-mentioned approaches, in this presented work, a conventional steel leaf spring (master leaf) is combined with two helical springs, each at both the sides of leaf spring. Modeling and analysis results showed very significant overall stress reduction in combined design compared to typical leaf spring model without helical spring.

Several research articles were devoted on researches related to suspension springs. Research works which have been done by researchers in the past are very useful for efficient designing of the proposed model, specially the papers on helical springs; because the overall better performance of the existing model will mainly depend upon the design of employed helical springs. Jiang and Henshall presented a general and correct finite element model (FEM) for helical springs subjected to axial loads. Vebil Yildirim and Ecosanctuary presented a detailed analysis of free vibration frequencies of a composite helical spring.

DESIGN AND MODELING

Following sections describe the designing and modeling procedures carried out for typical (conventional) and proposed mono leaf spring models: Modeling of Typical Mono Leaf Spring: A typical single leaf spring is designed and modeled in CATIA-

V5R20. The designed and modeled mono leaf in fact is a master leaf of any semi-elliptical leaf spring suspension system, employed in light vehicle mini trucks and buses. Modeling in CATIA-V5R20 is done considering the dimensions and properties as mentioned in Table 1 and selecting isotropic structural steel as design material [4]. Figure 1 is showing the design of this mono leaf spring model.

Table 1: Dimensions and Physical Properties of Mono Leaf Spring Model

Sr no.	Description	Specification
1	No. of Leaf	01
2	Width of leaf (b)	60 mm
3	Thickness of Leaf (t)	16 mm
4	Eye to Eye length of leaf (L)	1025 mm
5	Camber	90.8 mm
6	Poisson's Ratio (μ)	0.266
7	Density of material (ρ)	7860 kg/m ³
8	Coefficient of thermal expansion	1.17x10 ⁻⁵ K ⁻¹ Deg
9	Young's Modulus (E)	2x10 ⁵ N/mm ²
10	Yield Strength	250 N/mm ²
11	Material Type	Isotropic, Structural Steel
12	Weight	21.23 kg



Fig. 1: Typical Mono Leaf Spring Model

DESIGNING THE MONO LEAF

SPRING WITH COMBINATION OF HELICAL SPRINGS

Taking the same design parameters, dimensions and physical properties as mentioned in Table 1 of mono leaf spring, the model of leaf spring with combination of helical springs is designed in same software CATIA-V5R20. First of all, previously designed mono leaf spring part is inserted in CATIA-V5R20 and then at both the sides of mono leaf spring surfaces which are selected as a best location to mount the helical springs, a small rectangular platform of 60 mm x100 mm is made with a little height. On this platform through the accurate axis helical spring is designed and modeled using the wireframe feature of CATIA-V5R20. Number of coil turns in each helical spring is taken six. Both the helical springs are located at equal distance from the center hole on leaf spring surface. Center to center distance between both the helical springs is 960 mm. To fix the helical springs from upper side, a square shaped platform of 150 mm x150 mm x10 mm is created, which is firmly attached with the top most coil of each helical spring.

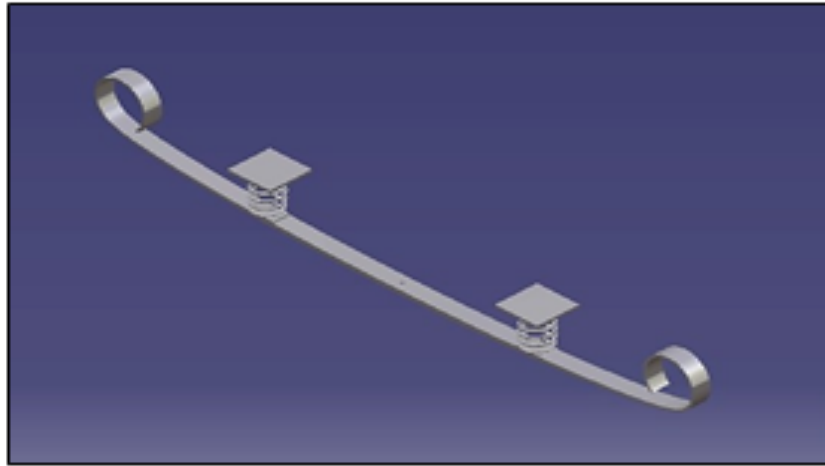


Fig. 2: Proposed Leaf Spring Model with Combination of Helical Springs.

Table 2: Dimensions and Physical Properties of Helical Springs.

Sr. No.	Description	Specification
1	No. of Helical Springs	2
2	Height of each helical spring h	136 mm
3	Wire Diameter d	10 mm
4	Inner diameter of coil D	70 mm
5	Pitch p	22.6 mm
6	No. of Coils n	6
7	Poisson's ratio μ	0.266
8	Density of material ρ	7860 kg/m ³
9	Coefficient of thermal expansion	1.17x10 ⁻⁵ K ⁻¹ Deg
10	Young's Modulus E	2x10 ⁵ N/mm ²
11	Yield Strength	250 N/mm ²
12	Material	Isotropic, Structural Steel
13	Weight of each helical	4.3 kg

Total weight of combined model is 34.23 kg. Total vertical height of each helical spring is 136 mm. The dimensions and properties of both the identical helical springs are covered in Table 2. And, the designed model with combination of leaf and helical springs is shown in Figure 2.

Histopathological examination of the heart tissue also showed that MSG induced myocardial infarction observed as areas of necrotic lesion in the cardiac tissue of the rats treated with MSG.

STRESS CALCULATIONS AND ANALYSIS

The theoretical maximum stresses and FEA stresses produced in typical mono leaf spring model and proposed modified model, at various loading conditions are calculated and analyzed as described in following sections.

Theoretical Stress Calculation of Typical Mono Leaf Spring Model

The design of mono leaf spring modeled in CATIA-V5R20 is a uniform width master leaf of a semi elliptical leaf spring. It is like a simply supported beam of uniform width, clamped at both the ends during the loading conditions. Therefore, the theoretical maximum bending stresses produced in this mono leaf spring model will be calculated by the following equation [21]:

Maximum Bending Stress,

$$\sigma_{max} = pWL/Nbt^2 \quad \text{Eq (1)}$$

Where, p=3 (a constant for simply supported beam of uniform width)

L=eye to eye distance=1025 mm,

N=number of leaves =1,

b=width=60mm,

t=thickness=16mm

Case (1):

At load W=1000 N

$$\sigma_{max} = \frac{3 \times 1500 \times 512.5}{1 \times 60 \times 16^2}$$

Maximum Stress (Bending)

$$\sigma_{max} = 100.09 \text{MPa}$$

Case (2):

At load W=1500 N

Maximum stress

$$\sigma_{max} = \frac{3 \times 1000 \times 512.5}{1 \times 60 \times 16^2}$$

$$\sigma_{max} = 150.14 \text{MPa}$$

Similarly, other calculations can also be done at various incremental loads to find out the maximum stresses produced in the mono leaf spring model by Eq. (1). Table 3 shows these theoretical stresses at various loading conditions.

Table 3: Theoretical Maximum Stresses in Mono Leaf Spring Model.

Sr. No.	Applied load N	Theoretical stresses MPa
1	1000	100.09
2	1500	150.14
3	2000	200.19
4	2500	250.24
5	3000	300.29
6	3500	350.34
7	4000	400.39
8	5000	500.48
9	7000	700.68
10	10000	1000.97
11	15000	1501.46

STATIC STRUCTURAL ANALYSIS OF TYPICAL MONO LEAF SPRING MODEL

The static structural analysis of the mono leaf spring model is carried out using the finite element analysis (FEA) in CATIA-V5R20. The load is applied at the center point of leaf spring (as shown in Figures 3–6) in upward direction. Meshing of the model is done with octree tetrahedron mesh elements. For all the model analysis in this work it is kept the same. Figures 5 and 6 are showing the mesh generation in models with stress analysis results. By applying the load and performing analysis and simulation, we get the stress distribution over the whole span of leaf, in the numeric as well as in the form of color scheme. By varying the load in constant but incremental order, and keeping all the parameters and conditions unchanged, stress analysis is carried out, and various result oriented informational images are captured. Figures 3–6 are showing the distribution of Von-Mises stresses produced in mono leaf spring model at varied loads by FEA in CATIA-V5R20. From Figures 3–6, it can be observed that the maximum stress level is near the center position of leaf where load was applied and near the eye ends.

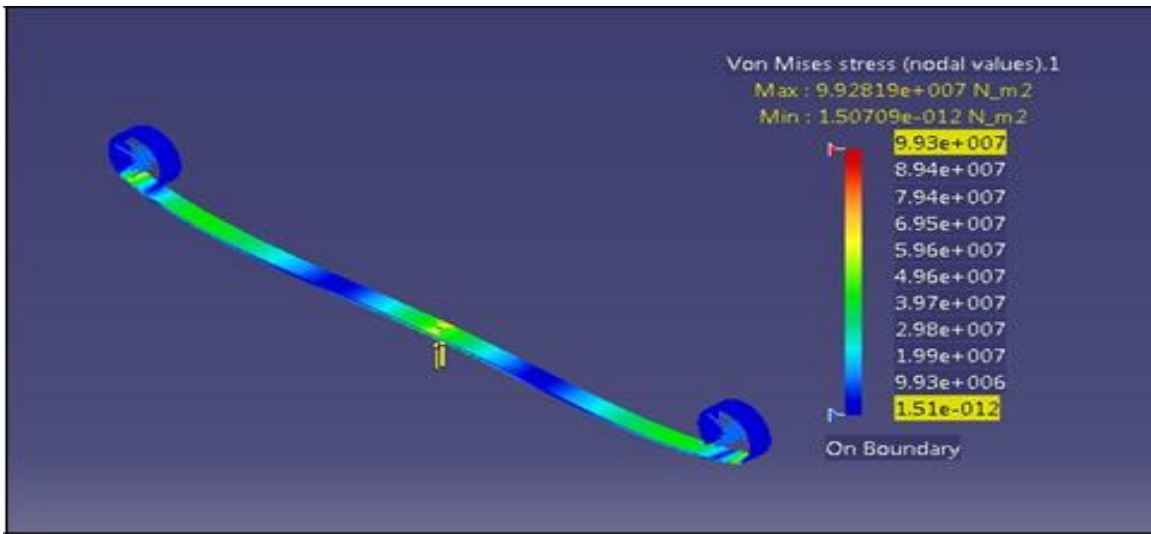


Fig. 3: Stresses in Mono Leaf Spring Model at Load 1000 N.

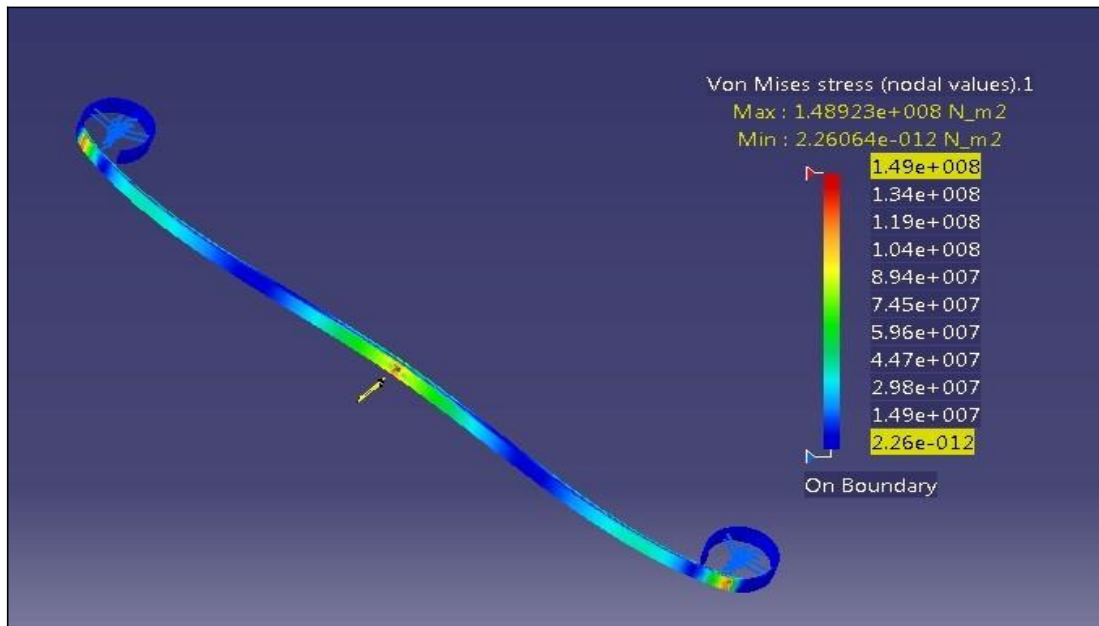


Fig. 4: Stresses in Mono Leaf Spring Model at Load 1500 N.

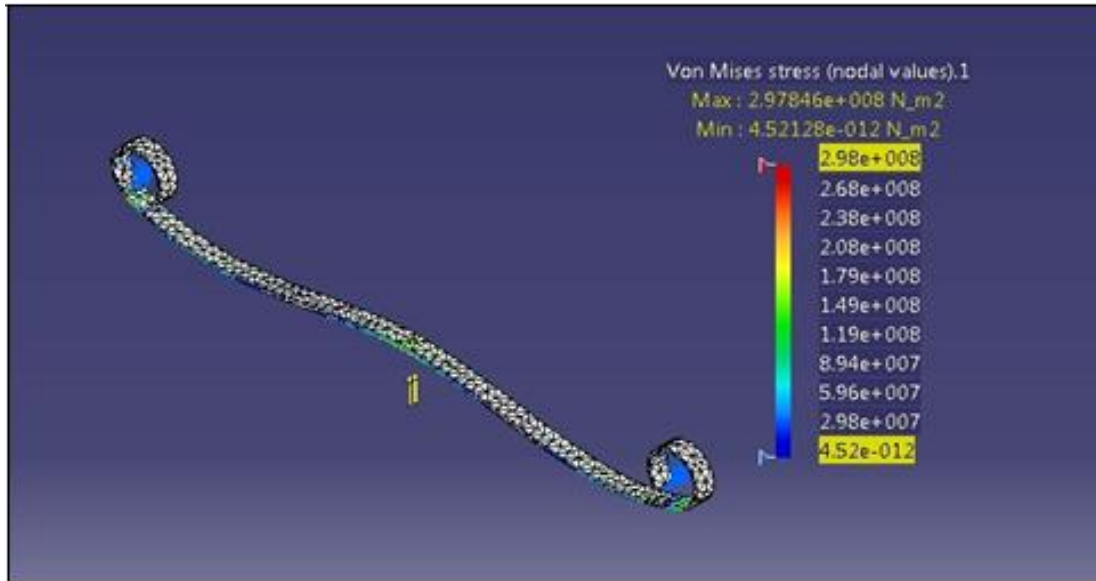


Fig. 5: Stresses in Mono Leaf Spring Model at Load 3000 N.

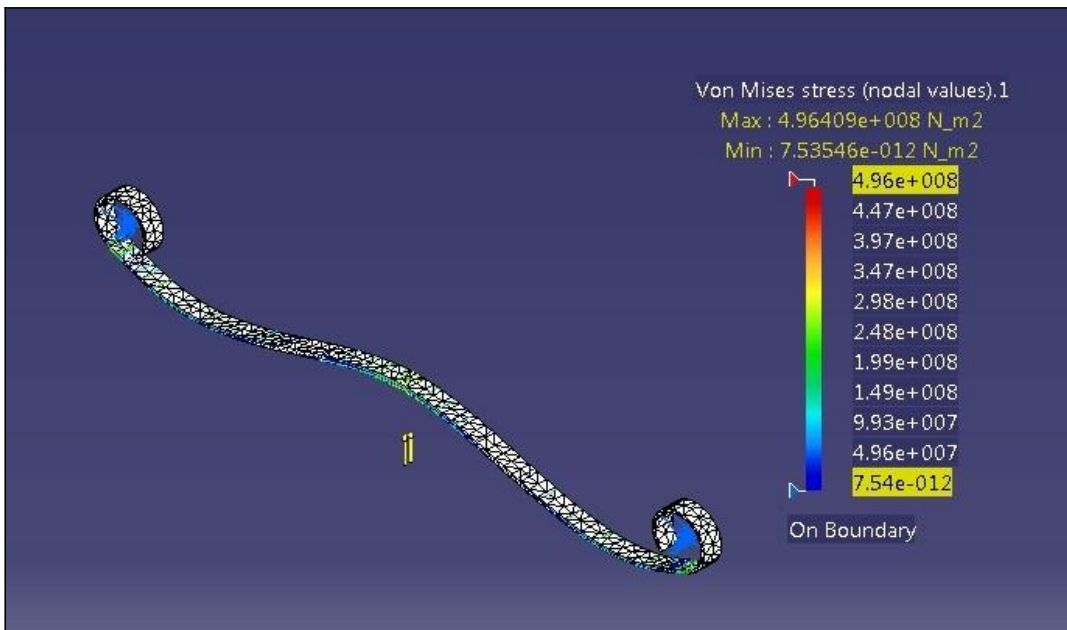
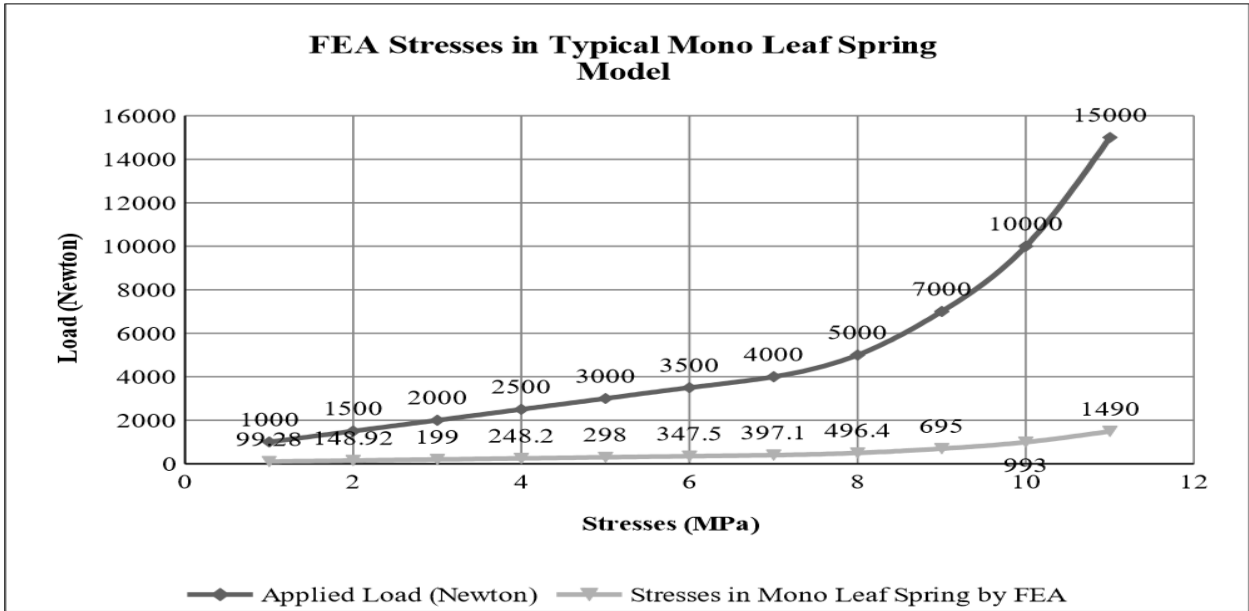


Fig. 6: Stresses in Mono Leaf Spring Model at Load 5000 N.

STATIC STRUCTURAL ANALYSIS OF COMBINED LEAF AND HELICAL SPRING MODEL

The static structural analysis of proposed combined leaf and helical spring model is carried out similarly as discussed above. Figures 8–11 are showing the finite element analysis results pertaining to stresses produced in this model at varied loads by CATIAV5R20. From Figures 8–11, it is clear that the maximum stress level is still near the center point of leaf where load is applied and near the eye ends, but now stress level is reduced here significantly (i.e. more than 8–10 MPa based on load), compared to typical mono leaf spring model as shown in Figures 3–6. Stress levels on helical springs are very low. Therefore, helical springs could be imagined in safe condition from the severe effects of stresses. All the stress analysis results of this model are shown in Table 4 and described in Figure 12 with a plot between loads versus stress diagram.



Graph 1: FEA Stresses in Typical Mono Leaf Spring Model.

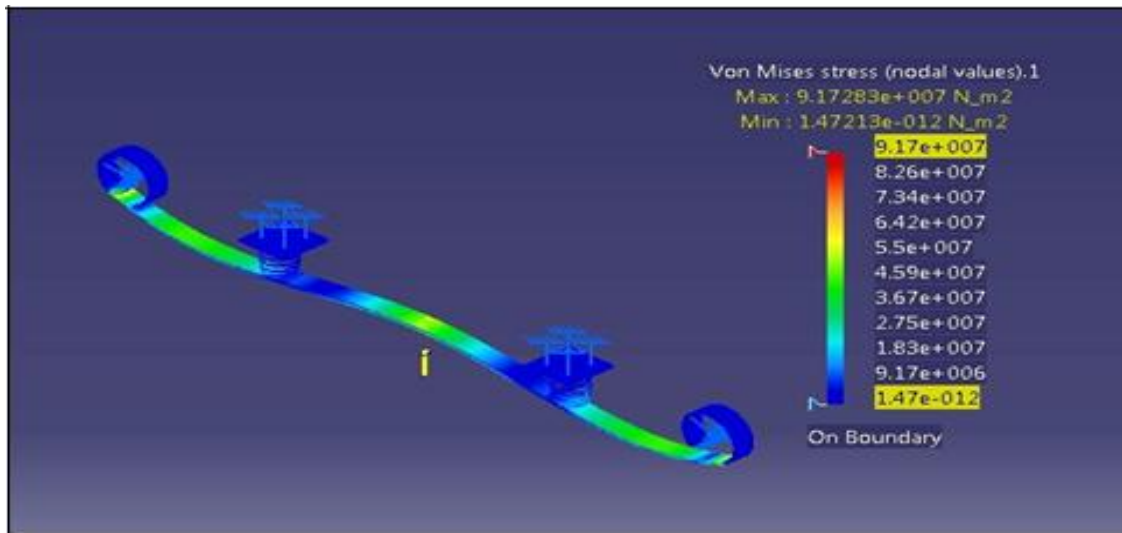


Fig. 8: Stresses in Combined Model at Load 1000 N.

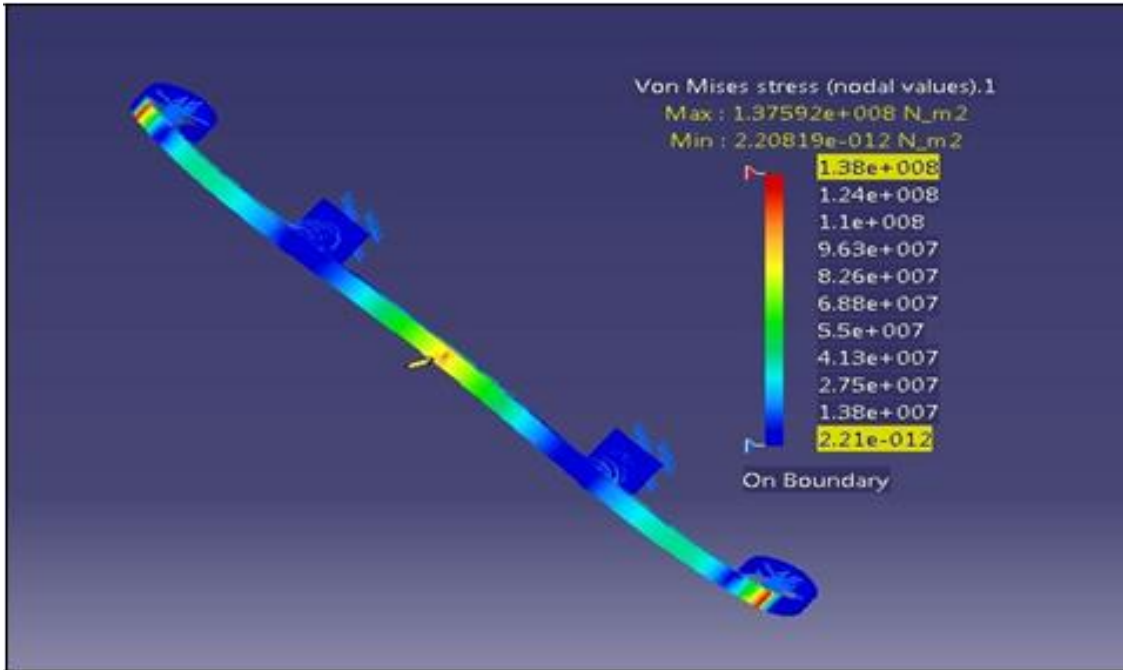


Fig. 9: Stresses in Combined Model at Load 1500 N

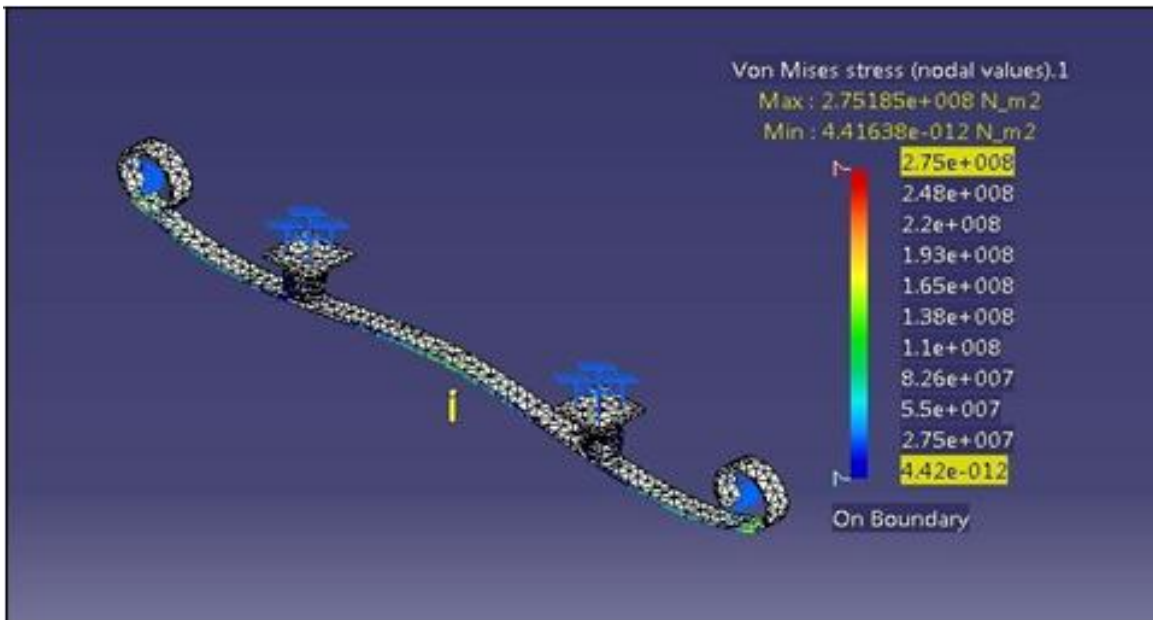


Fig.10: Stresses in Combined Modal at Load 3000 N.

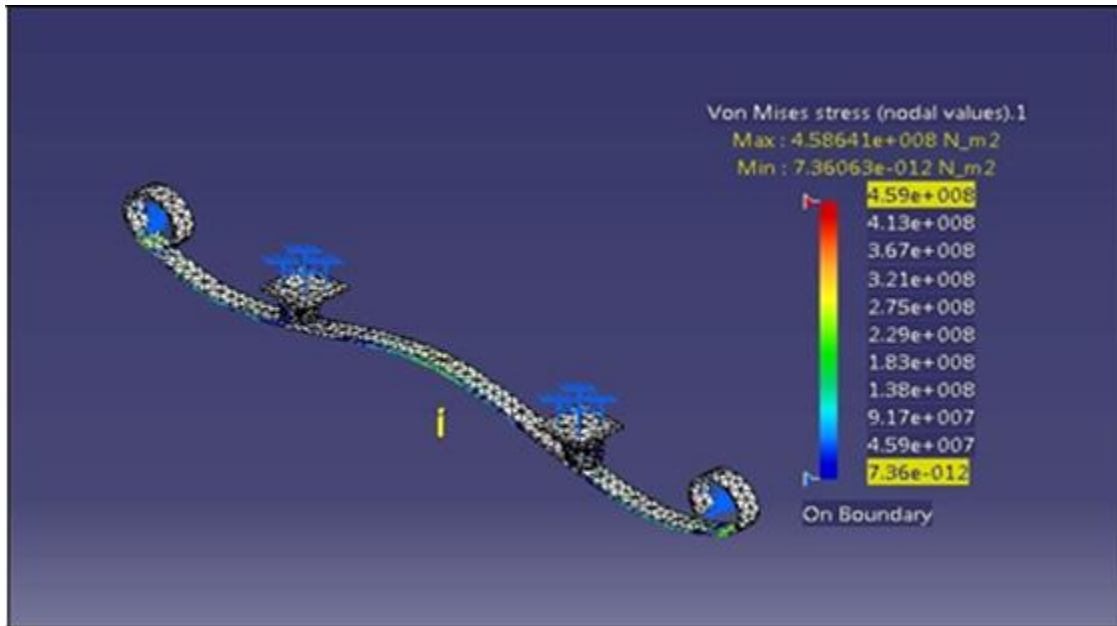
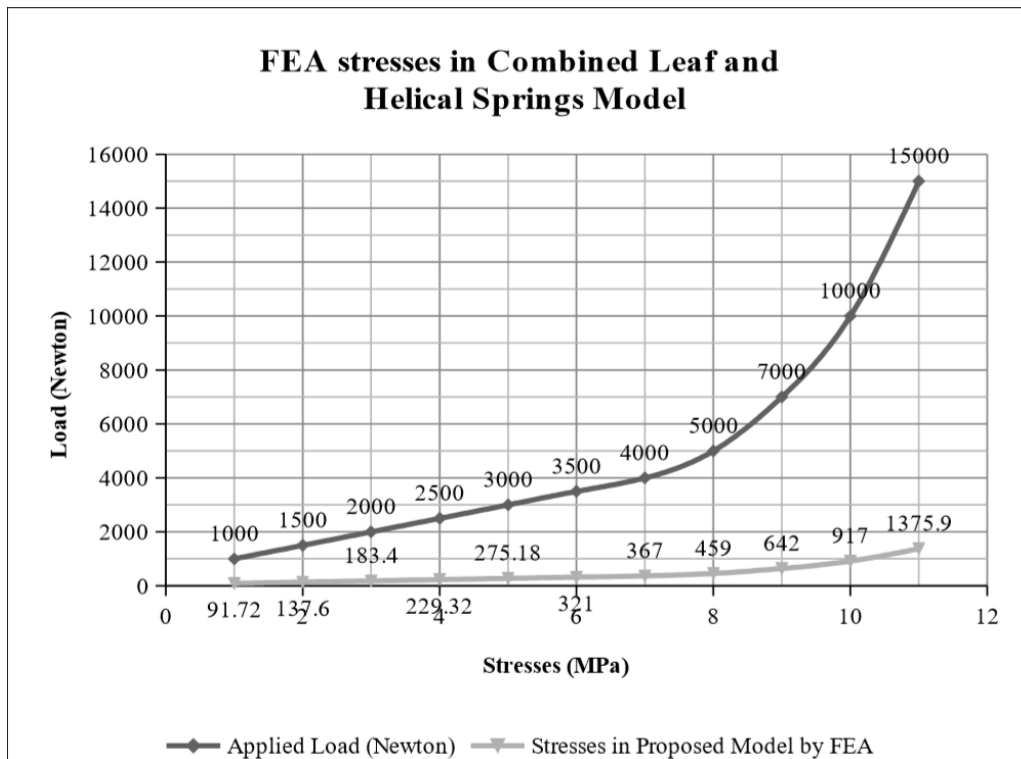


Fig. 11: Stresses in Combined Model at Load 5000 N.



Graph 2: FEA Stresses in Combined Leaf with Helical Springs Model.

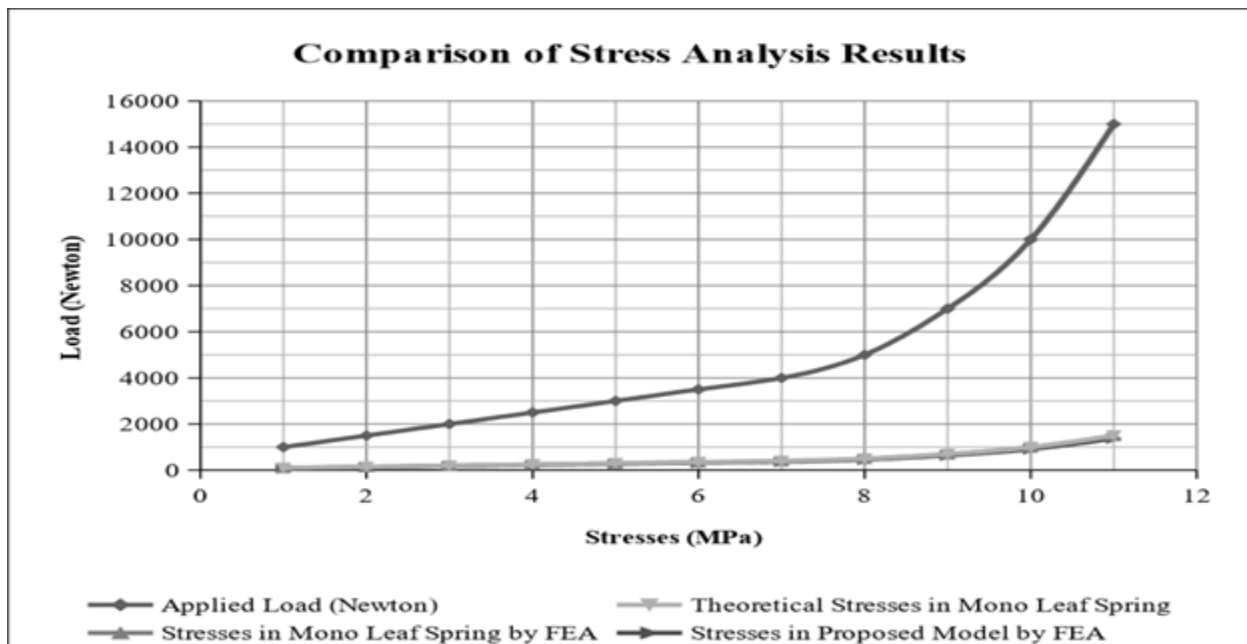
RESULTS AND DISCUSSIONS

The outcomes of the whole study and accomplished work are described under the following sub sections.

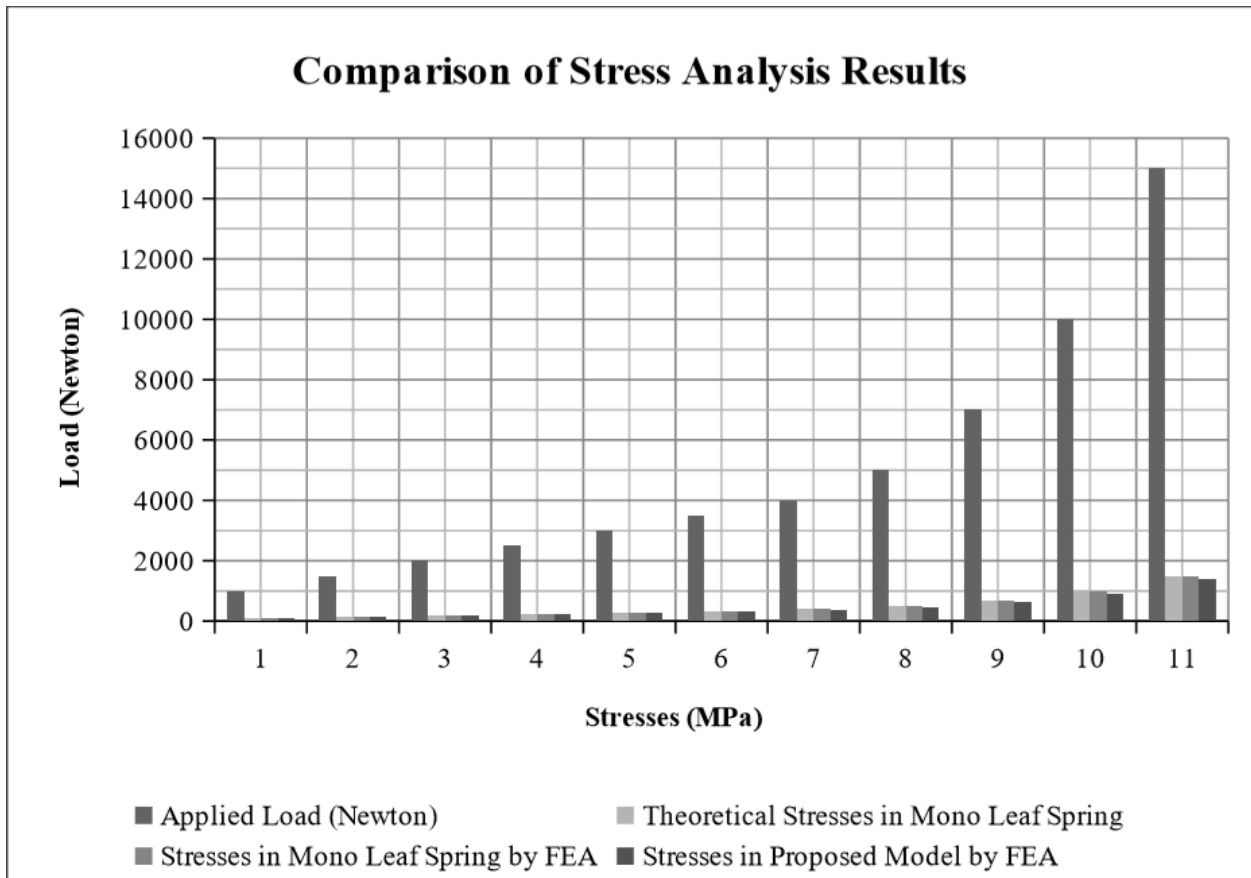
All the stress analysis results are tabulated in the form of Table 4, and their correlations are shown in Figures 13 and 14. From the mentioned Table, Figures and stress analysis colored images, it is clear that the maximum stresses produced in proposed combined leaf and helical springs model are significantly less than the theoretical bending stresses (by mathematical calculations) and FEA Von-Mises stresses by CATIA-V5R20, induced in typical mono leaf spring model of same dimensions and parameters. Therefore, the design of introduced combined leaf and helical spring's model can be said safe and considerable. The average % reduction in overall maximum stresses at different loading conditions is achieved by 8.3%, by the utilization of proposed combined model in comparison to typical mono leaf spring model (Table 5).

Table 4: Comparison of Stress Analysis Results (M Pa).

Sr. No.	Applied Load N	Theoretical stresses in mono leaf spring MPa	Stresses in mono leaf spring by FEA (MPa)	Stresses in proposed model by FEA (MPa)
1	1000	100.09	99.28	91.72
2	1500	150.14	148.92	137.60
3	2000	200.19	199	183.40
4	2500	250.24	248.20	229.32
5	3000	300.29	298.00	275.18
6	3500	350.34	347.50	321
7	4000	400.39	397.10	367
8	5000	500.48	496.40	459
9	7000	700.68	695.00	642
10	10000	1000.97	993	917
11	15000	1501.46	1490	1375.90



Graph 3: Comparison of Stress Analysis Results (Using Line Graph).



Graph 4: Comparison of Stress Analysis Results (Using Column Graph).

Table 5: % Reduction of Stresses by Combined Model.

Sr. No.	Load N	Theoretical maximum stresses in mono leaf spring model MPa	FEA stresses in combined model with helical springs MPa	Stress reduction in %
1	1000	100.09	91.72	8.36
2	15000	150.14	137.60	8.35
3	2000	200.19	183.40	8.38
4	2500	250.24	229.32	8.35
5	3000	300.29	275.18	8.36
6	3500	350.34	321	8.37
7	4000	400.39	367	8.34
8	5000	500.48	459	8.30
9	7000	700.68	642	8.37
10	10000	1000.97	917	8.38
11	15000	1501.46	1375	8.36

Benefits and Scope of the Proposed Model

Following points describe the advantages of the proposed model:

By incorporating such suspension springs model overall stresses can be reduced significantly.

By applying properly designed helical springs, deflection characteristics of leaf spring suspension can be controlled and maintained, so as to achieve optimized comfort during the vehicle ride [22].

Number of graduated leaves in existing conventional leaf spring system could be reduced by employing proposed model. So, a new compact design of existing leaf spring system could be possible.

A good balance between stiffness and rigidity of the typical leaf spring suspension could be maintained, so energy storage capacity can be increased by using such model to optimize the overall performance of the suspension.

It seems, no necessity of heavy changes in any accessory part or design of existing leaf spring suspension to incorporate proposed model.

CONCLUSION

The improved efficiency and optimized performance of the presented combined leaf and helical spring's suspension system model will majorly depend upon the best combination of design parameters of helical springs (i.e. wire diameter, pitch, number of coils) in proportion to leaf spring's design. Therefore, by maintaining the best combination of these suspension spring's design parameters, we can take advantages of benefits of each type suspension spring. And, this is to achieve a more optimized, flexible, stable and efficient typical leaf spring suspension system by incorporating the proposed designed model.

NOMENCLATURE

σ_{max}	Maximum bending stress
L	Eye-to-eye length of leaf spring
b	Width of leaf spring
t	Thickness of leaf spring
p	A constant for simply supported beam
p	Pitch of helical spring
W	Applied load
N	Number of leaves
FEA	Finite element analysis
μ	Poisson's ratio
ρ	Density of material
E	Young's modulus
h	Height of helical spring
d	Wire diameter of helical spring
D	Inner coil diameter of helical spring
n	Number of coils in helical spring

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