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# "STATIC STRUCTURAL ANALYSIS OF A MULTI-LEAF SUSPENSION SPRING FOR DIFFERENT GEOMETRIES AND SPRING STEELS USING ANSYS"

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## ABSTRACT

***This study investigates the effect of spring material and geometry on the static behaviour of a multi-leaf semi-elliptic suspension spring. An analytical design of a reference spring was first carried out using the SAE spring design practice, giving a total moment of inertia of 14120.3 mm⁴, a bending stress of 542.7 MPa and a deflection of 100.5 mm at the static load of 6550 N. Three three-dimensional models of the spring (M1, M2, and M3), with cambers of 80, 90, and 100 mm and leaf thicknesses of 8, 9, and 10 mm, were then prepared in SolidWorks and analysed in ANSYS Workbench under a central static load of 5000 N for four spring materials: chrome vanadium steel, plain carbon steel, chrome nickel molybdenum steel, and structural steel. The total deformation, equivalent (von Mises) stress, equivalent elastic strain, and factor of safety were obtained, and the exciting frequency produced by road irregularities was calculated for vehicle speeds of 20 to 140 km/h. The total deformation ranged from 1.025 to 1.506 mm, and in model M1 the maximum equivalent stress was about 222 MPa for all four materials, with the deformation lowest for chrome nickel molybdenum steel (1.264 mm) and highest for chrome vanadium steel (1.409 mm). The factor of safety was 0.991 for plain carbon steel, 1.125 for structural steel, 1.872 for chrome nickel molybdenum steel, and 2.789 for chrome vanadium steel, so plain carbon steel is not acceptable and structural steel has hardly any margin. Chrome nickel molybdenum steel gave the lowest deformation among the acceptable materials in all three models, whereas chrome vanadium steel gave the largest strength margin. The exciting frequency varied from 1.11 Hz to 38.89 Hz over the speeds and wavelengths considered. The results provide a basis for the selection of spring steel and geometry, and they identify mesh-convergence studies, modal and fatigue analysis, and experimental validation as the next steps.***

***Key Words:*** *Leaf spring; suspension system; static structural analysis; ANSYS; chrome vanadium steel; chrome nickel molybdenum steel; factor of safety; exciting frequency.*

## I. INTRODUCTION

The suspension system supports the weight of the vehicle, isolates the body from road shocks, keeps the tyres in contact with the road, and maintains the geometry of the wheels and axles. The leaf spring is one of the oldest suspension elements and is still widely used in commercial vehicles, light trucks, and pick-up vehicles because it is simple, robust, and able to carry large loads. The semi-elliptic spring consists of steel leaves of graduated length held together at the centre; the master leaf is rolled into eyes at its ends for attachment to the frame, and the spring acts as a beam supported at the eyes and loaded at the centre by the axle. In addition to carrying the load, the spring locates the axle and, through friction between the leaves, provides some damping. The spring forms part of the unsprung mass, so its weight affects ride comfort, road holding, and fuel consumption, and its strength determines the safety of the vehicle.

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The spring is made traditionally of medium-carbon and alloy steels, and the choice among them involves a trade-off between strength, stiffness, and cost. A good spring material should have a high strength-to-weight ratio, a high capacity to store elastic strain energy, a high fatigue strength, and good corrosion resistance. In recent years composite and hybrid materials have been proposed as lighter alternatives, but steel springs remain dominant and alloy steels are required where the loads are high. The finite element method gives the distribution of deflection, strain, and stress in the spring for a given load and allows several materials and geometries to be compared before prototypes are made, and ANSYS-based static analyses of leaf springs have been reported by many authors [1]–[3].

Gowd and Goud [1] determined the safe load of a light commercial vehicle spring in ANSYS and found the stress to be highest near the eyes. Sharma et al. [2] and Kumar and Reddy [3] compared steel springs with composite springs and found much lower stress in the composite springs, and Moulali et al. [4] and Sharma et al. [5] studied fatigue and vibration. Composite leaf springs were studied by Saini et al. [6], Pozhilarasu and Pillai [7], and Yinhuan et al. [8], and hybrid springs by Shanmugham et al. [9] and Gupta and Verma [10]. Pal and Kushwah [11] used grey relational analysis to select the best combination of parameters for a composite spring, and Arun Prakash et al. [12] compared spring steels in a static structural analysis and reported a deformation of 1.409 mm for chrome vanadium steel and 1.264 mm for chrome nickel molybdenum steel. However, most studies keep the geometry fixed, and few report the factor of safety, the strain, and the exciting frequency together. The present study therefore compares four spring steels in three geometric models under the same load and reports these quantities together.

## II. Problem Identification

The leaf spring carries the vertical load of the vehicle and is loaded repeatedly in service. If it is too weak it yields or fatigues prematurely, and if it is too heavy or too stiff it increases the unsprung mass and reduces ride comfort. The stresses are highest near the eyes and the centre clamp, so the strength margin must be assessed with care. The influence of the spring steel on the deformation, stress, and safety factor of the same spring is not always available for several geometries, and the effect of changes in camber and leaf thickness on the results is seldom reported together with the effect of the material.

The problem addressed in this study is to determine how the choice among four spring steels and three geometric configurations affects the deformation, stress, strain, and factor of safety of a multi-leaf suspension spring under a static load, to identify the material that gives adequate strength with the least deformation, and to relate the exciting frequency from the road to the vehicle speed so that the frequency range for later modal analysis is known.

## III. Research Objective

The main objectives of the present study are as follows:

- To carry out the analytical design of a reference leaf spring and to determine its stiffness, stress, and deflection.
- To prepare three-dimensional models of the leaf spring in SolidWorks for three combinations of camber and leaf thickness.
- To perform a static structural analysis of each model in ANSYS Workbench for four spring materials under a central load of 5000 N.
- To compare the total deformation, equivalent stress, equivalent strain, and factor of safety, and to identify the most suitable material.
- To determine the exciting frequency produced by road irregularities at different vehicle speeds.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

## IV. MODELING AND SIMULATION

### 4.1 Analytical design

The analytical design follows the SAE spring design practice [13] for a semi-elliptic spring carrying a laden mass of 2620 kg on four spring units, so that the load on one spring corresponds to 655 kg. The data are a required stiffness $k$ = 65.17 N/mm, a factor of safety of 2, a stiffening factor SF = 1.1, a half span $L$ = 1170 mm, a leaf width of 63 mm, a master-leaf thickness $t$ = 8 mm, and a Young's modulus $E = 2.1 \times 10^5$ MPa. The total moment of inertia of the leaves, the bending stress, and the deflection are obtained from

$$\Sigma I = k L^3 / (32\, E\, \mathrm{SF}) \qquad \sigma = L\, t\, P / (8\, \Sigma I) \qquad \delta = P / k \qquad (1)$$

which gives $\Sigma I$ = 14120.3 mm⁴. For the design load of 12 900 N (2 × 9.81 × 655 N) the stress is 1068.9 MPa and the deflection is 197.9 mm, and for the static load of 6550 N the stress is 542.7 MPa and the deflection is 100.5 mm. At the static load the yield-based safety factors would be 2.14 for chrome vanadium steel, 1.53 for chrome nickel molybdenum steel, 0.46 for structural steel, and 0.41 for plain carbon steel, so that the two plain steels cannot carry this reference design. These values are indicative, because they use the nominal bending stress without stress concentration.

### 4.2 Finite element analysis

The three-dimensional models were exported from SolidWorks to ANSYS Workbench 14.0 as IGES files. In the finite element method the structure is divided into small elements connected at nodes, a displacement field is assumed within each element, and the element equations are assembled into the global system $[K]\{u\} = \{F\}$, which is solved for the nodal displacements after the supports are applied; the strains and stresses are then obtained from the displacements. The material of each leaf was assigned in turn from the four materials, the contact between the leaves was generated automatically, and the model was meshed with the automatic mesh generator of the software (Figure 4.1). The analysis assumes linear elastic, homogeneous, and isotropic material behaviour, small deformations, temperature-independent properties, and static loading, so that inertia and damping effects are neglected.

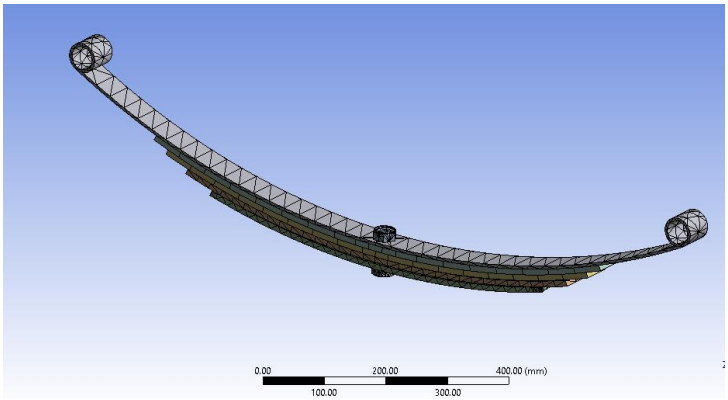



**Figure 4.1 Meshed model of the leaf spring in ANSYS**

### 4.3 Supports and loading

The eye ends of the spring were supported on the frame brackets and a static load of 5000 N was applied at the centre of the spring, where it is clamped to the axle (Figure 4.2). The outputs were the total deformation, the equivalent (von Mises) stress, the equivalent elastic strain, and the factor of safety, defined as the ratio of the yield strength to the maximum equivalent stress.

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SJIF Impact Factor : 6.190

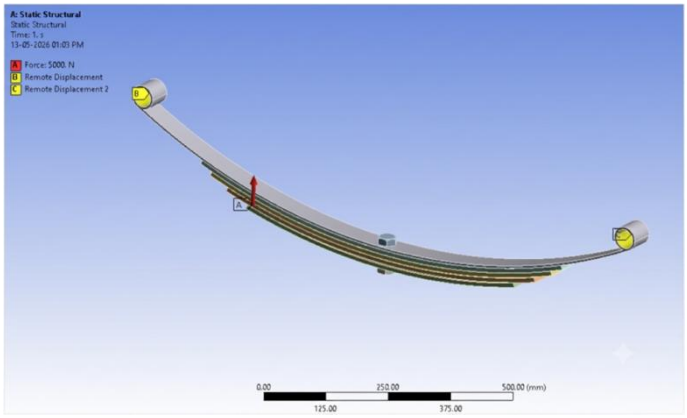



**Figure 4.2 Loading and support conditions of the leaf spring**

## V. DESIGN OF THE LEAF SPRING MODELS

The spring was modelled in SolidWorks as a set of three leaves of graduated length held together at the centre (Figure 5.1 shows the main dimensions of a leaf spring). Three models were prepared that have the same span of 120 mm, the same width of 50 mm, and the same number of leaves, while the camber and the leaf thickness were increased together from model M1 to model M3, as listed in Table 5.1.

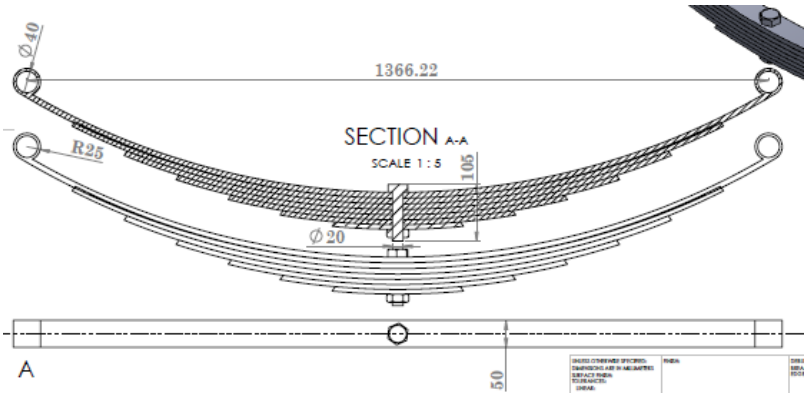



**Figure 5.1 Dimensions of a leaf spring**

**Table 5.1: Dimensions of the leaf spring models**

| Sr. | Parameter | Model M1 | Model M2 | Model M3 |
|---|---|---|---|---|
| 1 | Camber | 80 mm | 90 mm | 100 mm |
| 2 | Span | 120 mm | 120 mm | 120 mm |
| 3 | Thickness of leaves | 8 mm | 9 mm | 10 mm |
| 4 | Width | 50 mm | 50 mm | 50 mm |
| 5 | Number of leaves | 3 | 3 | 3 |

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SJIF Impact Factor : 6.190

Four spring materials were considered, with the properties given in Table 5.2. The Young's moduli of the four steels differ by less than 5%, whereas their yield strengths differ by more than a factor of five, so the choice of material is expected to affect mainly the strength margin and only slightly the stiffness.

**Table 5.2: Properties of the spring materials**

| Property | Chrome vanadium | Plain carbon | Chrome nickel molybdenum | Structural steel |
|---|---|---|---|---|
| Density (kg/m³) | 7860 | 7800 | 8440 | 7850 |
| Young's modulus (MPa) | $2.1 \times 10^5$ | $2.1 \times 10^5$ | $2.07 \times 10^5$ | $2.0 \times 10^5$ |
| Poisson's ratio | 0.37 | 0.29 | 0.325 | 0.29 |
| Yield strength (MPa) | 1160 | 220 | 830 | 250 |
| Ultimate tensile strength (MPa) | 1200 | 400 | 415 | 460 |

## VI. Result and Discussion

### 6.1 Total deformation and equivalent stress

Figures 6.1 and 6.2 show the contours of the total deformation and the equivalent stress for model M1. In all cases the deformation is largest at the centre of the spring, where the load is applied, and the stress is largest in the region near the centre and near the eyes. The values for all three models are given in Tables 6.1 and 6.2.

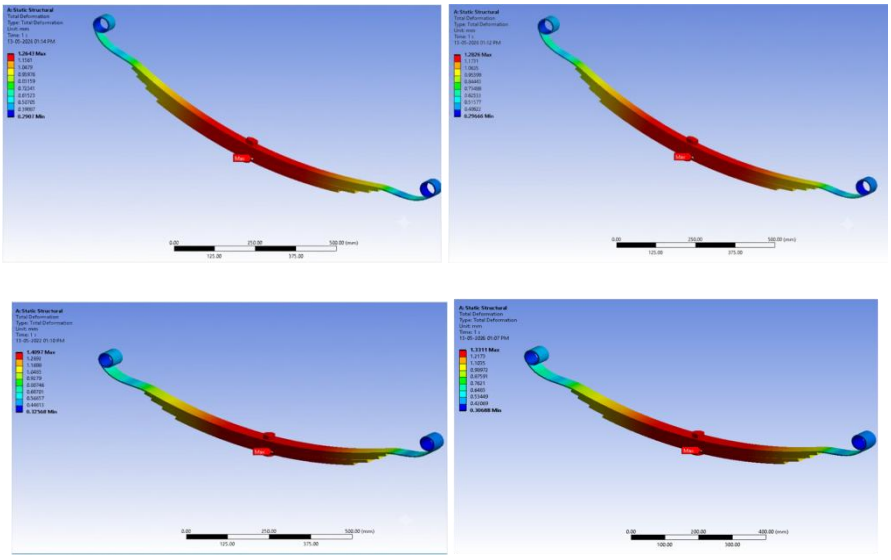


**Figure 6.1 Total deformation of the spring (model M1): (a) chrome nickel molybdenum, (b) plain carbon, (c) chrome vanadium, (d) structural steel**

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SJIF Impact Factor : 6.190

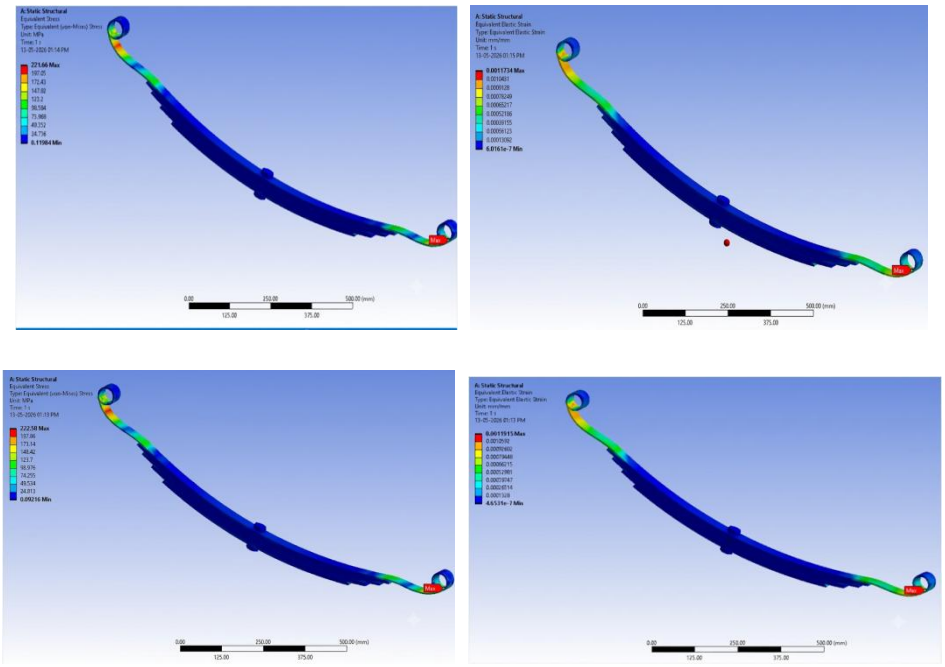


**Figure 6.2 Equivalent stress of the spring (model M1): (a) chrome nickel molybdenum, (b) plain carbon, (c) chrome vanadium, (d) structural steel**

**Table 6.1: Total deformation (mm) and factor of safety**

| Material | M1 | M2 | M3 | Factor of safety |
|---|---|---|---|---|
| Chrome vanadium steel | 1.409 | 1.305 | 1.506 | 2.789 |
| Plain carbon steel | 1.282 | 1.025 | 1.456 | 0.991 |
| Chrome nickel molybdenum steel | 1.264 | 1.126 | 1.345 | 1.872 |
| Structural steel | 1.331 | 1.230 | 1.402 | 1.125 |

**Table 6.2: Equivalent (von Mises) stress (MPa) and equivalent strain (× $10^{-3}$)**

| Material | σ M1 | σ M2 | σ M3 | ε M1 | ε M2 | ε M3 |
|---|---|---|---|---|---|---|
| Chrome vanadium steel | 222.31 | 202.51 | 232.35 | 1.31 | 1.25 | 1.31 |
| Plain carbon steel | 222.56 | 200.32 | 235.56 | 1.19 | 1.25 | 1.26 |
| Chrome nickel molybdenum steel | 221.64 | 221.50 | 303.56 | 1.17 | 1.12 | 1.26 |
| Structural steel | 222.08 | 222.08 | 222.50 | 1.23 | 1.20 | 1.36 |

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SJIF Impact Factor : 6.190

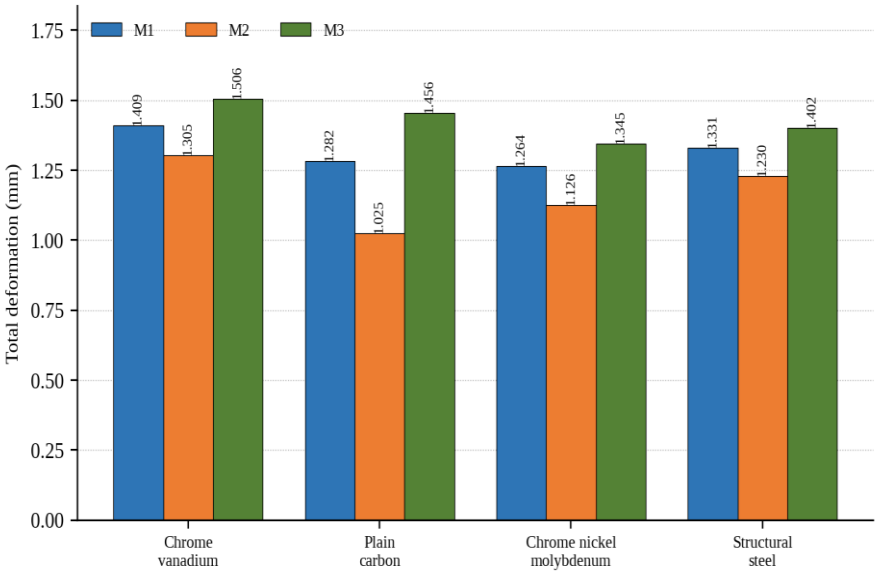



**Figure 6.3 Comparison of total deformation for different materials**

The total deformation lies between 1.025 mm and 1.506 mm. In model M1 the chrome nickel molybdenum steel spring deforms least (1.264 mm) and the chrome vanadium steel spring deforms most (1.409 mm). In model M2 the lowest deformation is that of plain carbon steel (1.025 mm), followed by chrome nickel molybdenum steel (1.126 mm), and in model M3 the lowest value is again that of chrome nickel molybdenum steel (1.345 mm). For every material model M2 has the smallest deformation and model M3 the largest, although the leaves of M3 are the thickest; since the camber and the thickness were increased together, the effect of each parameter alone cannot be separated from these results.

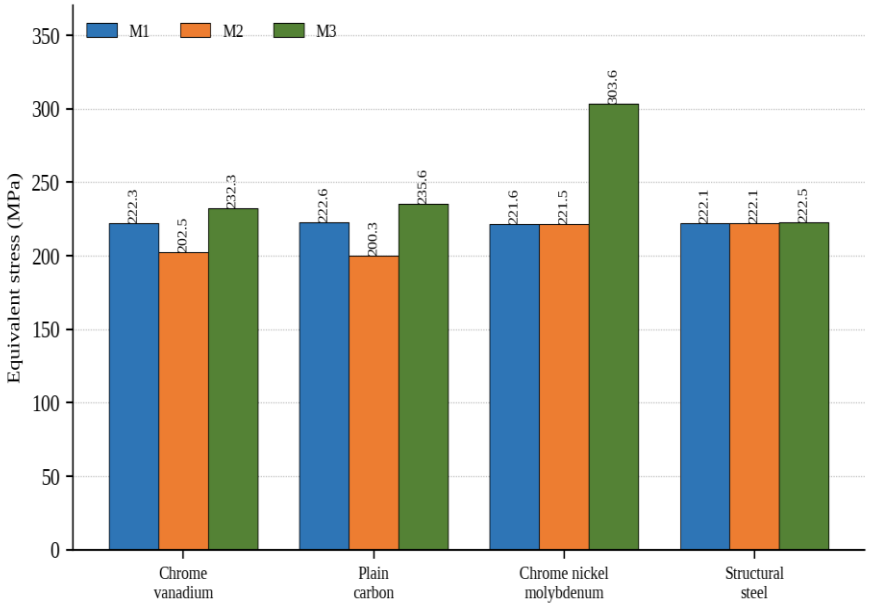



**Figure 6.4 Comparison of equivalent stress for different materials**

In model M1 the maximum equivalent stress is almost the same for all materials, between 221.64 and 222.56 MPa, which is expected for a linear elastic analysis in which the load and geometry are the same and the Young's moduli are nearly equal. In model M2 the stress is lower for chrome vanadium steel (202.51 MPa) and plain carbon steel (200.32 MPa), and in model M3 it rises for chrome vanadium steel (232.35 MPa), plain carbon steel (235.56 MPa), and, to a

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SJIF Impact Factor : 6.190

larger extent, chrome nickel molybdenum steel (303.56 MPa). The last value is much higher than the others in the same model and is not consistent with their near equality; it may be due to a local stress concentration in the contact region or to the mesh, and it should be verified by mesh refinement before it is used in design. The equivalent elastic strain follows the trend of the deformation, with values of about $1.1 \times 10^{-3}$ to $1.4 \times 10^{-3}$.

### 6.2 Factor of safety and choice of material

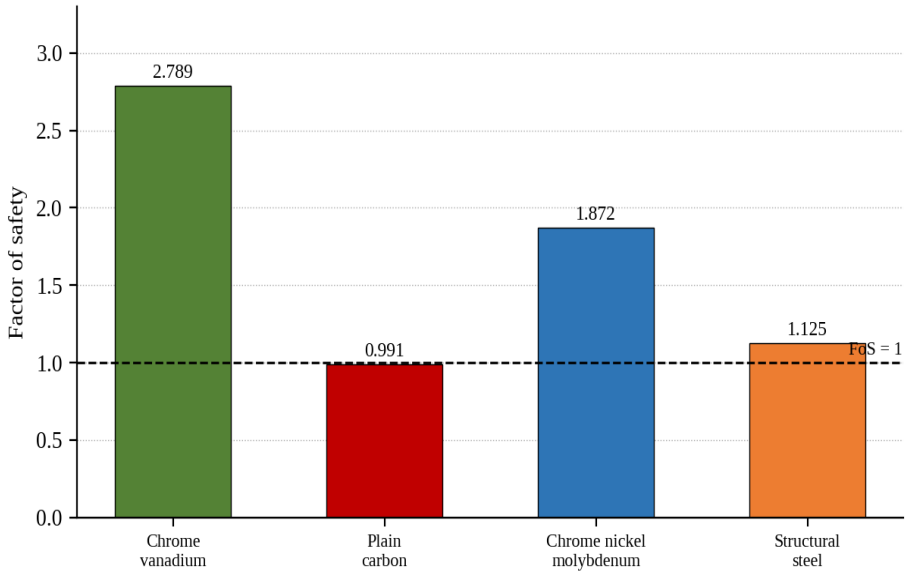



**Figure 6.5 Comparison of the factor of safety for different materials**

Plain carbon steel has a factor of safety of 0.991, below unity, so the spring would begin to yield under the load of 5000 N and the material is not acceptable. Structural steel has 1.125, above unity but with hardly any margin for dynamic loads, whereas chrome nickel molybdenum steel (1.872) and chrome vanadium steel (2.789) give adequate margins. If the factor of safety is recomputed from the yield strengths of Table 5.2 and the stresses of model M1, the values are 5.22 for chrome vanadium steel, 0.99 for plain carbon steel, 3.74 for chrome nickel molybdenum steel, and 1.13 for structural steel. The results for the two plain steels agree with those of the analysis, whereas the values for the two alloy steels are larger than those reported by the software, which indicates that the solver used lower yield strengths than those of Table 5.2; the order of the materials is the same in both cases. Considering stiffness and strength together, plain carbon steel is rejected, structural steel is marginal, chrome nickel molybdenum steel gives the lowest deformation among the acceptable materials in all three models, and chrome vanadium steel gives the largest strength margin at the cost of slightly larger deformation. Chrome nickel molybdenum steel is therefore recommended where stiffness governs, and chrome vanadium steel where the strength margin or fatigue resistance has priority. These findings are consistent with the deformations of 1.409 mm and 1.264 mm and the preference for chrome nickel molybdenum steel reported by Arun Prakash et al. [12] for the same four materials.

### 6.3 Exciting frequency

When a vehicle moves at speed $v$ over a road with periodic irregularities of wavelength $\lambda$, the wheel is excited at the frequency $f = v / \lambda$, with $v$ in m/s. Table 6.3 and Figure 6.6 give the frequency for speeds of 20 to 140 km/h and wavelengths of 1 to 5 m. The frequency increases in direct proportion to the speed and ranges from 1.11 Hz (5 m at 20 km/h) to 38.89 Hz (1 m at 140 km/h). To avoid resonance the natural frequencies of the spring should lie well away from this range; they were not determined in this work, so a modal analysis is recommended.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

**Table 6.3: Exciting frequency (Hz) at different speeds and wavelengths**

| Speed (km/h) | λ = 1 m | λ = 2 m | λ = 3 m | λ = 4 m | λ = 5 m |
|---|---|---|---|---|---|
| 20 | 5.56 | 2.78 | 1.85 | 1.39 | 1.11 |
| 40 | 11.11 | 5.56 | 3.70 | 2.78 | 2.22 |
| 60 | 16.67 | 8.33 | 5.56 | 4.17 | 3.33 |
| 80 | 22.22 | 11.11 | 7.41 | 5.56 | 4.44 |
| 100 | 27.78 | 13.89 | 9.26 | 6.94 | 5.56 |
| 120 | 33.33 | 16.67 | 11.11 | 8.33 | 6.67 |
| 140 | 38.89 | 19.44 | 12.96 | 9.72 | 7.78 |

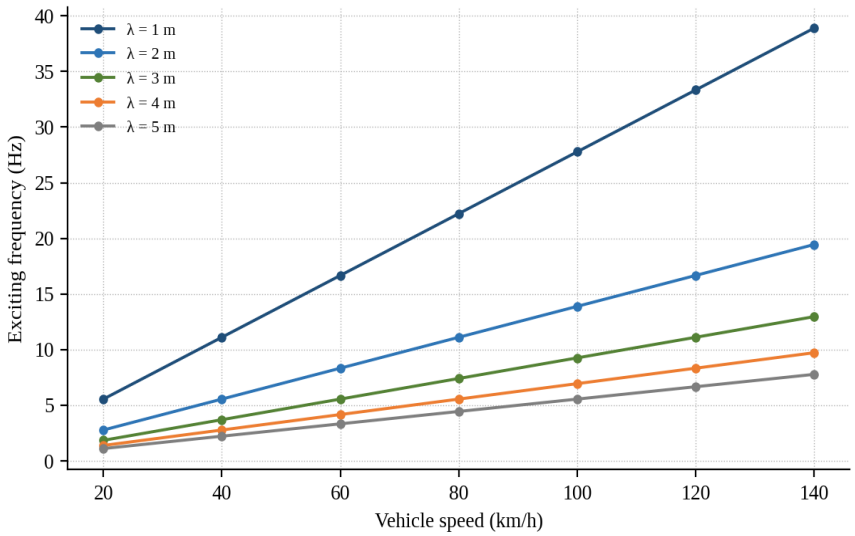



**Figure 6.6 Variation of exciting frequency with vehicle speed**

### 6.4 Limitations

The analysis is linear static and assumes isotropic linear elastic materials, so that fatigue, damping, temperature, and residual stresses from nipping and shot peening are not included. The differences in deformation between materials (about 11% in model M1) are larger than the differences in their Young's moduli (less than 5%) would suggest, and may be due to differences in Poisson's ratio, contact conditions, or the mesh; a mesh-convergence study was not reported and no experimental validation was performed. The results should therefore be regarded as a comparative guide for material selection.

## VII. CONCLUSION

A multi-leaf semi-elliptic suspension spring was analysed analytically and by finite element analysis in ANSYS for three geometric models and four spring steels. The analytical design gave a stress of 542.7 MPa and a deflection of 100.5 mm at the static load of 6550 N. In the finite element analysis under 5000 N the total deformation lay between 1.025 and 1.506 mm, and the equivalent stress in model M1 was about 222 MPa for all materials. The factor of safety was 0.991 for plain carbon steel, 1.125 for structural steel, 1.872 for chrome nickel molybdenum steel, and 2.789 for chrome vanadium steel, so plain carbon steel is not acceptable and structural steel is marginal. Chrome nickel molybdenum steel gave the lowest deformation among the acceptable materials in all three models and is recommended where stiffness governs, whereas chrome vanadium steel gave the largest strength margin. Model M2 showed the

ISSN : 2455-9679
SJIF Impact Factor : 6.190

smallest deformation and model M3 the largest for every material, although the camber and thickness were varied together. The exciting frequency rose in proportion to the vehicle speed and ranged from 1.11 to 38.89 Hz. Future work should include mesh-convergence verification, one-at-a-time variation of camber, thickness, and span, modal and fatigue analysis, experimental validation by load-deflection tests, and the study of composite and hybrid springs.

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