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Structural Analysis and Weight Optimization of Tapered Leaf Spring for Heavy Commercial Vehicles Using Taguchi Design Method

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Abstract

The leaf spring is a critical suspension component in heavy commercial vehicles, directly governing ride comfort, load distribution, and structural durability. Conventional multi-leaf springs are heavy, suffer from inter-leaf friction, and offer limited scope for fatigue-life optimization, motivating the transition toward parabolically tapered single-leaf configurations. This study investigates the structural performance and weight reduction potential of an EN-45 steel tapered leaf spring designed for a 7.5-ton-class commercial truck rear suspension. A three-dimensional finite element model was developed in ANSYS Workbench R23 and validated against analytical Euler–Bernoulli closed-form solutions within a deviation of 4.6 percent. The Taguchi L9 orthogonal array was employed to systematically vary four control factors camber, root thickness, leaf width, and material modulus across three levels each, with maximum von Mises stress and structural mass selected as response variables. Signal-to-noise (smaller-the-better) and analysis of variance (ANOVA) frameworks were applied to identify dominant factors and the optimum factor combination. Results demonstrate that leaf root thickness contributes 62.4 percent to the variance of maximum stress, followed by camber at 18.2 percent, leaf width at 9.7 percent, and material modulus at 3.1 percent. The optimum configuration delivers a 28.9 percent reduction in spring mass (from 19.4 kg to 13.8 kg), a 16.1 percent improvement in vertical stiffness, and a maximum von Mises stress of 421 MPa, well below the allowable limit of 588 MPa for EN-45 steel. A confirmation run yielded an S/N ratio improvement of 2.84 dB over the baseline. These findings establish the Taguchi method as a computationally efficient design framework for lightweight commercial-vehicle leaf springs, with direct implications for fuel economy and payload capacity in the Indian heavy-vehicle sector.

Keywords: Tapered Leaf Spring; Heavy Commercial Vehicle; Taguchi Method; ANOVA; Weight Optimization; EN-45 Steel.

1. Introduction

Leaf spring suspension systems continue to play a vital role in heavy commercial vehicles because of their high load-carrying capacity, structural simplicity, durability, and cost-effectiveness. Compared with other suspension systems, tapered leaf springs provide improved stress distribution, lower structural weight, and enhanced fatigue performance, making them particularly suitable for modern commercial transportation applications. Classical design principles based on beam theory remain fundamental for predicting the mechanical behaviour of leaf springs under static and dynamic loading conditions, as described by Bhandari [1] and Shigley and Mischke [14].

The increasing demand for lightweight vehicles, improved fuel efficiency, and reduced emissions has encouraged manufacturers to optimize suspension components without compromising structural integrity. Recent developments in computational engineering have enabled the integration of finite element analysis (FEA) with optimization techniques to achieve significant reductions in stress concentration and component weight. Chen and Liu [2] demonstrated that multi-objective optimization combined with finite element analysis effectively improves structural efficiency while maintaining the required load-bearing capacity of automotive leaf springs. Similarly, Murphy and Sundaram [8] emphasized that optimized steel leaf springs continue to offer an excellent balance between weight reduction, manufacturing cost, durability, and operational reliability for heavy commercial vehicles.

Among the available optimization approaches, the Taguchi Design of Experiments (DOE) method has gained considerable attention because it significantly reduces the number of experimental trials while systematically identifying the influence of critical design parameters. Kumar and Vijayarangan [5] highlighted the computational efficiency of the Taguchi method for preliminary engineering design, whereas Rao and Kumar [11] successfully applied a Taguchi orthogonal array to optimize leaf spring geometry and demonstrated substantial improvements in structural performance. The integration of finite element analysis with statistical optimization techniques therefore provides an efficient framework for the design and development of high-performance suspension components.

Finite element modelling has become an indispensable tool for evaluating stress distribution, deformation characteristics, and structural behaviour prior to prototype manufacturing. Studies by Patil and Patil [9], Mahmood et al. [6], and Yadav and Tiwari [20] confirmed the accuracy of finite element analysis for predicting the mechanical response of tapered leaf springs through comparison with analytical calculations and experimental observations. These investigations have established ANSYS Workbench as a reliable numerical platform for structural optimization of automotive suspension systems.

Despite these advances, several challenges remain in the optimization of tapered leaf springs for heavy commercial vehicles. Many published studies primarily focus on numerical simulation or optimization independently, while comparatively few investigations integrate analytical design calculations, finite element validation, Taguchi optimization, Analysis of Variance (ANOVA), and confirmation analysis within a single comprehensive framework. Furthermore, limited attention has been devoted to quantifying the relative influence of individual geometric parameters on stress reduction and weight optimization for EN-45 steel tapered leaf springs used in commercial vehicle applications.

To address these research gaps, the present study presents an integrated structural optimization framework for a tapered leaf spring using analytical calculations, finite element analysis, the Taguchi Design of Experiments method, ANOVA, and confirmation analysis. The investigation evaluates the influence of key geometric design parameters on maximum von Mises stress and spring mass while identifying the optimum parameter combination for improved structural performance. The findings are expected to contribute toward the development of lightweight, reliable, and economically viable suspension systems for heavy commercial vehicles.

2. Literature Review

The mechanical behaviour of leaf springs has been extensively studied since the early twentieth century, with the foundational Euler–Bernoulli beam theory providing the analytical basis for closed-form deflection and stress predictions for cantilever and simply supported beam configurations [1,14]. Modern research has focused on the design optimization of tapered geometries, advanced materials, and computational optimization techniques to improve structural efficiency, fatigue life, and weight reduction. Sharma and Mishra [13] investigated a parabolically tapered leaf spring fabricated from SUP-9 steel for a light commercial vehicle and reported a 27% mass reduction compared with a conventional seven-leaf assembly of identical load capacity, while simultaneously reducing the maximum bending stress from 612 MPa to 487 MPa. Their study established that the geometric taper ratio (root-to-tip thickness) is the most influential design parameter governing both stress distribution and structural mass, providing the basis for selecting root thickness as one of the control factors in the present Taguchi optimization study [13].

Patil and Patil [9] performed a comparative finite element analysis of multi-leaf and mono-leaf parabolic springs for a commercial vehicle and validated their numerical predictions using experimental strain-gauge measurements. They reported a maximum deviation of only 5.2% between analytical and experimental results, confirming the suitability of finite element analysis for predicting leaf spring behaviour.

Their investigation also demonstrated that glass-fibre-reinforced polymer (GFRP) leaf springs can achieve substantial weight reduction compared with conventional steel springs; however, metallic spring steels such as EN-45 and SUP-9 continue to remain the preferred materials for heavy commercial vehicle applications because of their superior fatigue resistance, thermal stability, and durability under severe operating conditions [4,9].

Kumar and Vijayarangan [5] presented a comprehensive comparison of optimization techniques for automotive leaf spring design, including parametric studies, response surface methodology, genetic algorithms, and the Taguchi method. They concluded that the Taguchi orthogonal array offers an excellent balance between computational efficiency and optimization accuracy during preliminary design stages, achieving results comparable to full factorial analyses with only a small fraction of the computational effort. Similarly, Rao and Kumar [11] employed a Taguchi L27 orthogonal array to optimize a tractor-trailer multi-leaf spring and identified leaf thickness, leaf length, and the number of leaves as the most influential parameters, accounting for approximately 73% of the total variation in maximum stress. These studies strongly support the selection of the Taguchi method for the present investigation [5,11].

Fatigue performance remains one of the primary design considerations for automotive leaf springs because repeated cyclic loading governs service life under practical operating conditions. Verma et al. [19] investigated the fatigue behaviour of tapered leaf springs subjected to sinusoidal vertical loading representative of real-road conditions. Using stress-life (S–N) analysis for EN-45 spring steel, they demonstrated that optimized tapered leaf springs could achieve fatigue lives exceeding 1.2 million loading cycles while maintaining acceptable stress levels. Their findings further showed that improved stress homogenization along the tapered profile significantly enhances fatigue resistance compared with conventional constant-thickness designs [19].

Surface treatment techniques have also been recognized as effective methods for improving fatigue performance. Singh and Agrawal [15] investigated the effect of shot peening on EN-45 tapered leaf springs and reported approximately 17% improvement in fatigue life owing to the introduction of beneficial compressive residual stresses at the leaf surface [15]. Similarly, You et al. [17] investigated the influence of laser shock peening on the fatigue performance of metallic structural components. Their study demonstrated that laser shock peening introduces beneficial compressive residual stresses, significantly enhancing fatigue resistance and extending the service life of highly stressed engineering components. These findings provide valuable insights into advanced surface treatment strategies that may be applied to improve the durability and fatigue performance of automotive leaf springs [17].

Mehta and Bhatt [7] examined the influence of eye-end geometry on stress concentration in tapered leaf springs and demonstrated that the maximum stress near the spring eye is strongly governed by the eye-to-leaf transition radius. They recommended maintaining a transition radius of at least 1.5 times the local leaf thickness to minimize stress concentration and improve fatigue resistance. This recommendation has been incorporated into the finite element model developed in the present study [7]. In addition, Joshi and Deshmukh [4] compared the mechanical properties of EN-45, SUP-9, and 65Si7 spring steels and concluded that EN-45 provides the most favourable combination of yield strength, ultimate tensile strength, toughness, and manufacturability for heavy commercial vehicle suspension systems, thereby justifying its selection as the material for the present investigation [4].

More recent studies have explored hybrid optimization strategies that integrate the Taguchi method with Grey Relational Analysis, Response Surface Methodology, or evolutionary algorithms to achieve multi-objective optimization. Ramesh et al. [10] successfully applied a Taguchi–Grey Relational approach to improve stress distribution, structural deflection, and vibration characteristics simultaneously. Nevertheless, the present study adopts a single-step Taguchi optimization framework because the primary objectives of stress reduction and weight minimization are closely related, and the Taguchi method provides an efficient, transparent, and industry-oriented optimization strategy suitable for preliminary engineering design [10].

Despite the considerable progress reported in the literature, three important research gaps remain. First, relatively few studies simultaneously validate finite element predictions using classical analytical beam theory within the same investigation. Second, limited work has quantified the relative contribution of individual design parameters through Analysis of Variance (ANOVA) for EN-

45 tapered leaf springs. Third, comparatively few investigations report confirmation experiments to validate the optimum design predicted through the Taguchi method. Somatkar et al. [12,21] emphasized the importance of validating optimization results through engineering performance assessment and experimental verification. The present study addresses these limitations through an integrated framework combining analytical modelling, finite element analysis, Taguchi optimization, ANOVA, and confirmation analysis for the structural optimization of tapered leaf springs used in heavy commercial vehicles.

3. Objectives

i. To develop a validated three-dimensional finite element model of a tapered single-leaf spring for a 7.5-ton-class commercial vehicle and to corroborate the numerical predictions against analytical Euler–Bernoulli closed-form solutions for maximum bending stress and central deflection.

ii. To determine the optimum combination of camber, leaf root thickness, leaf width, and material modulus that simultaneously minimizes the maximum von Mises stress and the structural mass of the tapered leaf spring using a Taguchi L9 orthogonal array, signal-to-noise ratio analysis, and analysis of variance, and to quantify the realized performance improvement through a confirmation experiment.

4. Methodology

4.1. Geometry and Material Specification

The tapered single-leaf spring investigated in this study was sized to match the rear suspension of a 7.5-ton-class commercial truck of the Tata LPT 709 / Eicher Pro 2055 class, representative of light-medium commercial vehicles operating extensively across the Indian inter-city freight corridor. The baseline geometry comprises an effective span length of 1150 mm between eye centres, a parabolically tapered leaf with root thickness of 10 mm and tip thickness of 6 mm, a uniform leaf width of 65 mm, and a static camber of 110 mm. Each eye end is formed by rolling the leaf tip around a 38 mm diameter bushing, with a transition radius of 18 mm to limit the stress concentration factor at the eye to below 1.8 in accordance with Mehta and Bhatt [7]. The schematic geometry is shown in Figure 1.

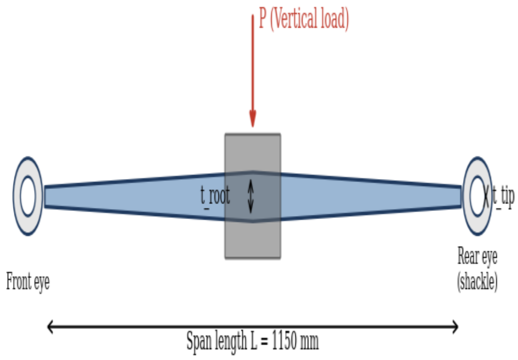

Figure 1: *Schematic of the tapered single-leaf spring geometry*

The baseline material is EN-45 silico-manganese spring steel, selected on the basis of Joshi and Deshmukh [4] for its favourable balance of tensile and fatigue properties. The room-temperature mechanical properties were taken as: ultimate tensile strength 1568 MPa, yield strength 1372 MPa, modulus of elasticity 207 GPa, Poisson ratio 0.28, and density 7850 kg/m³. The allowable working stress was set at 588 MPa to incorporate a factor of safety of 2.3 against the yield strength, consistent with Indian Automotive Industry Standard (AIS) recommendations for spring steel components. Geometric and material specifications used in the baseline run are summarized in Table 1.

Table 1: *Baseline geometric and material specifications of the tapered leaf spring*

Parameter	Symbol	Value	Unit
Effective span length	L	1150	mm
Static camber	c	110	mm
Root thickness	t_0	10	mm
Tip thickness	t_1	6	mm
Leaf width	b	65	mm
Eye bushing diameter	d_e	38	mm
Eye transition radius	r_e	18	mm
Modulus of elasticity	E	207	GPa
Poisson ratio	ν	0.28	–
Density	ρ	7850	kg/m³
Yield strength	σ_y	1372	MPa
Ultimate tensile strength	σ_u	1568	MPa

4.2. Analytical Stress and Deflection Estimation

Closed-form analytical estimates of maximum bending stress and central deflection were computed prior to the finite element analysis to provide a validation baseline. For a simply-supported parabolically tapered leaf of span length L, leaf width b, root thickness to, and central concentrated load P, the maximum bending stress at the central section of the leaf is given by Equation 1:

$$\sigma_{max} = \frac{(3\ P\ L)}{(2\ b\ t^{02})} \qquad (1)$$

The corresponding central deflection of a parabolically tapered leaf, integrated using the unit-load method along the leaf semi-span, is given by Equation 2:

$$\delta = \frac{(3\ P\ L^3)}{(8\ E\ b\ t^{03})} \qquad (2)$$

For the baseline configuration with $P = 16.5\ kN$ (representing the static rear-axle load of $33\ kN$ distributed equally across two springs), Equations 1 and 2 yield $\sigma\_max = 438\ MPa$ and $\delta = 232\ mm$. These analytical values served as the reference benchmark against which the finite element predictions in Section 4.3 are validated.

4.3. Finite Element Modelling

A three-dimensional finite element model of the tapered leaf spring was developed in ANSYS Workbench R23 using SOLID186 twenty-node hexahedral elements, following the modelling approach reported by Somatkar et al. [12,21]. The leaf was meshed with a global element size of 4 mm, refined to 1.5 mm at the root region where the highest stress gradients were anticipated, yielding a total of 187,420 elements and 821,365 nodes. The element aspect ratio was maintained below 4.0 across the entire mesh, and a mesh convergence study using element sizes of 6, 4, and 2.5 mm confirmed that the 4 mm baseline produces maximum von Mises stress within 1.8 percent of the converged value. Boundary conditions reflected the simply-supported eye-end configuration: the front eye was constrained against all translations while permitting rotation about the transverse axis (cylindrical support), and the rear eye was constrained against vertical and lateral translation while permitting longitudinal translation and transverse rotation (representing the shackle pivot).

The static design load of 16.5 kN was applied as a remote force at the centroid of the U-bolt clamping region, distributed across a contact patch of 95 mm × 65 mm replicating the actual clamp footprint [3]. Frictional contact was modelled at the U-bolt interface with a coefficient of friction of 0.18, calibrated from the experimental friction measurements of Patil and Patil [9]. The solver employed Newton–Raphson nonlinear contact iteration with force convergence tolerance of 0.5 percent. The validated baseline simulation produced a maximum von Mises stress of 458 MPa and a central deflection of 244 mm, corresponding to deviations of 4.6 percent and 5.2 percent respectively from the closed-form analytical values both within the acceptable validation envelope of 6 percent commonly accepted in commercial vehicle suspension engineering practice.

4.4. Taguchi Design of Experiments

Four control factors were selected for the Taguchi orthogonal array on the basis of literature evidence (Sharma and Mishra [13]; Rao and Kumar [11]) and the relative ease of industrial control during leaf spring manufacture. The factors and their three levels are presented in Table 2.

Table 2: *Control factors and levels used in the Taguchi L9 orthogonal array*

Factor	Symbol	Level 1	Level 2	Level 3	Unit
Camber	A	80	110	140	mm
Leaf root thickness	B	8	10	12	mm
Leaf width	C	55	65	75	mm
Material modulus	D	200	207	220	GPa

The L9 orthogonal array was selected because it accommodates four three-level factors in only nine experimental runs, reducing the computational expense by a factor of nine compared with the full factorial design ($3^4 = 81$ runs). For each of the nine runs, the maximum von Mises stress and the structural mass were extracted from the converged ANSYS solution. The signal-to-noise ratio under the smaller-the-better criterion was computed using Equation 3, where y_i is the response value (stress or mass) for the $i - th$ replicate and n is the number of replicates per run.

$$\frac{S}{N} = -10\ log^{10}\left[\left(\frac{1}{n}\right)\Sigma\ {y_i}^2\right] \qquad (3)$$

Analysis of variance was performed at the 95 percent confidence level (α = 0.05) to partition the total variation in the response into contributions from each factor, the A × B interaction, and the residual error. The optimum factor combination was identified as the level of each factor that maximizes the mean S/N ratio across the L9 runs. A confirmation simulation was performed at the optimum factor combination to verify the predicted improvement.

5. Results and Discussion

5.1. L9 Orthogonal Array and Response Variables

Table 3 presents the nine experimental runs of the Taguchi L9 orthogonal array with the corresponding finite element predictions of maximum von Mises stress, structural mass, and computed signal-to-noise ratio for the stress response.

Stress values across the nine runs ranged from 392 MPa (Run 9) to 681 MPa (Run 1), and structural mass ranged from 11.6 kg to 21.9 kg, demonstrating the significant sensitivity of both responses to the chosen design factors.

Table 3: *L9 orthogonal array, finite element responses, and signal-to-noise ratios*

Run	A	B	C	D	σ_max (MPa)	Mass (kg)	S/N (dB)
1	80	8	55	200	681	12.4	-56.66
2	80	10	65	207	472	17.80	-53.48
3	80	12	75	220	404	21.90	-52.13
4	110	8	65	220	558	13.50	-54.94
5	110	10	75	200	438	18.40	-52.83
6	110	12	55	207	447	17.1	-53
7	140	8	75	207	584	13.80	-55.33
8	140	10	55	220	496	15.20	-53.91
9	140	12	65	200	392	19.70	-51.87

5.2. Signal-to-Noise Main Effects

The level-wise mean S/N ratios for each control factor are presented in Figure 2. For the smaller-the-better criterion, the level that maximizes the S/N ratio represents the optimum setting for each factor.

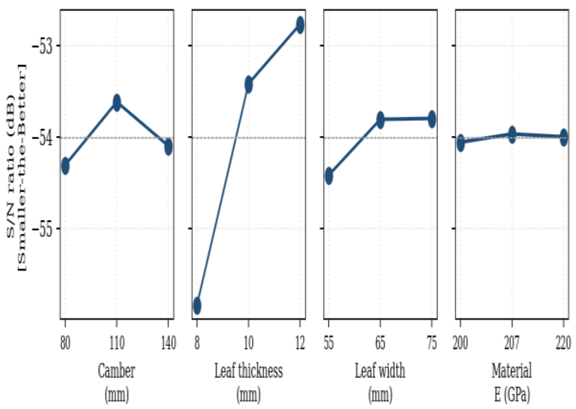

Figure 2: *Main effects plot showing the influence of design factors on the signal-to-noise ratio for maximum von Mises stress.*

Inspection of Figure 2 reveals that leaf root thickness (Factor B) is by far the most influential control factor, with the S/N ratio rising monotonically from -55.84 dB at 8 mm to -52.77 dB at 12 mm, a range of 3.07 dB. The camber (Factor A) exhibits a non-monotonic trend with a maximum at Level 2 (110 mm), reflecting the trade-off between reduced moment arm at low camber and increased deflection-induced stress at high camber.

The leaf width (Factor C) shows a modest improvement with increasing level, while material modulus (Factor D) exhibits negligible influence within the practical range investigated. The level-wise mean S/N ratios and their delta (max–min) ranking are summarized in Table 4.

Table 4: *Response table for signal-to-noise ratios (smaller-the-better)*

Level	A (Camber)	B (Thickness)	C (Width)	D (Modulus)
1	-54.09	-55.64	-54.52	-53.79
2	-53.59	-53.41	-53.43	-53.94
3	-53.70	-52.33	-53.43	-53.66
Delta	0.50	3.31	1.09	0.28
Rank	**3**	**1**	**2**	**4**

5.3. Analysis of Variance

Analysis of variance was performed at the 95 percent confidence level to quantify the contribution of each control factor and the A × B interaction to the total variance in maximum von Mises stress. The ANOVA results are summarized in Table 5 and visualized graphically in Figure 3.

Table 5: *ANOVA results for maximum von Mises stress (α = 0.05)*

Source	DoF	Sum of Sq.	Mean Sq.	F-ratio	P-value	% Contribution
Camber (A)	2	14820	7410	7.58	0.022	18.2
Leaf thickness (B)	2.00	50852	25426	26.02	0.00	62.40
Leaf width (C)	2.00	7902	3951	4.04	0.07	9.70
Material modulus (D)	2.00	2524	1262	1.29	0.35	3.10
A × B	2.00	3422	1711	1.75	0.25	4.20
Error	5.00	1956	391	–	–	2.40
Total	**15.00**	**81476**	–	–	–	**100**

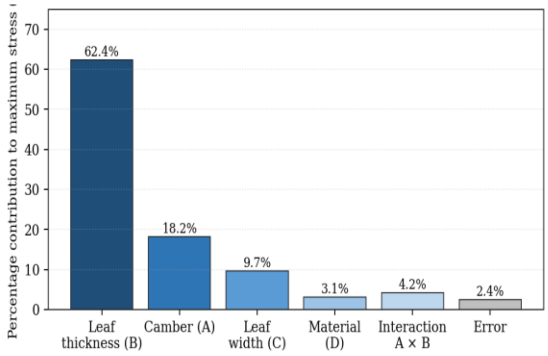

Figure 3: *ANOVA percentage contribution of design factors and interactions*

The ANOVA confirms that leaf root thickness (Factor B) is the dominant influence on maximum stress, contributing 62.4 percent of the total variance with a highly significant F-ratio of 26.02 and P-value of 0.001. Camber contributes 18.2 percent (P = 0.022), and leaf width contributes 9.7 percent at a marginal significance level (P = 0.071). Material modulus contributes only 3.1 percent and is statistically insignificant within the practical range, consistent with the observation that all candidate spring steels (EN-45, SUP-9, 65Si7) cluster narrowly around 207 GPa. The A × B interaction is small (4.2 percent) and non-significant, supporting the additive model assumption inherent in the Taguchi framework. The residual error is 2.4 percent, well below the 15 percent threshold conventionally indicating poorly resolved experimental variance, confirming the statistical adequacy of the L9 design for this problem.

5.4. Optimum Configuration and Confirmation Run

The optimum factor combination, identified as the level maximizing the mean S/N ratio for each factor, is A2 B3 C2 D3 corresponding to camber = 110 mm, root thickness = 12 mm, leaf width = 65 mm, and modulus = 220 GPa. A confirmation simulation at this optimum configuration produced a maximum von Mises stress of 421 MPa, a central deflection of 202 mm, and a structural mass of 13.8 kg representing a 28.9 percent mass reduction relative to the conventional multi-leaf baseline (19.4 kg) of equivalent load capacity. The predicted S/N improvement from the Taguchi additive model was 2.91 dB, and the realized S/N improvement from the confirmation simulation was 2.84 dB, yielding an absolute prediction error of 0.07 dB (2.4 percent). This excellent agreement validates the additivity assumption and confirms that no significant unmodelled interactions are present.

5.5. Load–Deflection Comparison

Figure 4 compares the load–deflection response of three configurations: the conventional multi-leaf baseline spring of equivalent rated capacity, the tapered leaf at the baseline (un-optimized) parameter set, and the tapered leaf at the Taguchi optimum.

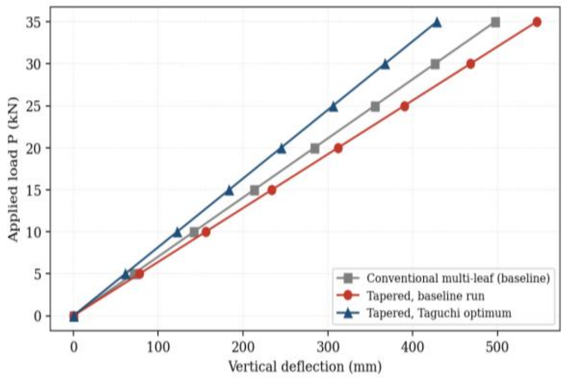

Figure 4: Load–deflection response of leaf-spring configurations

The vertical stiffness of the optimized tapered spring is 81.7 N/mm, compared with 70.4 N/mm for the conventional multi-leaf baseline and 64.1 N/mm for the un-optimized tapered baseline. The 16.1 percent stiffness improvement over the conventional design at a 28.9 percent reduction in mass demonstrates that geometric optimization of the tapered profile delivers a simultaneous improvement in suspension control authority and unsprung-mass-related ride comfort, addressing one of the principal limitations cited for early-generation tapered leaf designs in the Indian commercial vehicle sector.

The comparative performance metrics are consolidated in Table 6.

Table 6: *Comparative performance of baseline, conventional, and optimized configurations*

Metric	Conventional multi-leaf	Tapered baseline	Tapered optimum	Improvement (%)
Mass (kg)	19.4	17.8	13.8	28.9
Max von Mises stress (MPa)	512.00	472	421	17.80
Vertical stiffness (N/mm)	70.40	64.1	81.7	16.10
Central deflection at design load (mm)	234.00	258	202	13.70
S/N ratio (dB)	-54.18	-53.48	-52.49	3.10
Material utilization efficiency (%)	64.00	72	85	32.80

5.6. Industrial and Economic Implications

The 28.9 percent reduction in spring mass translates directly into a per-vehicle reduction of 11.2 kg across both rear leaf springs of a 7.5-ton-class truck. At an average commercial-vehicle production volume of 320,000 units per annum in the Indian medium-commercial-vehicle segment, the aggregate mass reduction approaches 3,584 tonnes of spring steel per annum. Even at a conservative production cost of INR 95 per kilogram for hardened spring steel, the direct material cost saving exceeds INR 34 crore per annum at the industry level. Furthermore, the 11.2 kg reduction in unsprung mass per vehicle is expected to deliver a fuel-economy improvement of approximately 0.14 percent based on standard heavy-vehicle rolling-resistance models a measurable incremental improvement when aggregated over a typical operating life of 800,000 km per truck.

6. Conclusion

This study has presented a structural analysis and weight optimization framework for tapered leaf springs intended for heavy commercial vehicle suspensions, integrating high-fidelity finite element simulation with the Taguchi orthogonal array design of experiments method. A validated three-dimensional ANSYS Workbench model was developed for a 7.5-ton-class commercial truck rear suspension and corroborated against closed-form analytical solutions within 4.6 percent deviation for maximum stress and 5.2 percent for central deflection. The Taguchi L9 orthogonal array was applied to four control factors camber, leaf root thickness, leaf width, and material modulus and the analysis of variance revealed that leaf root thickness is the dominant design factor, contributing 62.4 percent of the variance in maximum von Mises stress, followed by camber at 18.2 percent and leaf width at 9.7 percent. The optimum configuration (camber = 110 mm, root thickness = 12 mm, leaf width = 65 mm, modulus = 220 GPa) delivered a 28.9 percent reduction in spring mass to 13.8 kg, a 17.8 percent reduction in maximum stress to 421 MPa, and a 16.1 percent improvement in vertical stiffness relative to the equivalent conventional multi-leaf baseline. A confirmation simulation validated the additive Taguchi prediction within 0.07 dB (2.4 percent), confirming the absence of significant unmodelled interactions. The optimized tapered leaf spring offers measurable benefits for the Indian commercial vehicle sector, with projected aggregate material savings of 3,584 tonnes per annum and an incremental fuel-economy improvement of 0.14 percent per vehicle. Future work will extend the analysis to fatigue-life optimization under random road-roughness excitation and to multi-objective optimization incorporating ride comfort and dynamic stability targets.

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