ISSN 1533-9211

DOI: 10.5281/zenodo.14598797

EVALUATION OF THE IMPACTS OF ASPHALTED AND STEEL SPEED RAMPS ON HEAVY-DUTY TRUCK LEAF SPRINGS

ENOCK A. DUODU[1]* and ISAAC LEGSON MBEAH[2]

[1]Department of Mechanical and Automotive Engineering, Aamusted, Ghana.
*Corresponding Author Email: eaduodu@aamusted.edu.gh
[2]Department of Agricultural, Technical and Vocational Education Training Komenda College of Education, Ghana. Email: isaaclegsonmbeah@gmail.com

Abstract

This study analyses the implications of speed ramps on the structural behaviour, as well as the fatigue life and damping characteristics of heavy-duty rear-axle leaf springs positioned over asphalted and steel speed ramps, while subjected to varying induced loading conditions. The experimental data were meticulously collected and evaluated using MATLAB software. The results of the investigation demonstrate that the speed ramps exert considerable influence on both the structural integrity and fatigue life of the leaf springs. Furthermore, the analysis revealed that longer leaf springs positioned at the top experience reduced stress levels in comparison to their shorter counterparts at the bottom. This evaluation suggests that longer leaf springs endure heightened bending stress and deformation as a consequence of the elevation of the speed ramp and the associated loading capacity, thereby impacting the fatigue life of the leaf springs under the specified induced loading conditions. Moreover, the findings indicate that the deformation (stretch) of the leaf springs, instigated by the speed ramps, facilitates the absorption of shocks that would otherwise be experienced by the truck's occupants, while concurrently inducing stress and strain in the material that could diminish its lifespan over time as the truck persistently traverses that roadway. It is therefore, advisable for leaf spring manufacturers to augment the thickness of the initial three layers and the final three shorter layers on the leaf springs to enhance their capacity to absorb shocks for extended durations prior to failure resulting from frequent cyclical motions.

Keywords: Heavy-duty Truck, Leaf Springs, Asphalted Ramp, Steel Ramp.

1. INTRODUCTION

Speed ramps, often designated as speed bumps or traffic-calming apparatus, are typically observed within parking facilities and thoroughfares. In environments characterized by significant pedestrian or vehicular activity, their primary purpose is to mitigate vehicular velocities and enhance roadway safety. Various classifications of speed ramps, including speed humps, speed cushions, rumble strips, and speed tables, have proven efficacious in curtailing speeds; however, their implementation occasionally incites controversy. Globally, methodologies for traffic calming have been employed to diminish the frequency of accidents and fatalities while concurrently decelerating vehicular movement in the vicinity and mitigating the severity of collisions [1]. While speed ramps demonstrate effectiveness, they occasionally impose considerable stress on the leaf springs of heavy-duty trucks within automotive suspension systems. For the establishment of secure and efficient transportation networks, it is imperative to effectively regulate traffic flow on highways. The management of velocity on highway ramps is critical for minimizing congestion and improving the overall efficacy of the transportation infrastructure [2] In relation to speed bumps, the necessary

ISSN 1533-9211

DOI: 10.5281/zenodo.14598797

minimum speed for a vehicle to ascend a hump is estimated to be about 25 km/h, with corresponding minimum chord length and elevation of 3 m and 0.1 m, respectively [3].

A heavy-duty truck is a substantial and robust vehicle engineered for the transportation of heavy cargo over extensive distances. These trucks are meticulously designed to endure rigorous operational demands and are utilized across diverse sectors, including agriculture, construction, mining, and logistics. As per the findings of [4], a vehicle is classified as heavy-duty if it carries a gross vehicle weight rating (GVWR) greater than 26,000 lbs (115,195.43 N). Heavy-duty trucks are recognized for their elevated Gross Vehicle Weight Rating (GVWR), which reflects the maximum weight that the vehicle is sanctioned to transport securely, comprising its own mass as well as that of any cargo. The comfort, satisfaction, and safety of both the occupants and the vehicle represent a paramount concern for every automotive manufacturer; consequently, vehicles are equipped with suspension systems wherein leaf springs function as a crucial component. A leaf spring contributes to the support of the vehicle and its load, as well as to the maintenance of stability and control. The bending of the leaves, along with the friction generated between them as they slightly slide over one another during flexion, absorbs the weight of the vehicle and any irregularities encountered. The curvature of most leaf springs, also referred to as elliptical springs, facilitates the absorption of shock. The three essential roles of a vehicle's suspension system are to aid the vehicle in absorbing shocks from bumps, potholes, and other road imperfections. Leaf springs, in particular, play a vital role in the first two of these functions, supporting the weight of the vehicle while absorbing shocks and effectively distributing substantial loads over an extensive area.

Goodarzi and Khajepour [5] elucidate that suspension systems function to insulate the operator and occupants from the majority of road-induced shocks and wheel movements as the tires traverse the roadway. In both light and heavy commercial vehicles, suspension systems predominantly utilize leaf springs, which are characterized as relatively uncomplicated springs. These components are frequently employed in the rear suspension configurations of vehicles and are sometimes referred to as semi-elliptical, elliptical, or carriage springs. Each spring possesses a designated lifespan, contingent upon the materials utilized and the heat treatment administered, which is critical to maintaining its operational efficacy. Leaf springs are affixed to the axle and chassis in a manner that permits vertical flexing in response to surface irregularities encountered on the roadway. However, adverse road conditions significantly impede the leaf springs' ability to remain within their prescribed lifespan.

The investigation conducted by [6] indicates that suspension systems are engineered to fulfill additional criteria, such as fatigue strength, while simultaneously excelling in aspects of comfort and mobility. The leaf spring must effectively absorb vertical vibrations and impacts resulting from road irregularities through variations in spring deflection, thereby allowing potential energy to be stored as strain energy and subsequently released in a gradual manner. Consequently, enhancing the energy storage capacity of leaf springs is essential for achieving a more compliant suspension system.

As articulated by Akgümüş and Baltaci [7], leaf springs provide dampening of the loads transmitted between the wheels and the ground to the chassis while operating across diverse

ISSN 1533-9211

DOI: 10.5281/zenodo.14598797

road conditions when fully loaded. The failure of leaf springs, as documented by Andoh et al. (2022), is attributed to substandard road infrastructures and the implementation of locally constructed speed ramps in certain regions of the country. To ensure a safe and pleasurable driving experience, leaf springs, an integral component of the truck's suspension system, deliver support, stability, and shock absorption. Speed ramps may impose considerable dynamic stresses on the leaf springs due to their elevated profiles and sudden vertical transitions. These forces can lead to increased stress, fatigue, and eventual degradation of the leaf springs over time. Hence, this study aims to investigate the effects of speed ramps on the rear-axle leaf springs of heavy-duty trucks.

2. MATERIALS AND METHOD

2.1 Materials and Equipment

The materials utilized in this study encompass a heavy-duty truck equipped with steel leaf springs, digital measuring tape, digital vernier caliper, digital camera, and two speed ramps constructed from asphalt and steel to assess the various conditions under which the heavy-duty truck with steel leaf springs operates.

2.2 Theoretical Framework

Mathematical formulations were employed to calculate the stress and strain, bending stress, and total deflection experienced by the steel leaf springs under load conditions. The following equations (Eqs. 1-4) were adopted and modified as delineated in Andoh et al. (2022).

$$\sigma = \frac{F}{A} \tag{1}$$

Whereas;

σ is the stress (N/m²)

F is the force applied (N)

A is the cross-sectional area (m²)

$$\varepsilon = \frac{L - L_o}{L_o} \tag{2}$$

Hence**:**

ε is the strain,

L_o is the initial length (m)

L is the ultimate length (m)

However, for laminated semi-elliptic leaf spring, the stress and strain are represented as the bending stress and total deflection respectively.

ISSN 1533-9211

DOI: 10.5281/zenodo.14598797

$$\sigma_b = \frac{3FL}{nbt^2} \tag{3}$$

Thus;

σ_b is the bending stress (N/m²)

F is the load exerted on the leaf spring (N)

L is the length of the leaf spring (m)

n is the number of leaf springs

b represents the breadth of the leaves (m)

t represents the thickness of the leaf (m)

$$\delta_{\max} = \frac{3FL^3}{Ebt^3} \tag{4}$$

Where;

$\delta_{\max}$ is the total deflection (m)

F is the load exerted on the leaf spring (N)

L is the length of the leaf spring (m)

E is the Young's Modulus of the steel (N/m²)

b represents the breadth of the leaves (m)

t represents the thickness of the leaf (m)

2.3 Experimental protocol

An empirical investigation was undertaken utilizing a heavy-duty truck equipped with various loading capacities ranging from 116,000N to 120,000N, which incorporated steel leaf springs comprising seventeen (17) layers, traversing speed ramps constructed from both asphalt and steel. The conventional steel leaf springs utilized for this investigation are typically fabricated from plain carbon steel, exhibiting a Young's Modulus value of 200×10^9 N/m². Throughout the experimental procedure, measurements pertaining to the truck's leaf springs were recorded while the vehicle was positioned on the ramps with corresponding loads to ascertain the behavior of the leaf springs, employing a digital measuring tape and digital vernier calipers for precision. The resultant values were subsequently calculated and analyzed in accordance with established scientific principles, utilizing Eqs. (1-4) pertinent to semi-elliptical leaf springs. The parameters pertaining to the speed ramps employed in this study are delineated in Table 1

Table 1: Parameters of Speed Ramps Used

No.	Types	Length (m)	Width (m)	Height (m)
1.	Asphalt	9.00	4.80	0.20
2.	Steel	9.20	1.00	0.28

3. RESULTS AND DISCUSSION

The results were analysed at different loading conditions ranging from 116,000N - 120,000N over speed ramps considered (asphalt and steel) for structural dynamics and fatigue endurance.

3.1 Effect of speed ramps on the structural dynamics of leaf springs subjected to 116,000-120000N loading

Figure 1 illustrates the relationship between stress and the number of leaf springs as the truck bearing a load of 116,000N traversed an asphalt speed ramp. The findings presented in Figure 1 indicate that the shortest leaf spring (number 17) experienced the highest stress value of 5.16 MN/m² during the truck's passage across the ramp, while leaf springs numbers 1 and 2 recorded significantly lower stress values of 1.04 MN/m², with the remaining springs exhibiting noteworthy stress values attributable to their respective lengths.

This observation suggests that stresses are induced within the leaf spring material, which possess the capacity to influence the structural behavior of the leaf springs while the vehicle is positioned on the speed ramp, thus corroborating the findings of a study conducted by [8].

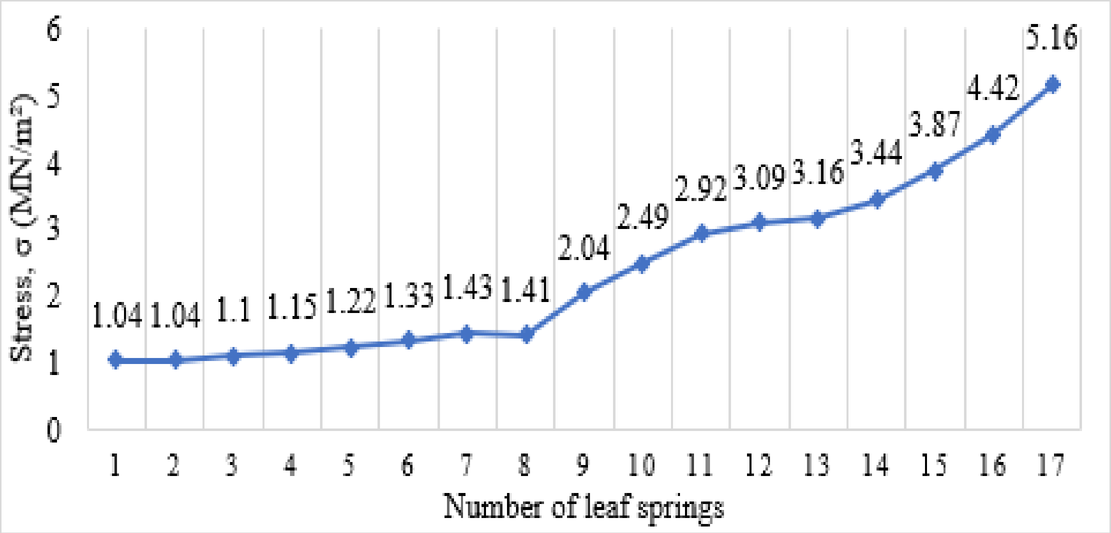


Figure 1: Structural behaviour of leaf springs with 116,000N loaded truck moved over asphalted speed ramp

The results depicted in Figure 2 illustrate the relationship between strain and the leaf springs, revealing that leaf number 13 recorded the highest strain value of 0.11, succeeded by leaf number 14 with a value of 0.10. Furthermore, Figure 2 indicates that the majority of the leaf springs exhibited strains within the range of 0.05 to 0.08, with leaf number 17, the shortest, exhibiting the least strain value of 0.03.

This implies that the strains induced within the leaf spring material could significantly impact the structural behavior of the leaf springs while the vehicle is on the speed ramp and is in agreement with the research conducted by [9].

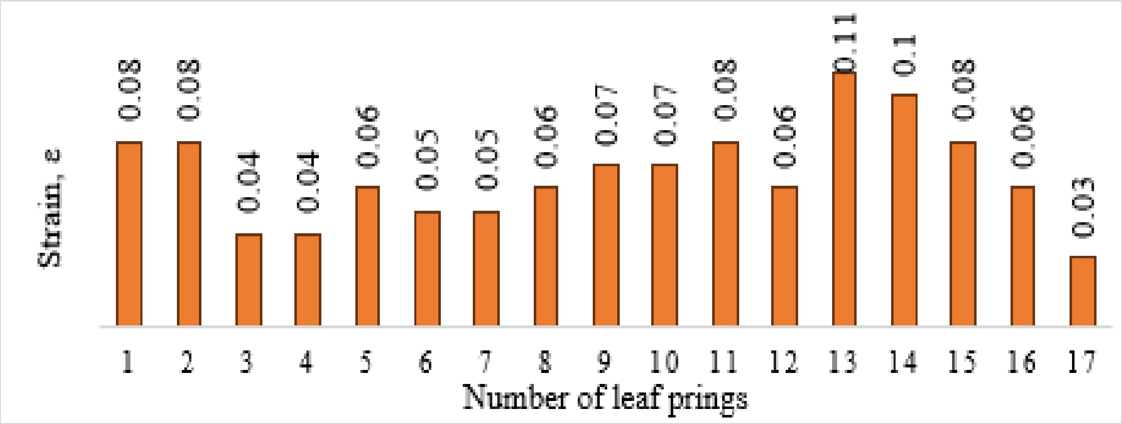


Figure 2: Structural behaviour of leaf springs with 116,000N loaded truck moved over asphalted speed ramp

Figure 3 presents the results illustrating the stress and strain experienced by the leaf springs as the truck traversed a steel speed ramp under a loading condition of 116,000N. The investigation reveals that leaf spring number 8 experienced a substantial strain of 0.41, followed by number 13 which recorded a strain of 0.18, whereas leaf spring number 17, being the shortest, encountered the minimal strain of 0.03 alongside a maximum stress value of 5.16 MN/m². The lowest stress values were documented for leaf spring numbers 1 and 2, recorded at 1.00 MN/m² as indicated in Figure 3. This suggests that both stresses and strains are generated within the leaf springs as the truck traverses the steel ramp and affirming the outcome of [10] publication, potentially compromising their structural integrity.

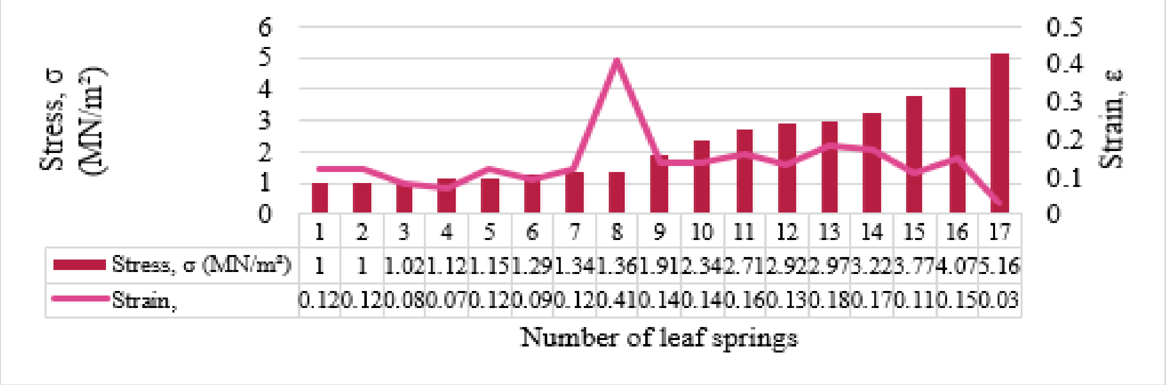


Figure 3: Structural behaviour of leaf springs under 116,000N loading condition on steel speed ramp

Figure 4 unveils the fascinating interplay of stress and strain against the number of leaf springs as they navigate the asphalted speed ramp, all under the weighty condition of 118,000N. The findings reveal that the elongated leaf springs, numbers 1 and 2, recorded the modest stress value of 1.04 MN/m² alongside a strain value of 0.09 each, respectively. In contrast, the compact leaf number 17 bore the brunt with a peak stress value of 5.24 MN/m², accompanied by a strain value of 0.03. Leaf number 10 showcased a strain value of 0.00 against a stress value of 2.50 MN/m², while leaf number 11 exhibited the utmost strain of 0.16 with a corresponding stress value of 2.76 MN/m². This suggests that the stresses and strains imposed upon the springs could significantly sway the structural dynamics of the leaf springs, resonating with previously published findings in [8].

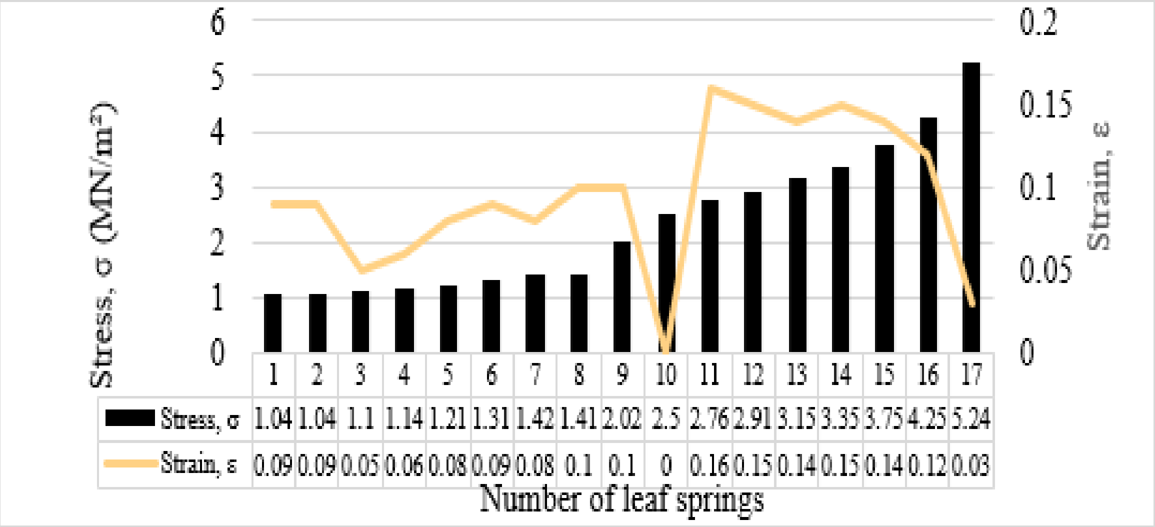


Figure 4: Structural behaviour of leaf springs with 118,000N loading condition over asphalted speed ramp

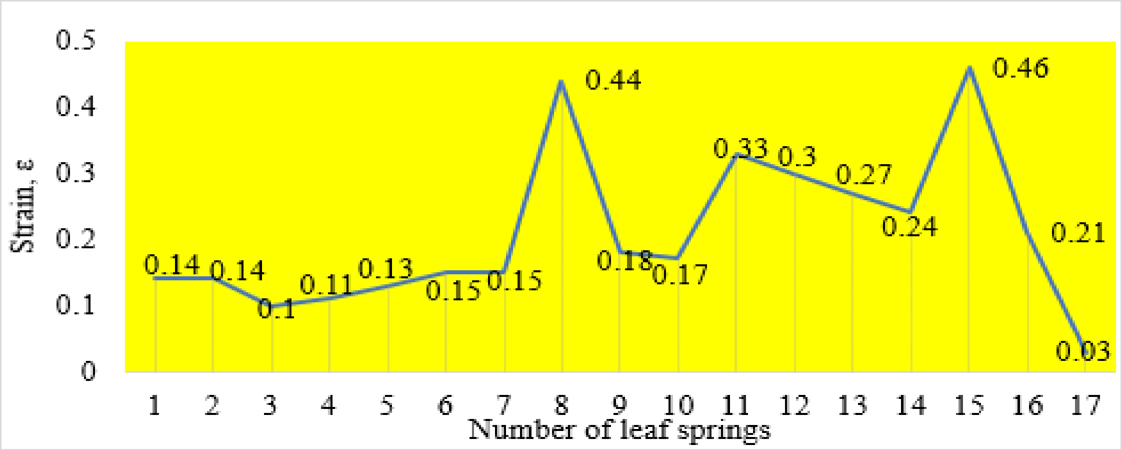


Figure 5: Structural behaviour of leaf springs under 120,000N loading condition on steel speed ramp

Figure 5 captures the strain values documented throughout this experiment under a 120,000N loading condition on the steel speed ramp. The zenith of strain values was achieved by leaf spring number 15 at 0.46, closely followed by leaf spring number 8 with 0.44, while the least strain of 0.03 was noted for leaf spring number 17. Both leaf springs 1 and 2 recorded identical

ISSN 1533-9211

DOI: 10.5281/zenodo.14598797

strain values of 0.14. This indicates that the strain values triggered in the leaf springs are accentuated as the truck, under a 120,000N loading capacity, traverses the steel speed ramp, potentially jeopardizing the structural integrity of the leaf springs, aligning with the findings of prior research with [11].

The relationship between stress and strain against the number of leaf springs under a loading condition of 120,000N traversing the asphalted speed ramp is depicted in Figure 6. The data reveals that the diminutive leaf number 17 recorded the pinnacle stress value of 5.33 MN/m², paired with a strain value of 0.03, while leaf springs numbers 14 and 15 each documented a stress value of 3.72 MN/m², with corresponding strains of 0.20 and 0.16 respectively. Both leaf springs 1 and 2 mirrored each other with stress values of 1.04 MN/m² and strain values of 0.12. The remaining leaf springs also showcased noteworthy stress and strain values. These observations imply that the accumulated stresses and strains resulting from the truck's passage over the ramp could markedly impact the structural behavior of the leaf springs, which resonates with the findings of [8].

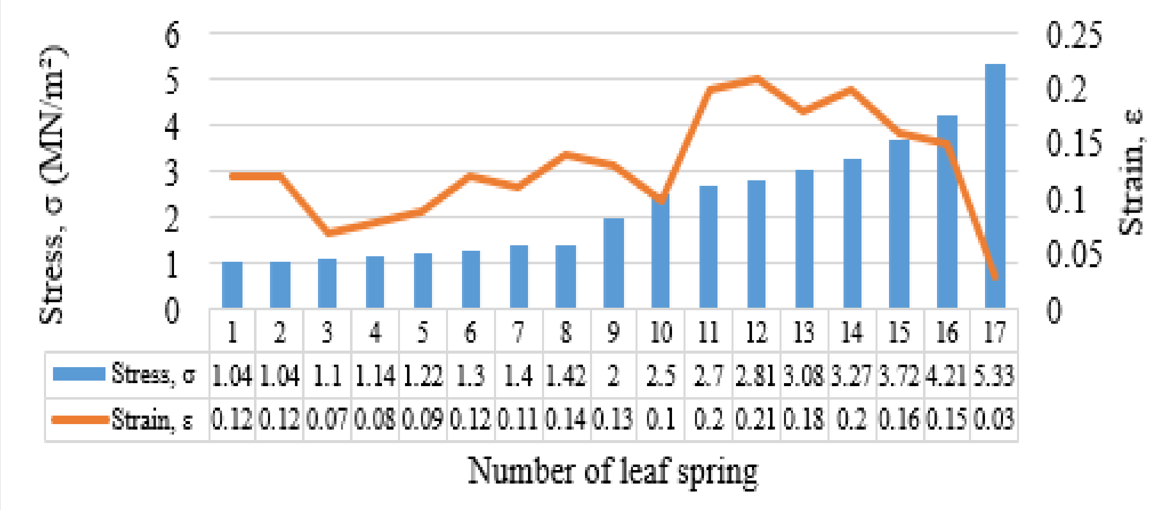


Figure 6: Structural behaviour of leaf springs with 120,000N loaded truck moved over asphalted speed ramp

3.2 Leaf springs endurance life under speed ramps with 116,000N-120,000N imposed loading conditions

Figure 7 illustrates the strain values captured by individual leaf springs under a loading condition of 116,000N on the steel speed ramp. Leaf springs 1 and 2 reported identical strain values of 0.12, whereas leaf spring number 17 recorded the lowest strain value of 0.03. Leaf spring number 8 distinguished itself with the highest strain value of 0.41, as portrayed in Figure 7. This suggests that the fatigue life of the leaf springs could be compromised if the truck repeatedly traverses this slope, substantiating the results presented in [12] research work.

ISSN 1533-9211

DOI: 10.5281/zenodo.14598797

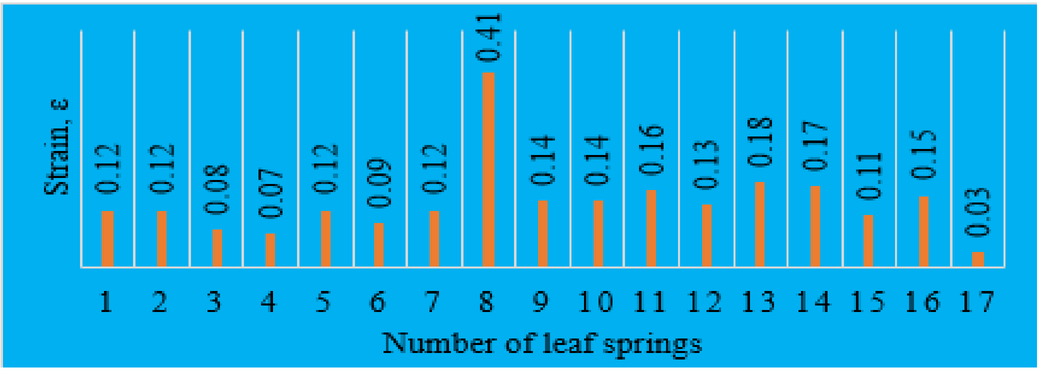


Figure 7: Fatigue life of leaf springs under 116,000N loading condition on steel speed ramp

Table 2: Spring fatigue life under 116,000N loading condition on asphalted speed ramp

Parameter	**Value**																
Leaf spring No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stress, σ (MN/m²)	1	1	1	1	1	1	1	1	2	3	3	3	3	3	4	4	5

Table 2 unveils the stress values captured by each leaf spring under a 116,000N load as it traverses an asphalted speed ramp, revealing that leaf springs numbered 1 to 8 bore the lightest stress of 1 MN/m² apiece, whilst leaf number 17 bore the brunt with a peak stress of 5 MN/m².

Following closely were leaf springs 15 and 16, which each faced a notable stress value of 4 MN/m², and leaf springs numbered 10 to 14 also registered a stress value of 3 MN/m² each. These findings suggest that relentless passage over this ramp may jeopardize the fatigue lifespan of the leaf springs, potentially leading to their failure, thereby supporting previously documented result by [13].

Figure 8 illustrates the correlation between stress and the quantity of leaf springs under the specified loading condition of 118,000N on an asphalt speed ramp. Empirical examination indicate that leaf springs numbered 1 and 2 exhibited the minimal stress values of 1.04 MN/m² each, whereas leaf spring number 17 demonstrated the maximum stress value of 5.24 MN/m², closely followed by leaf spring number 16, which recorded a stress value of 4.25 MN/m². Additionally, leaf springs numbered 13 to 15 reported notable stress values of 3.15 MN/m², 3.35 MN/m², and 3.37 MN/m², respectively.

This suggests that as the vehicle traverses the ramp, stresses are imparted onto the individual leaf springs, and the repeated use of that roadway segment may considerably influence the fatigue life of the leaf springs, corroborating the findings presented by [14].

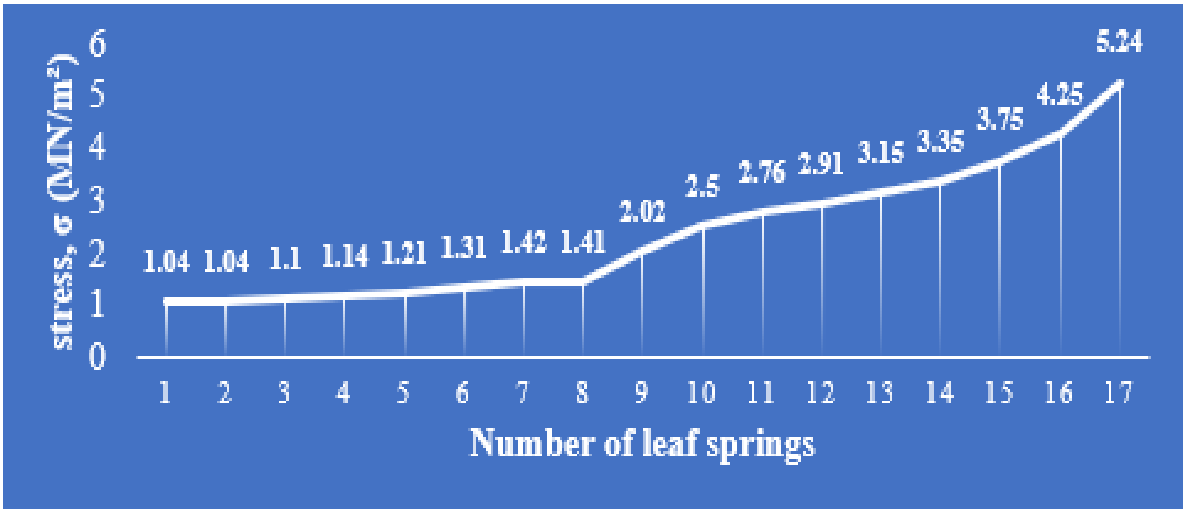
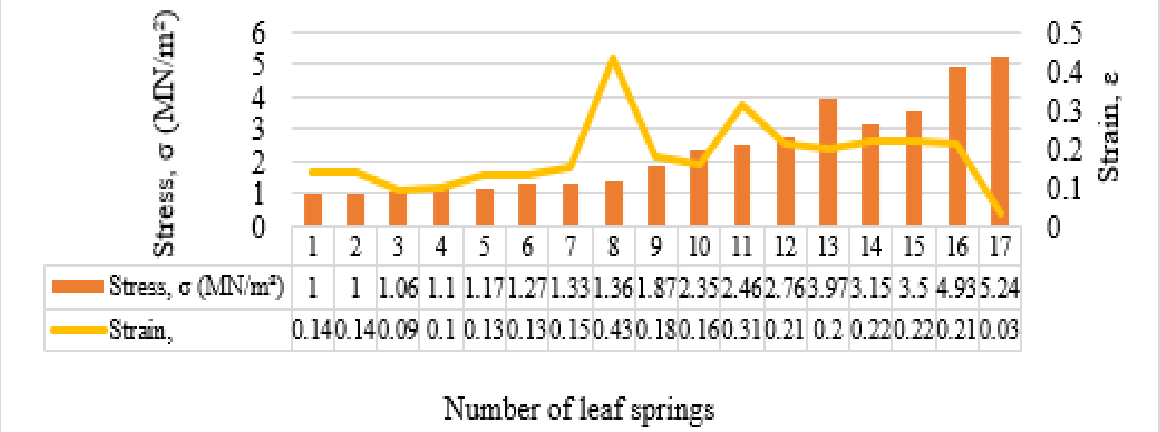


Figure 8: Fatigue life of leaf springs under 118,000N loading condition on asphalted speed ramp

Figure 9 displays the relationship between stress and strain for leaf springs under a loading condition of 118,000N on a steel speed ramp. The findings reveal that the shortest leaf spring, number 17, exhibited the highest stress value of 5.24 MN/m², accompanied by a strain value of 0.03, while leaf springs numbered 1 and 2 demonstrated identical stress values of 1.00 MN/m² with corresponding strain values of 0.14 each. The peak strain value of 0.43 was noted for leaf spring number 8, which corresponded to an equivalent stress value of 1.36 MN/m². These findings imply that the stresses and strains induced by the truck's movement over the ramp could significantly impact the fatigue life of the leaf springs, aligning with the conclusions of the research conducted by [15] and also supported by [16].



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
🟧 Stress, σ (MN/m²)	1	1	1.06	1.1	1.17	1.27	1.33	1.36	1.87	2.35	2.46	2.76	3.97	3.15	3.5	4.93	5.24
🟨 Strain,	0.14	0.14	0.09	0.1	0.13	0.13	0.15	0.43	0.18	0.16	0.31	0.21	0.2	0.22	0.22	0.21	0.03

Figure 9: Fatigue life of leaf springs under 118,000N loading condition on steel speed ramp

DOI: 10.5281/zenodo.14598797

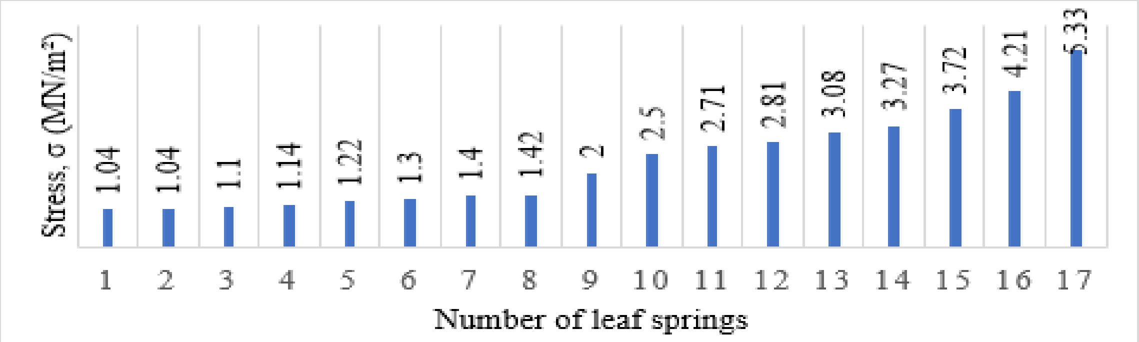


Figure 10: Fatigue life of leaf springs under 120,000N loading condition on asphalted speed ramp

Figure 10 illustrates the intricate relationship between stress and the leaf spring numbers under a 120,000N load on the asphalted speed ramp. The evidence shows that leaf spring numbers 1 and 2, the longest in the lineup, experienced the least stress of 1.04 MN/m² each. In contrast, the shortest leaf spring, number 17, suffered the highest stress value of 5.33 MN/m². The remaining leaf springs displayed stress values that fluctuated between 1.10 MN/m² and 4.21 MN/m². These observations underscore that substantial stress values are exerted on the leaf springs, reinforcing the gathered findings, and could inflict harm upon the leaf springs over time as the truck continually navigates that section of road over such speed bumps. Figure 11 captures the dynamic interplay of stress and strain in leaf springs subjected to a 120,000N load on a steel speed ramp. The diminutive leaf spring, number 17, showcased the most significant stress value of 5.33 MN/m² alongside a strain value of 0.03. Leaf springs numbered 1 and 2 mirrored each other with stress and strain readings of 1.01 MN/m² and 0.14 respectively, while leaf spring number 15 exhibited the highest strain of 0.46 with a corresponding stress value of 3.56 MN/m². This signifies that the stresses and strains triggered as the truck navigates over the ramp could profoundly influence the fatigue lifespan of the leaf springs, aligning with the results by [17].

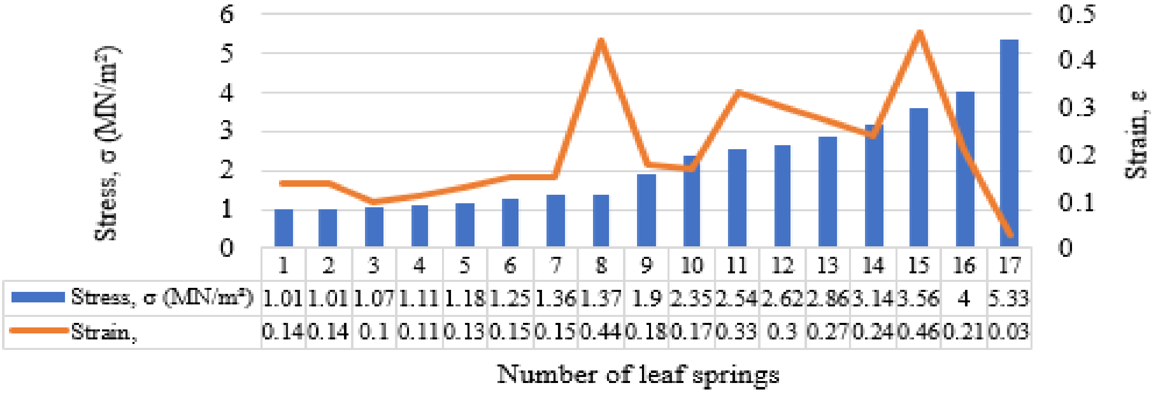


Figure 11: Fatigue life of leaf springs under 120,000N loading condition on steel speed ramp

3.3 Damping effects of leaf springs under speed ramp settings conditions of 116,000N-120,000N loading

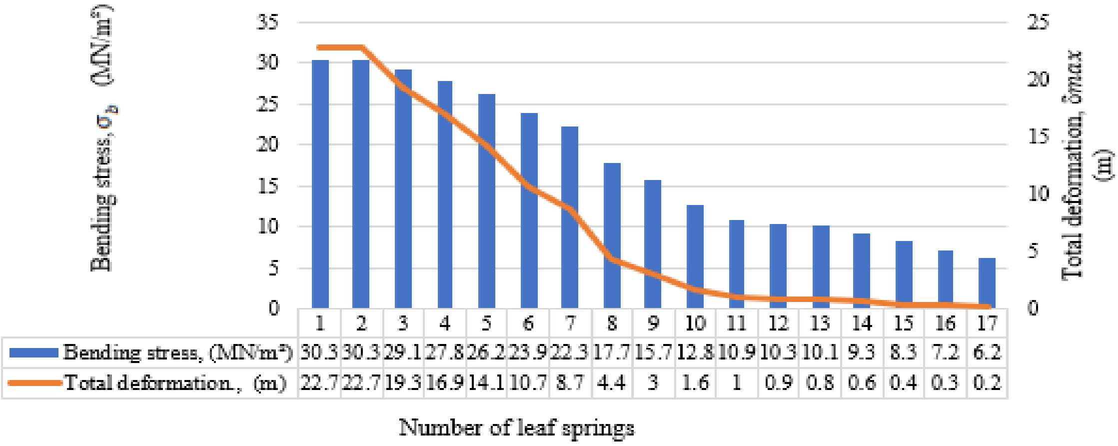


Figure 12: Damping effects of leaf springs under 116,000N loading condition on asphalted speed ramp

The findings regarding bending stress and total deformation of leaf springs under a 116,000N load on the asphalted speed ramp are depicted in Figure 12, revealing that leaf springs numbered 1 and 2 achieved the highest readings of 30.30 MN/m² for bending stress and 22.70 m for total deformation, while the least bending stress and total deformation were recorded by the shortest leaf spring (number 17), measuring 6.20 MN/m² and 0.20 m respectively. The data further illustrates a consistent escalation in both bending stress and total deformation among the leaf springs. The rise in deformation is a telling indication of the leaf springs' capacity to absorb shocks, resonating with the published literature [18] as the truck traversed the asphalted speed ramp; nonetheless, the shocks absorbed may eventually lead to the spring's demise over time.

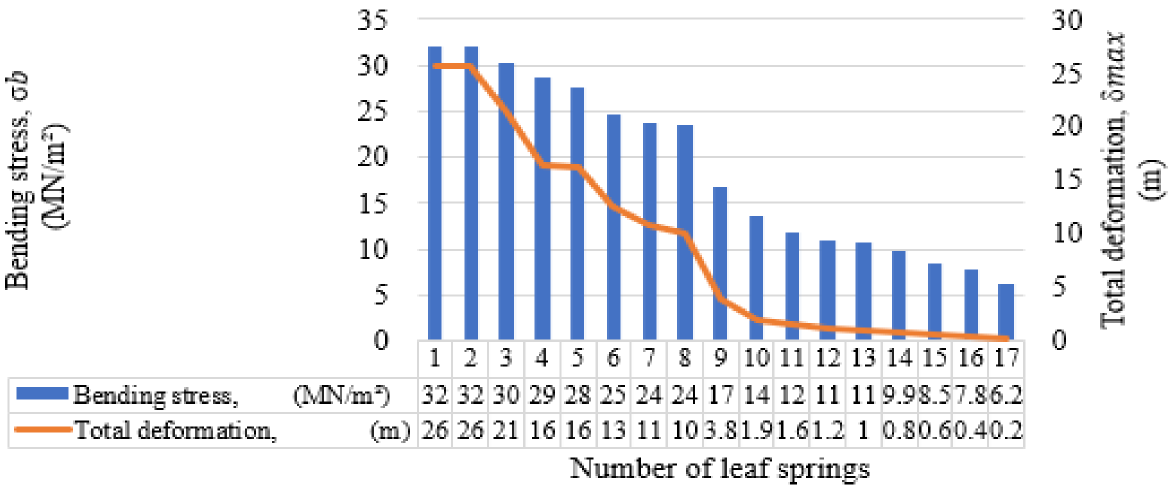


Figure 13: Damping effects under 116,000N loading condition over a steel speed ramp

DOI: 10.5281/zenodo.14598797

Figure 13 illustrates the outcomes of bending stress and overall deformation under a hefty loading condition of 116,000N as the truck gracefully glided over a steel speed ramp. Leaf spring number 17, the most compact among the bunch, registered the minimal bending stress value of 6.20 MN/m² alongside a total deformation of 0.20 m, while leaf spring numbers 1 and 2 dominated the metrics with their towering bending stress and total deformation values, each clocking in at 32.00 MN/m² and 26.00 m respectively. This unveils a clear narrative that longer leaf springs endure greater deformation and bending stress than their shorter counterparts. The elevated deformation value amplifies the prowess of leaf springs in absorbing shocks, harmonizing with the findings of [19], yet the repeated traversal over the ramp may lead to the emergence of cracks.

Figure 14 unveils the findings for bending stress and total deformation in relation to the quantity of leaf springs under a robust loading condition of 118,000N on an asphalted speed ramp. As highlighted in Figure 4.10, the principal (longest) two leaf springs achieved the pinnacle values of 31.68 MN/m² and 24.08 m for bending stress and total deformation respectively, contrasting sharply with leaf spring number 17, which recorded the lowest figures of 6.29 MN/m² and 0.19 m. The elevated deformation value signifies the springs' formidable capacity to absorb shocks experienced during the truck's passage over the ramp, resonating with the research conducted by [20]; however, this also generates stress and strain in the leaf springs, potentially rendering them more fragile.

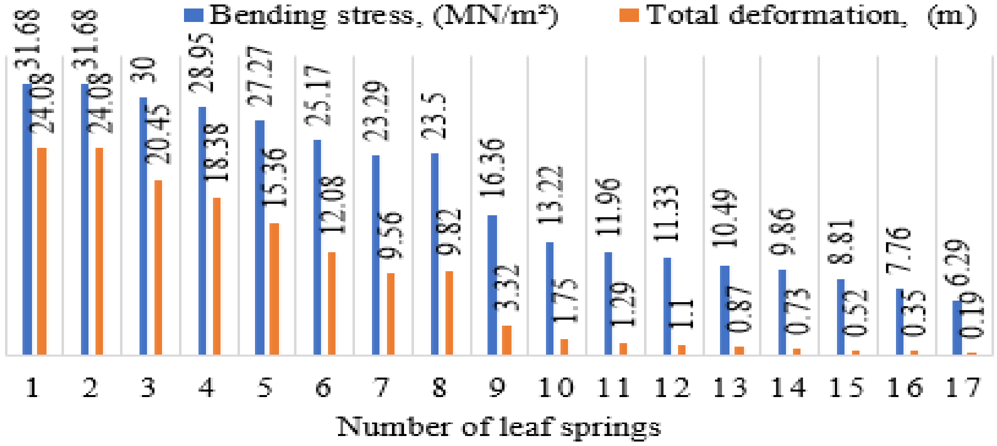


Figure 14: Damping effects of leaf springs under 118,000N loading condition on asphalted speed ramp

Figure 15 depicts the outcomes of bending stress as juxtaposed with the quantity of leaf springs under an imposing loading condition of 118,000N on a steel speed ramp. The data reveal that leaf springs numbers 1 and 2 attained the summit of bending stress at 32.94 MN/m² each, while leaf spring number 17 languished at the bottom with a bending stress of 6.29 MN/m². The remaining leaf springs showcased noteworthy values, and the escalation in bending stress levels exerts pressure on the leaf springs, which could lead to rupture if the truck frequently navigates over the ramp, aligning with the observations made in [21] publication.

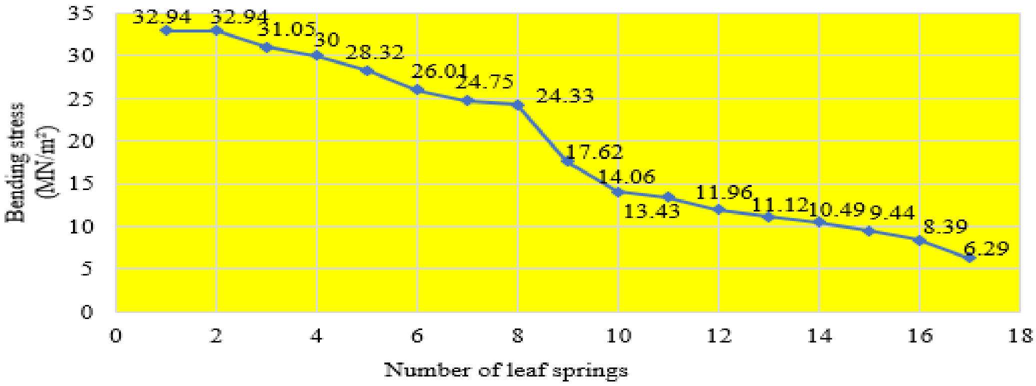


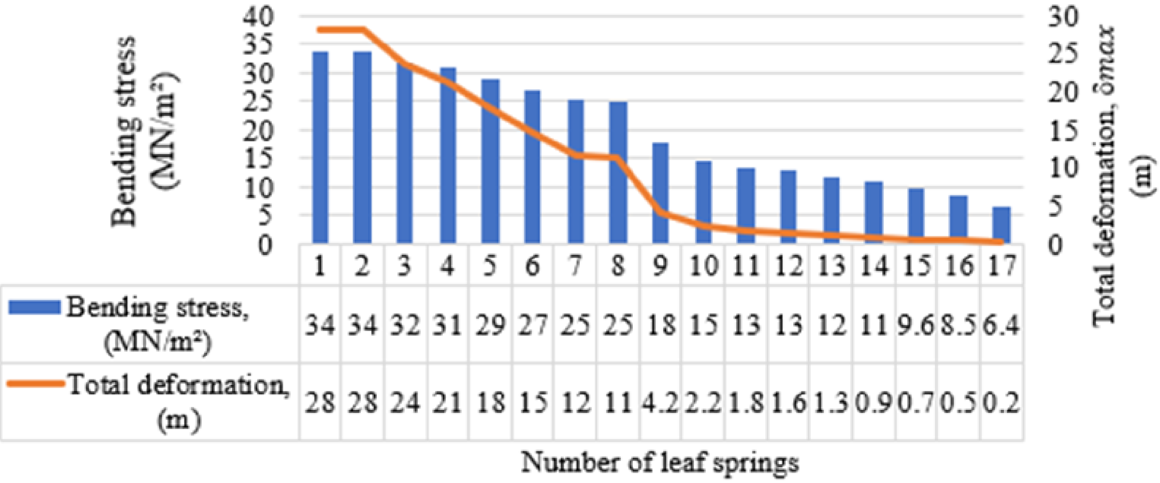
Figure 15: Damping effects of leaf springs under 118,000N loading condition on steel speed ramp

The data concerning bending stress and total deformation of leaf springs under a loading condition of 120,000N on an asphalt speed ramp are presented in Table 3, revealing that leaf springs numbered 1 and 2 recorded the maximum values of 32.85 MN/m² for bending stress and 22.59 m for total deformation. Conversely, the minimal values for both bending stress and total deformation were attributed to leaf spring number 17, recognized as the shortest, as detailed in Table 3. The implications of these elevated values suggest that the springs possess the capacity to absorb shocks while simultaneously inducing stresses and strains that may precipitate their failure due to the frequent passage of the truck over the ramp, thereby reinforcing the conclusions of the study conducted by [22].

Table 3: Damping effects of leaf springs under 120,000N loading conditions on asphalted speed ramp

Leaf spring No.	Bending stress, σ_b (MN/m^2) (120,000N)	Total deformation, δ_{max} (m) (120,000N)
1	32.85	22.59
2	32.85	22.59
3	30.93	20.79
4	29.87	18.29
5	27.95	15.27
6	26.24	11.68
7	24.32	9.73
8	24.11	4.84
9	17.07	3.42
10	13.65	1.78
11	12.59	1.32
12	12.16	1.06
13	11.09	0.89
14	10.45	0.65
15	9.17	0.49
16	8.11	0.33
17	6.40	0.19

Figure 16 illustrates the data obtained from the analytical evaluation of bending stress and total deformation experienced by a steel speed ramp with a load capacity of 120,000N. The findings indicate that elongated leaf springs exhibit superior deflection characteristics compared to their shorter counterparts, with respective bending stress and deformation measurements of 34.00 MN/m² and 28.00 m recorded for leaf spring numbers 1 and 2. Conversely, the most diminutive leaf spring (number 17) recorded the minimal values of 6.40 MN/m² and 0.20 m for both bending stress and deformation metrics. Furthermore, the data suggest a consistent increase in both bending stress and deformation from the shortest to the longest leaf springs, as illustrated in Figure 16. This observation implies that while the leaf springs possess the capability to absorb shocks as published by [21], which also serve as a critical factor in the potential failure of the truck as it traverses the ramp repeatedly.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
▬ Bending stress, (MN/m²)	34	34	32	31	29	27	25	25	18	15	13	13	12	11	9.6	8.5	6.4
▬ Total deformation, (m)	28	28	24	21	18	15	12	11	4.2	2.2	1.8	1.6	1.3	0.9	0.7	0.5	0.2

Figure 16: Damping effects of leaf springs under 120,000N loading condition on steel speed ramp

CONCLUSION

The research presents an exhaustive examination of the influence exerted by speed ramps on the structural characteristics of heavy-duty leaf springs across a spectrum of loading capacities and ramp designs. The investigation reveals that both the elevation and the quality of construction of speed ramps, particularly concerning the type of steel utilized, exert a significant effect on the stress and deformation encountered by leaf springs. Leaf springs of greater length situated at the apex of the suspension system demonstrate diminished stress levels in comparison to their shorter counterparts located at the base. However, these elongated springs are more susceptible to bending stress and deformation, which are exacerbated by the height of the speed ramp and the loading capacity of the truck. The study elucidates that increased ramp heights result in amplified effects on the structural behavior of leaf springs, thereby influencing their fatigue longevity. The outcomes once again articulate that the deformation of the leaf springs, triggered by the speed ramps, enhances the capacity to absorb shocks that would otherwise jolt the truck's occupants, while simultaneously inflicting stress and strain on the material that could erode its durability over time as the truck consistently traverses that thoroughfare. Continuous passage over speed ramps induces considerable stress and strain, thereby accelerating deterioration and potentially precipitating premature failure. The findings underscore the pivotal importance of speed ramp design and construction integrity in alleviating stress and prolonging the operational lifespan of leaf springs.

Acknowledgements

Authors are grateful to the anonymous referees and editor for their constructive comments.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare no financial interests/personal relationships which may be considered as potential competing interests.

Authors' contributions

Author 1' designed the study, performed the statistical analysis and wrote the protocol. Author '2' wrote the first draft of the manuscript and managed the analyses of the study. 'Author 1' managed the literature searches. All authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

All data generated or analyzed are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

List of abbreviations

Not applicable.

References

1) Gyaase D, Newton S, Adams CA, Enuameh Y, Adjei BN, Nakua EK. Effect of speed humps on injury consequences on trunk roads traversing towns in Ghana: A quasi-experimental study. Injury prevention. 2023;29:68-73.

2) Shen ZE. Optimal Highway Ramp Speed Control with Deep Reinforcement Learning. 2023.

3) Mohanty M, Raj Y, Rout S, Tiwari U, Roy S, Samal SR. Operational effects of speed breakers: a case study in India. European Transport. 2021;81.

4) Cunanan C, Tran M-K, Lee Y, Kwok S, Leung V, Fowler M. A review of heavy-duty vehicle powertrain technologies: Diesel engine vehicles, battery electric vehicles, and hydrogen fuel cell electric vehicles. Clean Technologies. 2021;3:474-89.

5) Goodarzi A, Khajepour A. Vehicle suspension system technology and design: Springer; 2017.

6) Mantilla D, Arzola N, Araque O. Diseño óptimo de resortes de ballesta para suspensiones de vehículo sometidas a condiciones de carga cíclica. Ingeniare Revista chilena de ingeniería. 2022;30:23-36.

7) Gök DA, BALTACI A. Design and fatigue life analysis of air suspension Z type leaf springs used in heavy commercial vehicle. Politeknik Dergisi. 2023:1-.

8) Goenaga B, Underwood S, Fuentes L. Effect of speed bumps on pavement condition. Transportation research record. 2020;2674:66-82.

9) Garcia-Pozuelo D, Gauchia A, Olmeda E, Diaz V. Bump modeling and vehicle vertical dynamics prediction. Advances in Mechanical Engineering. 2014;6:736576.

10) Agostinacchio M, Ciampa D, Olita S. The vibrations induced by surface irregularities in road pavements–a Matlab® approach. European Transport Research Review. 2014;6:267-75.

11) Lin H-Y, Ho C-Y. Adaptive speed bump with vehicle identification for intelligent traffic flow control. IEEE Access. 2022;10:68009-16.

12) Andoh PY, Mensah L, Dzebre D, Amoabeng KO, Sekyere CKK. Investigating The Failure of Leaf Springs in Automobile Suspension on Ghana Road. Journal of Applied Engineering and Technological Science (JAETS). 2022;4:1-15.

13) Soner M, Senocak C, Erdogus T, Karaagac M, Kanbolat A, Ozcelik G, Ceyhun V. Leaf Spring Safety and Ride Comfort Circumstances Against Fatigue Behaviour. SAE Technical Paper; 2013.

14) Aher V, Sonawane P. Static and fatigue analysis of multi leaf spring used in the suspension system of LCV. International Journal of Engineering Research and Applications. 2012;2:1786-91.

15) Dighe A. A review on testing of steel leaf spring. International Research Journal of Engineering and Technology. 2016;3:492-6.

16) Shaikh S, Hujare D, Yadav S, Swarnakar P. Development of analytical tool model architecture to establish the fatigue life cycle of leaf spring for different parameters using SAE standards. AIP Conference Proceedings: AIP Publishing; 2024.

17) Hasan S, Ahmed A, Ahmed N, Mamun M. A Finite Element Analysis of Automobile Leaf Spring. Recent Trends in Manufacturing and Materials Towards Industry 40: Selected Articles from iM3F 2020, Malaysia: Springer; 2021. p. 395-407.

18) Çetinkaya MB, İşci M. ANSYS based analysis of multi-level parabolic leaf spring systems. Alexandria Engineering Journal. 2023;73:109-21.

19) Manaba B, Hashe VT. A review of composite leaf springs for automotive vehicles. MATEC Web of Conferences: EDP Sciences; 2021. p. 00031.

20) Jaiswal SK, Gajbhiye S. A Review on Finite Element Analysis of Composite Leaf Spring for Automotive. International Research Journal of Engineering and Technology, 8/4,(2021). 2021:1067-70.

21) Trzesniowski M. Springs and Dampers. Suspension System: Springer; 2023. p. 163-238.

22) Yang Z, Zhang R, Guo Z, Guo J, Zhou Y. Research on the optimal speed of vehicles passing speed bumps on the highway based on an immune algorithm. Mechanical Sciences. 2024;15:315-30.