ANALYSIS OF THE INFLUENCE OF CONCRETE AND CLAY SPEED BUMPS ON HEAVY-DUTY TRUCK LEAF SPRINGS

ENOCK ANDREWS DUODU[1]*, ISAAC LEGSON MBEAH[1]

1 Department of Mechanical and Automotive Engineering, AAMUSTED, Ghana; eaduodu@aamusted.edu.gh

2 Department of Agricultural, Technical and Vocational Education Training Komenda College of Education, Ghana; isaaclegsonmbeah@gmail.com

* Correspondence: eaduodu@aamusted.edu.gh; +233 54 7779929

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Abstract: This study examines the structural behavior, fatigue lifespan, and damping characteristics of heavy-duty truck leaf springs subjected to concrete and clay speed ramps under various induced loading scenarios. The findings showed that extended leaf springs positioned at the top experience diminished stress levels compared to their shorter counterparts located at the bottom. This research suggests that elongated leaf springs endure substantial bending stress and deformation attributable to the elevation of the speed ramp and the imposed loading capacity, which in turn impacts the fatigue lifespan of the leaf springs under induced loading conditions.

Keywords: heavy-duty truck, leaf springs, speed ramp, rear-axle

1. INTRODUCTION

Various categories of speed ramps, encompassing speed humps, speed cushions, rumble strips, and speed tables, have been effectively implemented to regulate vehicular speeds. However, their application is occasionally contentious. Internationally, speed calming measures have been adopted to curtail the rate of accidents and fatalities, while also reducing traffic velocity in the nearby area and lessening the impact of accidents [1]. While speed ramps are efficacious, they can sometimes impose substantial stress on heavy-duty truck leaf springs within a vehicle's suspension system. To ensure secure and seamless transportation networks, it is imperative to effectively regulate traffic flow on highways. The management of speed on highway ramps is crucial for mitigating traffic congestion and enhancing the efficiency of the transportation system [2]. For speed bumps, the requisite minimum velocity for a vehicle to successfully ascend a hump is approximately 25 km/h, accompanied by a minimum chord length and elevation of 3 m and 0.1 m, respectively [3].

A heavy-duty truck represents a substantial and robust vehicle designed for the transportation of significant loads across extensive distances. These trucks are engineered to endure challenging conditions and find application across a multitude of sectors, including agriculture, construction, mining, and logistics. Cunanan et al. [4] codify a heavy-duty vehicle as one possessing a gross vehicle weight rating (GVWR) exceeding 26,000 pounds (115,195.43 N). Heavy-duty trucks exhibit a considerable Gross Vehicle Weight Rating (GVWR), which delineates the maximum weight that the vehicle can securely carry, encompassing both its mass and any cargo. Every automotive manufacturer emphasizes the well-being and satisfaction of the occupants, in addition to the vehicle's safety. Thus, the vehicle is outfitted with a suspension system, wherein leaf springs constitute a principal component. A leaf spring functions to support the vehicle and its load while preserving stability and

* Corresponding author, email: eaduodu@aamusted.edu.gh

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control. The flexure of the leaves, along with the frictional interaction between them as they glide slightly over one another during bending, mitigates the vehicle's weight and any irregularities. The majority of leaf springs (also referred to as elliptical springs) possess a curvature that enhances their capacity to absorb shock. The prime roles of a vehicle’s suspension system are to facilitate the vehicle's absorption of bumps, potholes, and other irregularities in the roadway. Leaf springs, in particular, contribute significantly to the initial two functions: they bear the weight of the vehicle while attenuating bumps and are effective in distributing heavy loads over a broad area.

According to Goodarzi and Khajepour [5], the suspension system serves to insulate the driver and passengers from the majority of road-induced shocks and wheel movements as the wheels traverse the road surface. Suspension systems in both light and heavy commercial trucks consistently employ simpler springs known as leaf springs. These springs are frequently utilized in the rear suspensions of automobiles and are sometimes referred to as semi-elliptical, elliptical, or carriage springs. Each spring is bound by a life cycle that it must comply with function effectively, contingent upon the materials utilized and the thermal treatment applied. Leaf springs are attached to the axle and chassis in such a manner that they can flex vertically in response to disturbances in the road surface. Regrettably, the conditions of the roadway hinder the leaf springs' ability to sustain their operational lifespan.

Mantilla et al. (2022) observe that suspension systems are engineered to fulfil supplementary criteria, such as fatigue strength, while still providing exceptional comfort and mobility. The leaf spring is intended to absorb vertical vibrations and shocks induced by irregularities in the roadway through alterations in spring deflection, thereby storing potential energy as strain energy and gradually releasing it. Augmenting the energy storage capacity of leaf springs results in a more compliant suspension system. In Akgümüş and Baltaci [6], leaf springs serve to mitigate the forces transmitted from the wheels and the roadway to the chassis while functioning on diverse types of roadways under fully loaded conditions.

Andoh et al. [7] assert that the degradation of leaf springs is attributed to substandard road infrastructure and the implementation of locally produced speed ramps on thoroughfares across various regions of the nation. To facilitate secure and comfortable vehicular operation, leaf springs, which constitute a crucial element of the truck's suspension system, furnish support, stability, and dampening of shocks. Due to their elevated profiles and abrupt vertical transitions, speed ramps can induce significant dynamic stress on leaf springs. Such forces may lead to augmented tension, fatigue, and ultimately, deterioration of the leaf springs over time. Accordingly, this study aims to investigate the effects of speed ramps on heavy-duty vehicles.

2. EXPERIMENTAL SETUP

2.1. Materials and equipment

The materials utilized in this investigation encompass a heavy-duty truck, equipped with steel leaf springs on the real axle, a digital measuring tape, a digital vernier caliper, a digital camera, along two-speed ramps fabricated from concrete and clay, to assess the varying conditions under which the heavy-duty truck with steel leaf springs operates.

2.2. Mathematical model

Mathematical formulae were used to determine the stress and strain, bending stress and total deflection experienced on the steel leaf springs under loads. The following formulations (Equations 1-4) were adopted and adapted as in [7].

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

where σ are 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 are the strain, L_o is the initial length (m), L is the ultimate length (m).

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

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

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 δ_{max} are 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 procedure

An experimental investigation was conducted utilizing a heavy-duty truck with varying loading capacities between 122,000 N and 124,000 N, incorporating steel leaf springs comprising seventeen (17) layers, traversing speed ramps constructed from concrete and clay. The conventional steel leaf springs utilized in this study are typically manufactured from plain carbon steel with a Young's Modulus value of 200×10^9 N/m².

In this study, the leaf springs located on the rear-axles were employed, and a uniform distributed load along the length of the leaf springs was applied. During the experimental procedures, measurements of the truck's leaf springs were recorded while the vehicle was positioned on the ramps under load to evaluate the behavior of the leaf springs, employing digital measuring tape and digital vernier calipers. The acquired values were calculated and analyzed in accordance with scientific principles utilizing Equations (1-4) on semi-elliptical leaf springs. The parameters of 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.	Concrete	9.93	6.00	0.26
2.	Clay	9.90	2.00	0.32

3. RESULTS AND DISCUSSION

The results were analyzed at different loading scenarios ranging from 122,000 - 124,000 N over speed ramps considered (concrete and clay) for structural behavior and load-carrying capacity.

3.1. Influence of speed ramps on the structural dynamics of leaf springs subjected to 122,000 N and 124,000 N loading conditions

The outcomes of stress and strain in relation to the leaf springs, as depicted in Figure 1, indicate that leaf spring number 17 exhibited the highest stress value of 5.42 MN/m², concomitant with a strain of 0.03. Leaf springs numbers 1 and 2, due to their respective lengths, registered identical values for both stress and strain at 1.02 MN/m² and 0.15, while the maximum strain value of 0.42 was noted for leaf number 8 against a stress measurement of 1.41 MN/m²; respectively. This implies that the stress and strain applied to the leaf springs as a consequence of the truck traversing the speed ramp could significantly affect their structural behavior and potentially lead to failure, corroborating the findings of the study conducted by [8]. This vividly illustrates the presence of stresses and strains acting upon the leaf springs, which may influence their structural integrity as the truck traverses the ramp.

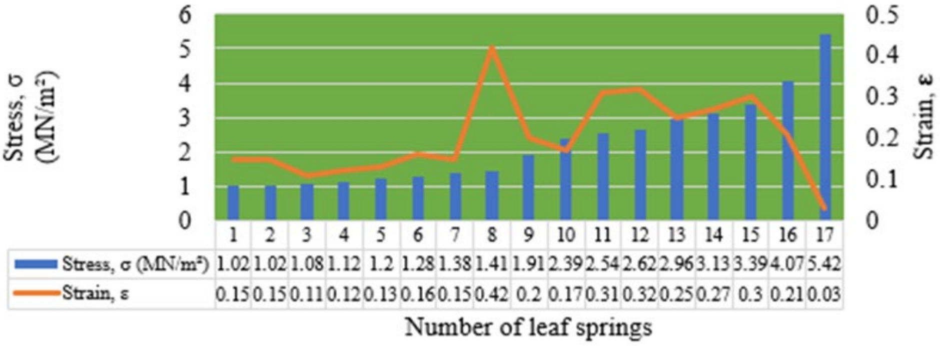

Fig. 1. Structural behavior of leaf springs under 122,000 N loading condition on concrete speed ramp.

The visuals in Figure 2 reveal the intricate dance of stress and strain as leaf springs endure the weight of a 124,000N truck gliding over a concrete speed ramp, revealing recorded values of 1.02 MN/m² and 0.17 for leaf springs numbered 1 and 2, respectively. Leaf spring number 17 astonishingly captured the pinnacle stress value of 5.51 MN/m², juxtaposed with a minimal strain value of 0.03, while leaf spring number 8 showcased the peak strain value of 0.47 alongside a corresponding stress value of 1.39 MN/m², with other springs displaying a variety of stress and strain figures. The gathered data illustrates a remarkable absorption of these forces, which undeniably could influence the structural integrity of leaf springs, aligning with the findings of [9].

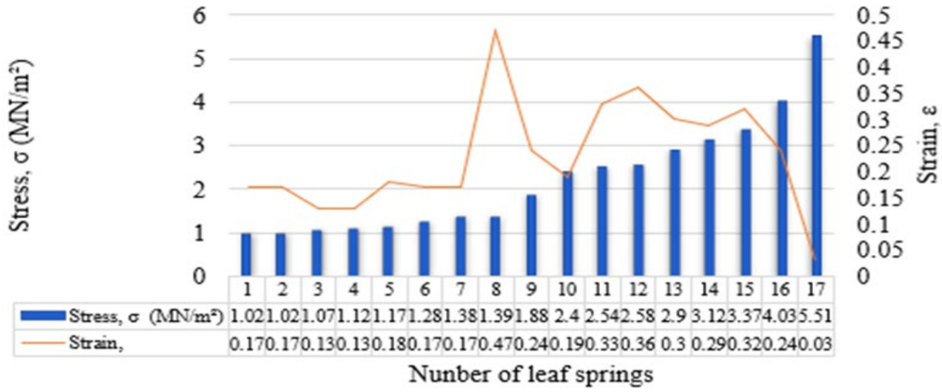

Fig. 2. Structural behavior of leaf springs under 124,000 N loading condition on concrete speed ramp.

Table 2 shows the stress and strain values for leaf springs under a 122,000N load on a clay ramp, where leaf spring number 8 emerged with a striking strain value of 0.5 against a stress measurement of 1.00 MN/m². The findings further reveal that leaf springs 1 and 2 exhibited stress and strain metrics of 1.00 MN/m² and 0.20 each, while the elongated leaf spring 17 achieved the highest stress reading of 5.00 MN/m², accompanied by a strain value of 0.03. This compelling evidence underscores the presence of stresses and strains acting on the leaf springs, corroborating the assertions made by [10], which suggest potential alterations in their structural dynamics as the truck rolls over the ramp.

Table 2. Structural behavior of leaf springs under 122,000 N loading capacity on the clay 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	2	2	3	3	3	3	4	5
Strain, ε	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.5	0.3	0.3	0.4	0.4	0.3	0.3	0.4	0.3	0.03

The diagram presented in Figure 3 embody the stress and strain experienced by leaf springs under the burden of a 124,000N truck traversing a clay ramp, revealing stress and strain values of 0.99 MN/m² and 0.21 for leaf springs numbered 1 and 2, respectively. Once again, leaf spring number 17 recorded a peak stress value of 5.51 MN/m², paired with a minimal strain value of 0.03, while leaf spring number 8 reached the maximum strain value of 0.53, with an associated stress value of 1.33 MN/m², while the other springs exhibited varying stress and strain values as shown in Figure 3. The outcomes indicate a significant absorption of these forces, resonating with the research published in [8], which highlights the potential for leaf spring failure.

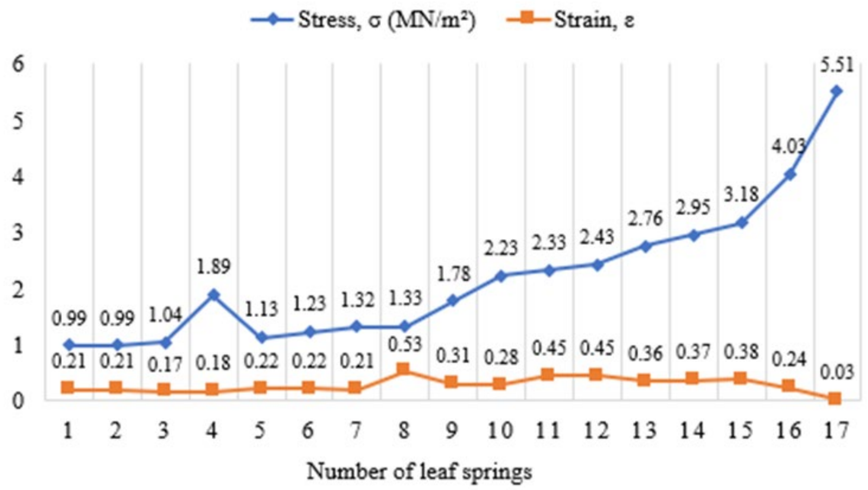

Fig. 3. Structural behavior of leaf springs under 124,000 N loading capacity on clay speed ramp.

3.2. Leaf springs endurance limit under speed ramps with 122,000 N and 124,000 N imposed loading conditions

The findings derived from the analysis of leaf springs subjected to a formidable 122,000N load on a concrete speed ramp are encapsulated in Table 3, revealing that leaf springs numbered 1 through 8 each faced a stress value of 1.00 MN/m², while those numbered 11 to 15 experienced a stress of 3.00 MN/m² each. In contrast, leaf spring number 17 claimed the title of the highest stress value, juxtaposed with the minimal strain value of 0.03. Notably, leaf spring number 8 achieved the pinnacle strain value of 0.4, although the majority hovered between the realms of 0.2 and 0.3, as illustrated in Table 3. This suggests that the leaf springs are engaged in a dance of stress and strain absorption, potentially leading to a plethora of defects, thereby echoing the findings shared by [11].

Table 3. Fatigue life of leaf springs under 122,000 N loading condition on the concrete 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	2	3	3	3	3	3	4	5
Strain, ε	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.03

Figure 4 portrays the stress and strain outcomes for leaf springs under a 124,000N load on a concrete speed ramp, highlighting that leaf number 8 recorded the maximum strain value of 0.47 alongside a corresponding stress value of 1.39 MN/m². The data also reveals that leaf springs numbered 1 and 2 each manifested stress and strain values of 1.02 MN/m² and 0.17, respectively. Meanwhile, an impressive stress value of 5.51 MN/m² was attributed to the longest leaf (number 17), accompanied by an equivalent strain value of 0.03. This evidence distinctly illustrates that stresses and strains affect the leaf springs, corroborating the findings of Arora et al. [12]. which bear significant implications for their fatigue life as the truck traverses the ramp.

The insights gleaned from the data concerning leaf springs under a steadfast 122,000N loading condition on a clay speed ramp are showcased in Figure 5, revealing that leaf spring number 8 stood out with the highest strain value of 0.48, counterbalanced by a stress value of 1.36 MN/m². The results also highlight that leaf spring numbers 1 and 2 encountered stress and strain levels of 1.00 MN/m² and 0.18 each. Meanwhile, the longest leaf spring (number 17) displayed the most substantial stress value of 5.42 MN/m², aligning with a strain value of 0.03. This compelling evidence underscores the stresses and strains acting upon the leaf springs, which could significantly impact their fatigue life as the truck maneuvers over the ramp, corroborating the research conducted by [13].

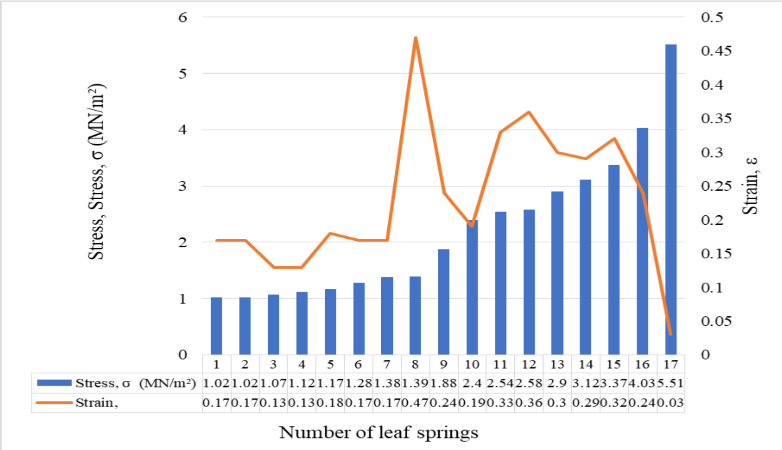

Fig. 4. Fatigue life of leaf springs under 124,000 N loading condition on concrete speed ramp.

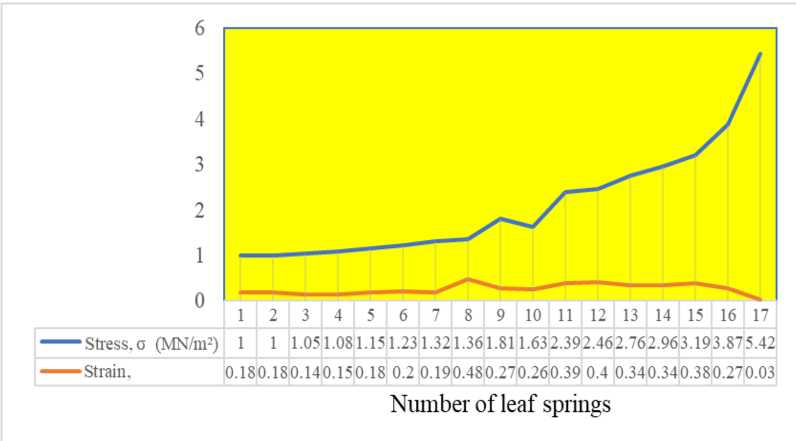

Fig. 5. Fatigue life of leaf springs under 122,000 N loading condition on clay speed ramp.

Table 4 delineates the stress and strain observations for leaf springs under a loading condition of 124,000N on a clay speed ramp. In a significant contrast, leaf number 17 achieved a maximum stress value of 5.51 MN/m² while presenting a minimum strain of 0.03, whereas leaf spring number 8 recorded an apex strain value of 0.53 with a stress measure of 1.33 MN/m². Leaf springs numbered 1 and 2 mirrored each other with identical stress and strain values of 0.99 MN/m² and 0.21, respectively, as depicted in Table 4. This underscores the notion that the leaf springs are subjected to induced stresses and strains, potentially leading to structural abnormalities. This study further validates the findings by [14] as documented in the literature review.

Table 4. Fatigue life of leaf springs under 124,000 N loading condition on clay speed ramp.

Leaf spring No.	Stress, σ (MN/m²)	Strain, ε
1	0.99	0.21
2	0.99	0.21
3	1.04	0.17
4	1.89	0.18
5	1.13	0.22
6	1.23	0.22
7	1.32	0.21
8	1.33	0.53
9	1.78	0.31

10	2.23	0.28
11	2.33	0.45
12	2.43	0.45
13	2.76	0.36
14	2.95	0.37
15	3.18	0.38
16	4.03	0.24
17	5.51	0.03

3.3. Damping effects of leaf springs under speed ramp settings with conditions of 122,000N and 124,000N loading

The visual display in Figure 6 unveils the total deformation results observed in leaf springs subjected to a formidable 122,000N load while traversing a clay speed ramp. The data reveals that the elongated leaf springs numbered 1 and 2 underwent the most considerable deformation of 31.31 m each, a stark contrast to leaf spring number 17, which only experienced a minimal deformation of 0.20 m. The other leaf springs showcased notable deformation values ranging from 0.54 m to 26.92 m, reflecting the differences from the shortest to the longest among them. Each of these deformations transpired within individual leaf springs as the truck rolled over the ramp, aligning with the insights presented by [15], which suggest that frequent traversal of that road segment could severely compromise the integrity of the leaf springs.

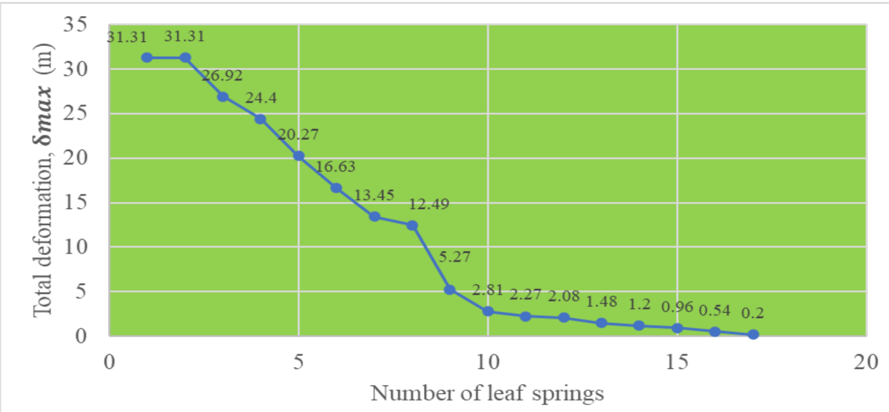

Fig. 6. Damping effects of leaf springs under 122,000 N loading condition on clay speed ramp.

Table 5 shows the accounts of total deformation experienced by leaf springs under a mighty 124,000N loading condition on a clay speed ramp, revealing that leaf springs numbered 1 and 2 exhibited the peak bending stress of 37.00 MN/m² and a deformation of 33.00 m each, respectively. The findings also illustrate that leaf spring number 17 demonstrated the lowest bending stress (7.00 MN/m²) and deformation (0.20 m), while the others showcased a notable rise, as illustrated in Table 5. The increased deformation signifies the leaf spring's resilience to absorb shocks as the truck traverses the clay speed ramp, echoing the research conducted by [16]. Nevertheless, this could pose a serious risk to the leaf spring due to the exerted loads.

Table 5. Damping effects of leaf springs under 124,000 N loading condition on clay speed ramp.

Parameter	Value																
Leaf spring No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
σ_b (MN/m²)	37	37	35	34	32	30	28	27	21	16	16	15	13	12	12	9	7
δ_{max}(m)	33	33	30	26	23	18	14	5	3	3	2	2	1	1	1	1	0.2

Plot in Figure 7 are the deformation results encountered by leaf springs under the same 122,000N loading condition while navigating a concrete speed ramp. The findings highlight that leaf springs numbered 1 and 2 achieved identical maximum deformation values of 27.34 m, whereas the minimum deformation of 0.2 m was recorded by leaf spring number 17. The remaining leaf springs also faced substantial deformation values, indicating their ability to absorb shocks, which in turn generates stress and strain within the leaf springs, as noted by [17]. This continuous strain could potentially lead to breakage over time as the truck persistently crosses the ramp.

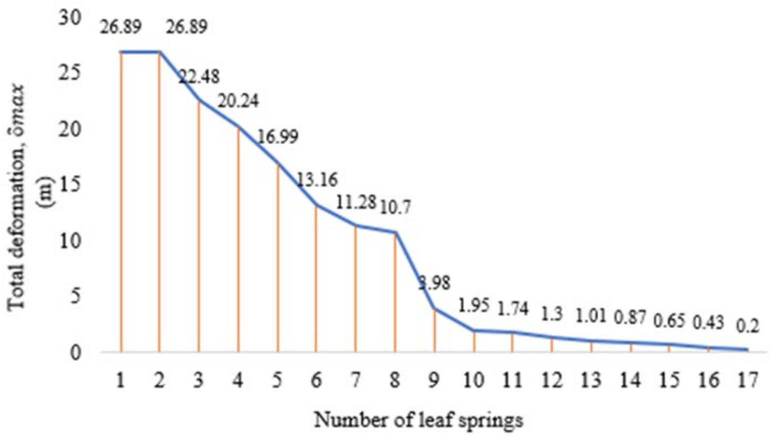

Fig. 7. Damping effects of leaf springs under a loading capacity of 122,000N on concrete speed ramp.

Figure 8 showcases the deformation records of leaf springs under a 124,000N load condition on a concrete speed ramp, revealing even greater deformation values of 27.34 m for leaf springs numbered 1 and 2, juxtaposed against the least deformation of 0.2 m observed in the shortest leaf spring (number 17). The remaining leaf springs similarly encountered significant deformation values, suggesting their capacity for shock absorption while inadvertently inducing stress and strain that may lead to breakage over time, reiterating the findings of [18] as the truck continuously navigates the ramp.

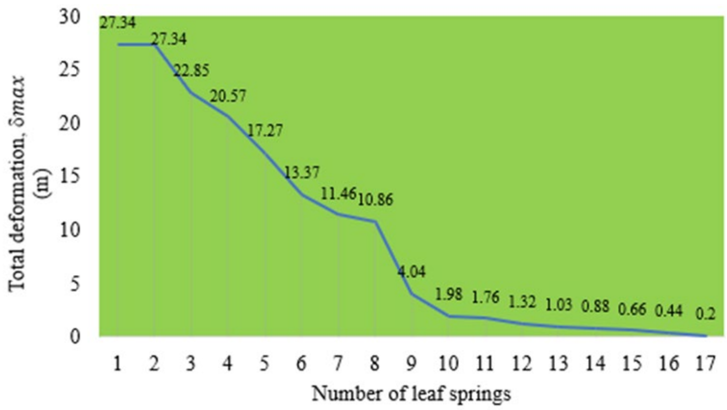

Fig. 8. Damping effects of leaf springs under 124,000 N loading condition on concrete speed ramp.

4. CONCLUSIONS

The investigation offers a comprehensive analysis of how speed ramps influence the structural dynamics of robust leaf springs with differing load capacities and ramp types. It was discovered that both the elevation and quality of construction of speed ramps, especially the clay variant, significantly affect the stress and deformation that leaf springs undergo. Extended leaf springs positioned at the top of the suspension framework endure less stress compared to their shorter counterparts positioned below. Yet, the longer springs are more vulnerable to bending stress and deformation, exacerbated by the speed ramp's elevation and the truck's load weight. The revelations reiterate that the deformation (stretching) of the leaf springs, instigated by the speed ramps, aids in softening the shocks that would otherwise jolt the truck's passengers, all the while generating internal stress and strain within the material, which may gradually diminish its longevity as the truck continues to navigate that bumpy roadway. The research indicated that increased ramp heights considerably impacted the structural integrity of leaf springs, influencing their fatigue lifespan. Repeatedly navigating over speed ramps generates substantial stress and strain, accelerating wear and potentially precipitating early failure. The results underscore the critical role of speed ramp design and construction quality in mitigating stress and enhancing the longevity of leaf springs. It is, therefore, advocated that leaf spring manufacturers enhance the thickness of the initial three layers and the final three shorter layers on the leaf springs to enable them to absorb increased shocks for an extended duration prior to failure due to recurrent cyclic motions.

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