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DESIGN AND PERFORMANCE ASSESSMENT OF VARIOUS LEAF SPRINGS

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ABSTRACT
Long, narrow plates called leaf springs are fastened to the trailer's frame and sit either above or below the axle. The suspension absorbs the loads from the chassis and the floor. When a leaf spring is loaded, it will distort; when the weight is released, it will return to its former shape. The leaf spring, an automobile component used to absorb vibrations created during vehicle motion, was selected for analysis. The performance of leaf springs of three different vehicle models are calculated by designing in CATIA V5, and then subjected to structural load in ANSYS 16.0

Keywords:
Leaf spring, CATIA V5 Software is use for design & Ansys (version 16.0) software used for Analysis

I Introduction

Leaf springs play an essential role in vehicle suspension systems, contributing to ride comfort, stability, and handling. The design of these springs entails a complicated interaction of material choice, geometry, and manufacturing methods. Historically, design strategies depended on empirical equations and experimental validation, but modern computational tools and simulation methods have enhanced the design process.

For vehicles to be safe, dependable, and operate well, leaf spring performance evaluation is essential. It entails assessing the leaf spring's resistance to a range of loads, such as lateral, longitudinal, and vertical stresses. Stiffness, strength, fatigue life, and damping properties are examples of performance measurements. Different leaf spring types, such as longitudinal, transverse, multi-leaf, and mono-leaf leaf springs, are employed in various applications. Every type has distinct design elements, benefits, and drawbacks. Road conditions, suspension travel, vehicle weight, and speed all influence the type of leaf spring that is chosen

High-performance, lightweight leaf springs have been made possible by recent developments in manufacturing processes and materials. Leaf spring behaviour is model using computational methods including computational fluid dynamics (CFD) and finite element analysis (FEA) under various loading scenarios. To assess leaf spring performance, analytical modelling and experimental testing are also utilized.

In conclusion, the design and performance assessment of leaf springs are critical aspects of vehicle development. Advanced computational tools, innovative materials, and manufacturing techniques have improved the design process, enabling the creation of high-performance leaf springs that meet the demanding requirements of modern vehicles.

Types of leaf springs:
- Semi- elliptical leaf spring
- Quarter -elliptical leaf spring
- Transverse leaf spring

- ❖ Full elliptical leaf spring
- ❖ Plat form type leaf spring

Factors influencing fatigue life:

Overloading: The higher the loads or deflections seen by a spring, the lower its fatigue life.

Shock Absorbers: When the car encounters a bump, a well-performing shock absorber tends to lessen the spring deflection. Longer fatigue life is the result of reduced operating stresses on the spring caused by smaller spring deflections. For full taper springs, which lack the strong interleaf friction necessary to reduce spring deflections, this is particularly true. To extend spring life, damaged or missing shock absorbers must be replaced.

Brake Adjustments: Improperly adjusted brakes can also reduce spring life. Under braking, springs are expected to absorb some of the braking forces. If the brakes on an axle are unevenly adjusted one spring will have to absorb more than its share of braking force which can reduce its fatigue life.

Protective Coatings: One of the main causes of the decline in spring life is corrosion. Spring corrosion can be slowed down by using the right coatings and exercising caution when handling and installing them. The only permissible treatment for complete taper springs is to apply zinc-rich paint to each leaf separately. This paint can be identified by its distinctive grey hue.

Surface Condition: The condition of the spring surface also has an effect on fatigue life. Generally, a fatigue crack will start at some sort of surface defect on the spring leaf. Therefore, care needs to be used when manufacturing and installing springs to reduce these defects to a minimum.

Shot Peening: According to extensive testing, shot peening can extend spring life by at least three times. But just shot peening the first one or two leaves in an assembly is insufficient; all leaves need to be shot peened. Every major automaker mandate that each leaf shot be peened on its original equipment manufacturer springs

Decarburization and Steel Quality: Fatigue life may be shortened by inefficient production processes. For example, improperly regulated heat treat furnaces may cause the leaf surface to be overly decarburized. The technique of decarburization gives steel a softer leaf surface once heat treatment is complete by removing carbon from the steel's surface. The incapacity of this delicate layer to tolerate the spring forces will lead to early failure. Poor steel quality may also affect spring life. If steel contains an excessive number of impurities, its fatigue life will be reduced.

Maintenance:

- Finally, improper maintenance will affect spring life.
- Spring eyes and other suspension components should be regularly greased to prevent binding.
- U-bolts should never be reused.
- Axle seats, top plates and other components should be periodically inspected and replaced as required.

Automobile leaf springs used:

- ➢ Model-1
- ➢ Model-2
- ➢ Model-3

Model-1:

The arrangement of leaf spring of Model-1. It contains 16 leaf springs is to provide comfort to the passengers by minimizing the vertical vibration caused by the non-uniformity of road geometry.

Model-1- Leaf spring

The arrangement of leaf spring attached with vehicle by using U-bolts of Model-1.U-bolts fit around the axle and secure to a metal plate that rests against the leaf springs.

Model-2:

The arrangement of leaf spring of Model-2.It contains 16 leaf springs is to provide comfort to the passengers by minimizing the vertical vibration caused by the non-uniformity of road geometry.

Model-2

The arrangement of leaf spring attached with vehicle by using U-bolts of Model-2 .U-bolts fit around the axle and secure to a metal plate that rests against the leaf springs.

Model-3

The arrangement of leaf spring of Model-3. It contains 16 leaf springs is to provide comfort to the passengers by minimizing the vertical vibration caused by the non-uniformity of road geometry

Leaf spring of Model-3

Leaf spring attached with vehicle of Model-3.U-bolts fit around the axle and secure to a metal plate that rests against the leaf springs.

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Specifications of leaf spring as show in table: 1
Maximum load capacity is consider for every vehicle 25 ton.
All dimensions in the table are in mm:

Table 1: Specifications of Leaf Spring

Specifications	MODEL-1	MODEL-2	MODEL-3
Number of leaf ‘s	16	13	16
Length of leaf	1310 mm	1300 mm	1300 mm
Width of leaf	80 mm	80 mm	80 mm
Thickness of leaf	18mm	14.5 mm	16 mm
Outer diameter of eye	70 mm	63.5 mm	70 mm
Inner diameter of eye	40 mm	35.1 mm	35 mm

Problem statement:

Over time, the production of trucks and other transportation vehicles has grown in importance since these vehicles are essential to our everyday existence and make it easier to move people and products. Manufacturing facilities must pay attention to the suspension system because trucks are subjected to a variety of loads and operating circumstances.

This paper aims to study and compare the various suspension systems of these three models

Objectives:

- Enhance load bearing capacity
- Improve Ride comfort and stability
- Increase Durability and Reliability
- Optimize fuel efficiency
- Keep the truck safe

II.. Literature

Prof . Rithesh banpurkar et.al.[1]: The main aim of this paper is to design a leaf spring with a change in composition of leaf springs. The leaf springs weight reduced upto 10% - 20%., but the capacity of load carrying was not reduced . The catia V5R20 was used to design the leaf spring. At the end of the composite leaf spring of E-Glass/epoxy given good performance by replace of steel.

Snehal s . Besekar et.al [2]: The leaf spring of different types which are used to automotive suspension system. The main thing of leaf spring is to absorb shocks and vibrations gives stable conditions. E-Glass/epoxy composition leaf spring is used to design and analysis the leaf spring. It given safe loads by restoring the vibration and shocks FEA (Finite element Analysis) is used to analysis the leaf spring. By this method the leaf spring is enless the plastic stage above 90556 N.

Chada Jithendra et al. [3] The main objective of this to analysis the leaf springs of different types of cross-section for fatigue test. A fatigue test is performed under different loads on the leaf springs (trapizoidal, rectangular and Capuslar) Catia V5 is used to design. The capuslar cross-section leaf Spring is with stand the fatigue test. Remain two cross-sectional leaf springs are gives poor performance in the test.

Sunil chintha & N. Jeevan kumar [4] The benefits of Leaf Spring over Helical spring is that the End of the spring may be leaded along a defiend path as if spring is Explored in the form of Elastic body. The spring is placed on vehicle's axle. The Complete vehicle load rests on the leaf spring. Research result from testing the leaf springs under static bonding Containing the stresses and deflection Ove placed. The present Work leaf spring is developed and static analysis is moved out by using ANSYS software and it is for the given requirements of the leaf spring.

Danish Khan et.al. [5]. Leaf Spring is the potential Component for weight reduction in order to achieve high fuel efficiency and better ride characteristics. in economic manner without Compromising the strength comfort level and performance of the vehicle has become one of the main targets of all automobile industries. The main aim of the present work is to optimize the material salivation for the Leaf Spring. The maximum load during leaf was 25kg with on load interval of 5kg started from no load conditions.

Dilkush kumar & prof Rahul shrivastava[6].The paper studies about reduction in weight to enhance fuel efficiency and conserve energy was not achieved through innovative material combinations design optimization and advanced manufacturing techniques. Parabolic leaf springs and composite leaf springs are used to develop by replace traditional steel springs, to increase higher fatigue life, several composite leaf spring material are used, carbon fiber reinforced polymer (CFRP). Was chosen to replacement for SAE 5160 steel. CFRP offers significant weight reduction. response surface methodology (RSM) and finite element analysis (FEA) makes this research highlights the potential of composite material in modern vehicle suspension system the author used CATIA software to design leaf spring and ANSY work bench software is used for analysis the leaf springs.

Dr. J Kingston barnabask et.al.[7]. In this journal the leaf spring is designed to increase leaf spring material strain energy capacity. The author is going to increase leaf spring number to increase the load capacity as well as the equal weight distribution among all leaf springs in heavy duty trucks. he used a parabolic leaf spring with varying in thickness, minimizing inter leaf friction. the author used advanced materials and specialized design and improved manufacturing process for weight reduction in leaf spring.

Dhiraj K.bhandarkar et.al. [8]. This paper discusses about the design of a non -traditional leaf springs for rear suspension in LCV. If the engine is placed in front, middle of the vehicle chassis the leaf spring need to carry the weight of engine also the author FEA to analysis the leaf spring. he designed a new leaf spring by changing the parameters, to get a better suspension system.

Salem Elsheltat & Abdul Baset Alshara [9]. This paper explains about the types of leaf springs used in vehicles for heavy transportation to low, medium transportation. The author explains about flat leaf springs vary in length and shape. these leaf springs carried out the stress analysis on entire geometry structure. the author studied current design of leaf springs, redesigned using Pro-engineer software and analysed through Ansys. He applied different loads at regular intervals at the end of the study the leaf spring author designed leaf spring gets better results compared to older design.

A. Raveendra & Mohameed Abdul Mubashir [10]. In this paper the author designed a leaf spring by cutting down a metal strip with vary in thickness. He designed a leaf spring in CATIA V6 software for designing the leaf spring. The author going to differentiate between both steel leaf spring (SLS) and composite leaf spring (CLS). In this he used different composite materials like E-glass epoxy, S-glass epoxy, carbon fibre reinforced polymer and kelvar. He compared about deformation stress and strain between SLS and CLS. For that he used (FEM) finite element method of ANSYS (version 14.5) software to analysis. at the end of research, the find that kelvar is better among all CLS.

Bandi manasa & R. Lokanandham [11] The author studies between the 55 si 7 steel and composite leafspring the author designed a semi elliptical leaf Spring Using CATIA V5R20 software increasing in radius of curvature for the main leaf than the graduated leaves. Finite Element. Analysis. (FEA) method is used analysis in Ansys (Version 12.1). The comparision take between the total deformation stress and strain by two leaf spring at different loads hybrid composite spring gives the lesser stress and deflection compared. to conventional steel leaf spring for composite leaf spring weight is reduced to 2kg. To get fuel efficiency. At the end the author concluded hybrid composite leaf spring seen better compared to steel Leaf Spring.

Mahesh Dasgaonkar [12] The author compared a conventional leaf spring and titanium alloy Leaf Spring along with composite material s. For this he generated 3 model leaf spring using Solid works 2013, The leaf springs are observed at static load conditions. To analysis the three Leaf springs finite element Analysis is used in Ansys 16.0. The author want to reduce weight in convectional leaf spring, Improve the deflection attributes of leaf spring. At static loads the Leaf springs observed the deflection, stress and strain of the end of study the 3 different leaf spring conventional steel, Titanium alloy. and composite material (s- glass fibre, ep -epoxy e-glass) shown different values of static loads.

Gorli Harsh Vardan.et.al.[13] In heavy commercial vehicles (HCVs), leaf springs are linked to distribute and balance loads across multi-axle or tandem axle suspension systems. Experimental fatigue life estimation of these suspension systems is complex, time-consuming, and costly. To address this, Finite Element Analysis (FEA) is employed to reduce testing complexity while maintaining suspension quality. This study designs and analyzes a bell crank suspension system with various geometrical parameter combinations for the rear axle to perform effective and reliable FEA simulations. The research focuses on evaluating stresses and fatigue life cycles of the suspension system, correlating the fatigue life of leaf springs and their linkages to improve overall system durability. The analysis considers vertical loading conditions, stress distribution, deflections, and load transfer to understand the suspension system's performance. The results indicate an optimal suspension model with a fatigue life ratio close to unity, signifying balanced durability between the leaf spring and its linkage. This study provides insights into optimizing leaf spring assemblies to enhance the fatigue life of HCV suspension systems, ensuring reliability and longevity while reducing the need for extensive experimental testing.

Sohail shaikh & Deepak hujare [14] This study focuses on replacing multi-leaf steel springs with mono-composite leaf springs while maintaining the same load-carrying capacity and stiffness. The suspension system plays a crucial role in passenger comfort and vehicle durability, with leaf springs supporting vertical loads and absorbing road-induced vibrations. However, their behavior is complex due to clamping effects and inter-leaf contact. Composite materials, with their superior elastic strain energy storage and strength-to-weight ratio, enable weight reduction without compromising performance. The study aims to design a mono-composite leaf spring that meets the required stress and displacement constraints. Using ANSYS software, both steel and composite leaf springs were modeled and analyzed to validate the feasibility of replacing steel with composite materials while maintaining structural integrity.

Magala.Anilkumar & T.N Charyulu [15] In this journal Using the results of the steel leaf spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS. Main consideration is given to the optimization of the spring geometry. The objective was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. The design constraints were stresses (Tsai–Wu failure criterion) and displacements. The results showed that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

Mayuri A.et.al.[16] The leaf spring, an automobile component used to absorb vibrations created during vehicle motion, was selected for analysis. When a leaf spring is loaded, it will distort; when the weight is released, it will return to its former shape. Long, thin plates called leaf springs are fastened to the trailer's frame and sit either above or below the axle. A semi-elliptical leaf spring with eight leaves is used for the operation. Depending on load capacity, the number of leaves varies. The goal of this work is to estimate the stresses and deflections using a manual calculation and compare the results with the FEA. The Leaf spring's Finite Element Analysis (FEA) model was created in CATIA V5 R17 and loaded into ANSYS 14.5. They are the most often used CAE instruments. Stresses and deflections are the design constraints. The FEA software is used to validate the strength.

Baviskar A. et.al.[17] This review paper examines the design and analysis of leaf springs, a crucial component in vehicle suspension systems. Leaf springs, subjected to numerous stress cycles, can lead to fatigue failure. The automobile industry is increasingly interested in replacing steel springs with composite leaf springs, with fiberglass being found to be more durable and lightweight. The paper also discusses failure analysis and the use of computer simulation for design verification.

G. Harinath gowd & E. Venu Gopal gowd [18] Leaf springs are unique suspension systems used in automobiles, serving to support vertical load and isolate road-induced vibrations. They undergo millions of load cycles, leading to fatigue failure. This study analyzes the safe stress and pay load of a typical leaf spring configuration of a TATA-407 light commercial vehicle, using finite element analysis to determine safe stresses and pay loads.

Rohit ghosh.et.al.[19] This study aims to estimate bending stresses in semi-elliptical steel multi-leaf springs, focusing on graduated-length and full-length leaves. The research validates the cantilever beam concept in theoretical analysis. Advancements in material materials like E-glass/epoxy and carbon/epoxy have improved weight reduction and load carrying capacity. The study proposes a new idea for multi-leaf spring construction based on practical applications and cost analysis. The multi-leaf spring was modeled and analyzed using ANSYS software.

Godatha Joshua Jacob & Mr. M Deepak [20] Leaf springs are long, narrow plates attached to trailer frames, used for suspension in wheeled vehicles. They come in mono leaf and multi leaf versions, with mono leaf springs being thicker and tapering out towards the end. The project aims to design and model leaf springs for different loads, using forged steel and Mild Steel and Glass Carbon composite materials. Strength variations will be tested using FEA Structural Analysis and Modal and Fatigue Analysis. Pro/Engineer software will be used for modeling and ANSYS for analysis.

Dr. Satish.et.al. [21] This study analyzes the static and dynamic performance of steel 55Si2Mn90 parabolic leaf springs and composite leaf springs made of E-Glass, Carbon, and Kevlar fibers. With a focus on reducing vehicle weight and improving ride quality, the study compares load-carrying capacity, stiffness, and weight reduction. Composite materials, due to their high strength-to-weight ratio and corrosion resistance, offer a lighter alternative to steel while maintaining or enhancing performance. The research highlights that composite leaf springs provide superior ride quality and weight savings compared to traditional steel springs under the same design criteria.

Ajahar Sayyad.et.al. [22] This study compares the stresses, deformations, and weight reduction of composite leaf springs with conventional steel leaf springs, with stiffness as the design constraint. Composite materials like E-glass/epoxy, epoxy carbon, aluminum alloy, and titanium alloy are analyzed for their high strength-to-weight ratio and corrosion resistance. The leaf springs were modeled in CATIA and analyzed in ANSYS to evaluate stress, deformation, elastic strain, and weight savings. The findings support the automobile industry's interest in replacing steel leaf springs with composite alternatives for improved performance and reduced weight.

Sushanta Ghuku & Kashi Nathasha [23] This study focuses on the design and performance analysis of two different leaf spring testing rigs to address deficiencies in experimental modeling. Leaf springs, commonly used in vehicle suspension, fail mainly due to excessive bending under load. The first test setup models the leaf spring as a curved cantilever beam with a tip load, but it has limitations like unknown clamping force and improper support modeling. To improve accuracy, a second setup simulates a three-point bending test, incorporating roller supports and asymmetry in the master leaf geometry. Deflection profiles are obtained using image processing, and strain measurement is conducted using strain gauges.

Priyanka Kothari & Amit Patel [24] This paper reviews research on the design, analysis, and fabrication of composite leaf springs, highlighting the shift from steel to composite materials, especially fiberglass, due to their superior strength and lower weight. Leaf springs play a crucial role in vehicle suspension, affecting ride comfort and stability but are prone to fatigue failure. Various studies have explored alternative materials to enhance performance. The review summarizes findings on material selection and its impact on leaf spring efficiency in commercial vehicles.

Syambabu Nutalapati [25] This study focuses on the design and analysis of a composite leaf spring for the Mahindra Commander 650 DI, aiming to reduce weight while maintaining strength. E-glass/epoxy composite material is compared with conventional steel, with stiffness as the design constraint. The analysis, conducted in Pro/ENGINEER and ANSYS 12.0, shows an 85% weight reduction in the composite leaf spring. Fatigue life comparison of steel and composite springs further supports the advantages of composite materials for automotive applications.

III . DESIGN

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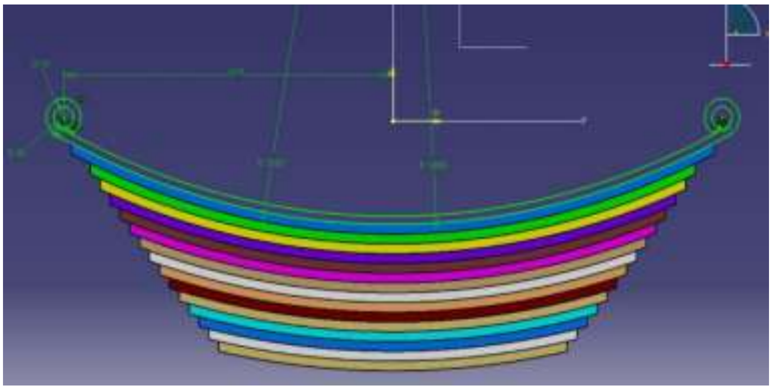
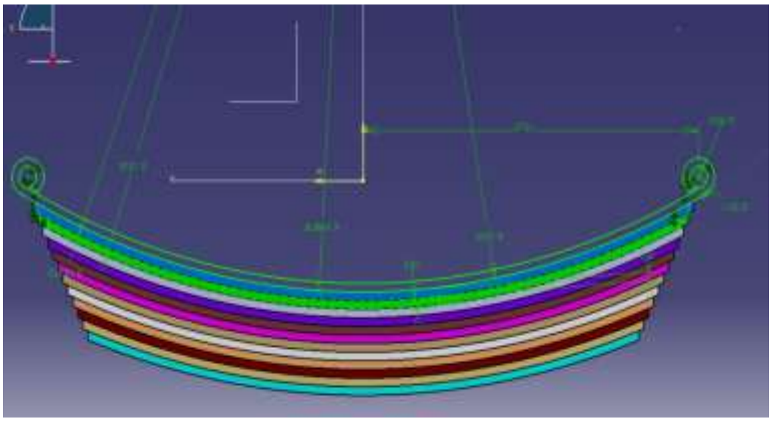
CATIA V5:

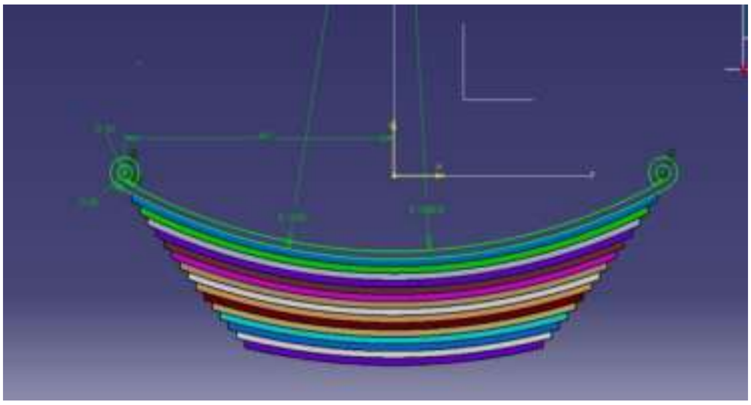
CATIA (Computer-Aided Three-Dimensional Interactive Application) is more than just CAD software; it's a comprehensive CAD and 3D Product Lifecycle Management suite. Developed by Dassault Aviation in 1977 for 3D modelling and NC functions, it was later renamed CATIA in 1981 under Dassault Systems. It supports product development from design to manufacturing across multiple disciplines, including mechanical and systems engineering. Widely used in aerospace, automotive, and architecture, CATIA has powered projects like Boeing aircraft and Frank Gehry's architectural designs. Evolving over decades, it became cloud-based with Dassault's 3D EXPERIENCE Platform in 2014, enhancing collaborative engineering and digital design.



Model-1 Suspension system design in CATIA V5



Model -2 Suspension System Design in CATIA V5



Model-3 Suspension system design In CATIA V5

IV.ANLYSIS

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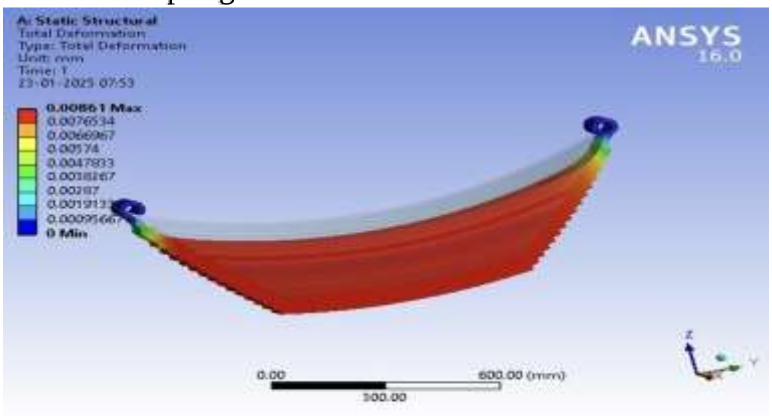
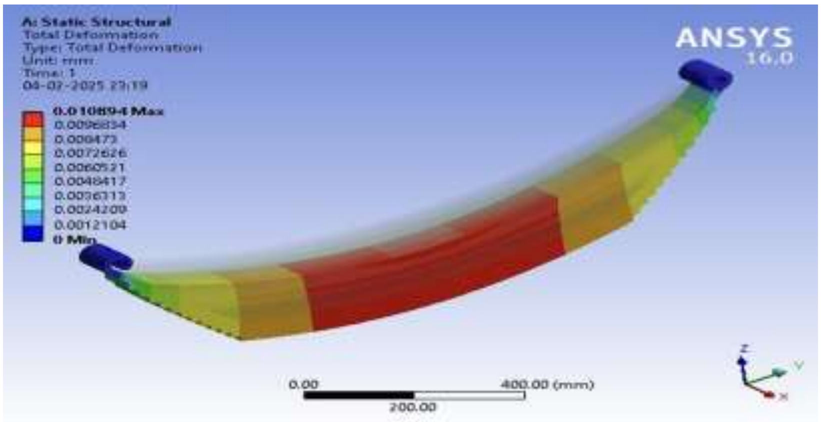
ANSYS:

The first step in ANSYS analysis is setting up the job, which takes the most time. This includes defining the job name, analysis title, element type, real constants, material properties, and model geometry using the PREP7 pre-processor. The job name identifies the ANSYS job and is used as a prefix for all generated files. The analysis title is set via **Utility Menu > File > Change Title** and appears in graphics and solution outputs. ANSYS does not assume units, so consistency is crucial. The element type, selected from ANSYS's extensive library, defines degrees of freedom and dimensionality via **Main Menu > Pre-processor > Element Type > Add/Edit/Delete**.

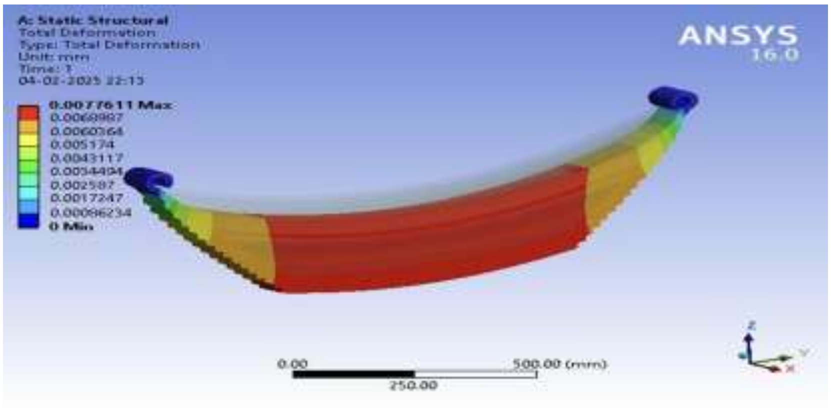
Total Deformation of three leaf springs:



Total deformation of Model-1



Total deformation of Model-2



Total deformation of Model-3

Equivalent stress of three leaf springs:

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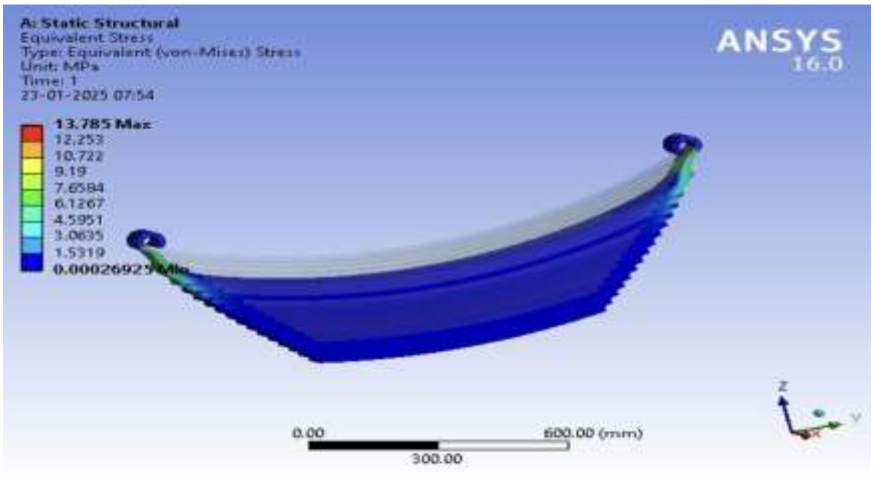
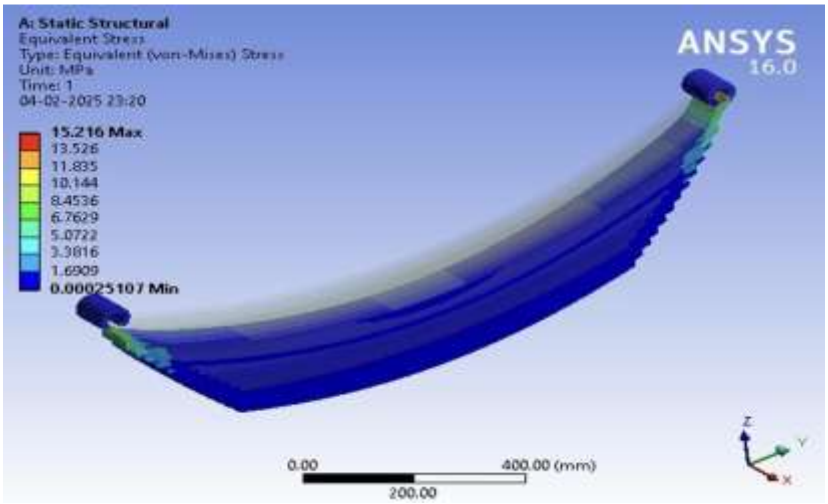
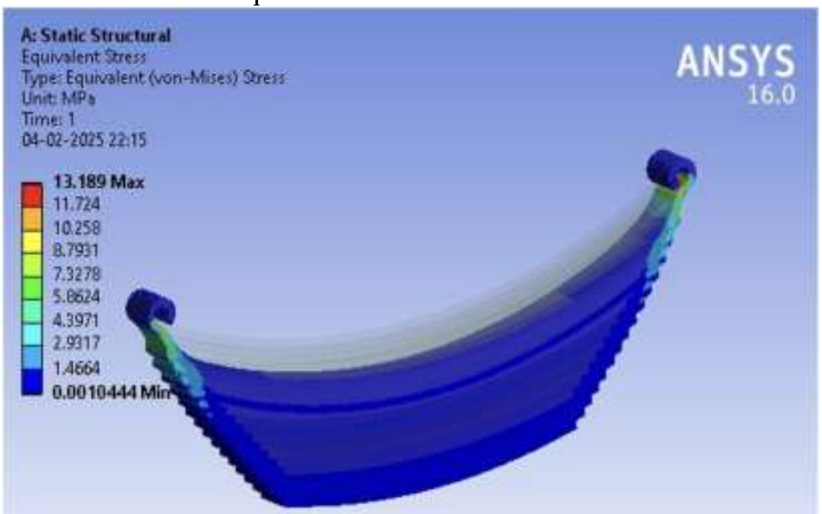


Equivalent stress of Model-1



Equivalent stress of Model-2



Equivalent stress of Model-3

Shear stress of three leaf springs:

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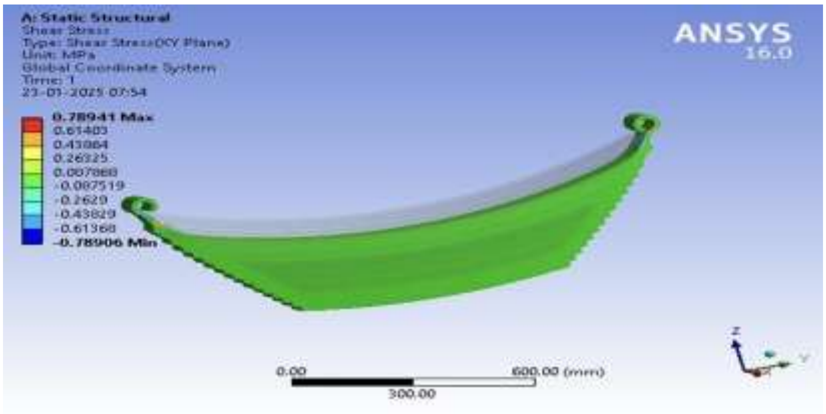
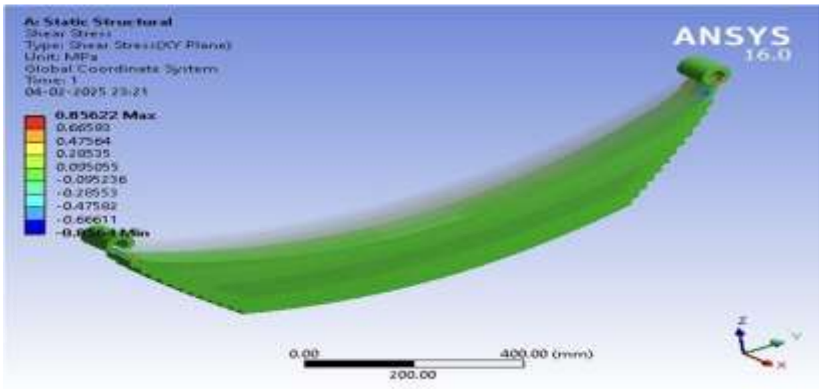
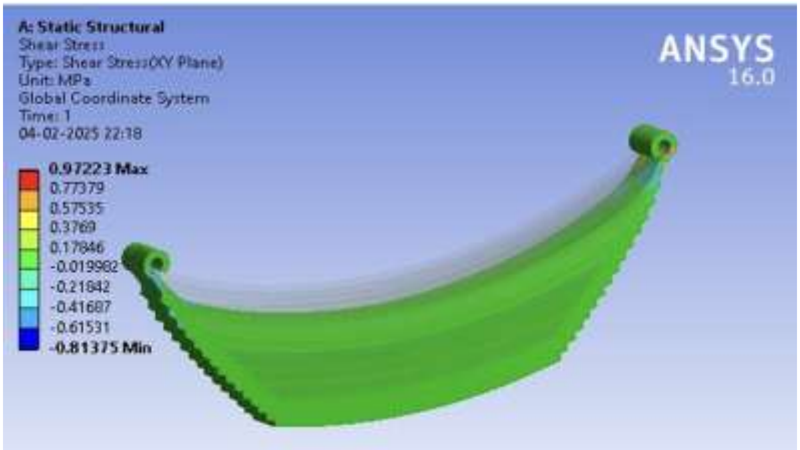


Shear stress of Model-1



Shear stress of Model-2



Shear stress of Model-3

V. RESULTS

TOTAL DEFORMATION AT THREE LOADS

The following Table are the deformation values (are in mm) at three loads:

LOAD(N)	MODEL-1	MODEL-2	MODEL-3
12000	0.0086	0.0108	0.0077
18725	0.013	0.016	0.012
25000	0.017	0.022	0.016

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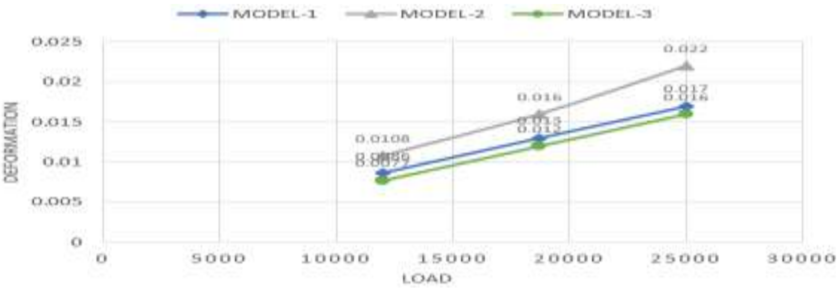
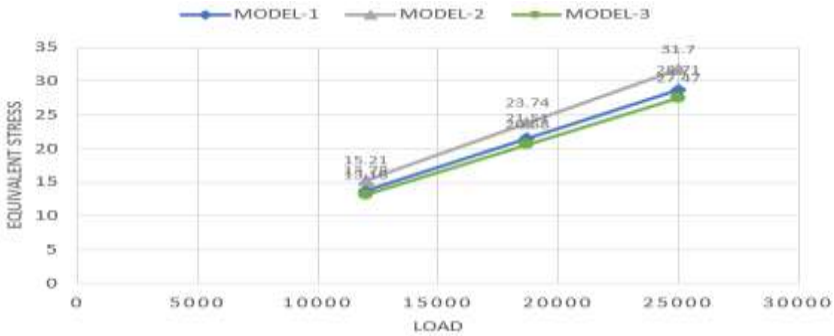


The graph shows total deformation of 3 models at three loads

EQUIVALENT STRESS AT THREE LOADS

The following Table shows the Equivalent stress values (are in N/mm^2) at three loads:

LOAD(N)	MODEL-1	MODEL-2	MODEL-3
12000	13.78	15.21	13.18
18725	21.51	23.74	20.58
25000	28.71	31.7	27.47

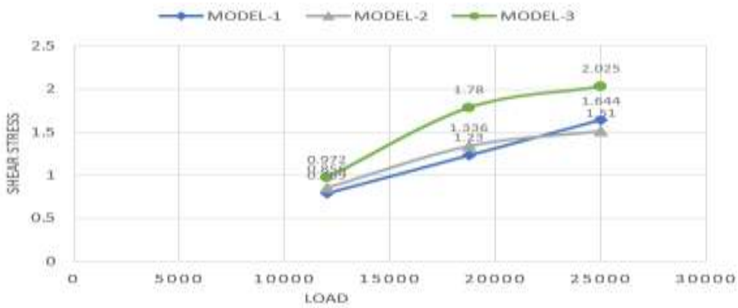


The graph shows Equivalent stress of 3 models at three loads

SHEAR STRESS AT THREE LOADS:

The following Table shows the shear stress values (are in N/mm^2) at three loads:

LOAD(N)	MODEL-1	MODEL-2	MODEL-3
12000	0.789	0.856	0.972
18725	1.23	1.336	1.78
25000	1.51	1.644	2.0255



The graph shows shear stress of 3 models at three loads

VI. DISCUSSIONS

The performance comparison of the Model-3 with the Model-1 and Model-2 under varying loads (12,000N, 18,725N, and 25,000N) highlights its structural superiority. Deflection, a key indicator of frame rigidity, is lowest in the Model-3, ensuring better load-bearing capacity, stability, and reduced structural deformation. Additionally, its equivalent stress is lower, indicating a more efficient stress distribution across the frame and chassis, reducing the risk of fatigue failure. The truck also exhibits lower shear stress values, enhancing its resistance to torsional forces, particularly in rough terrains and uneven loading conditions. These factors contribute to its durability and reliability in demanding applications. With superior frame strength, minimal stress concentration, and enhanced structural efficiency, the Model-3 stands out as the best choice among the three, offering longevity, stability, and safety for heavy-duty operations

VII.CONCLUSIONS

The Model-3 outperforms the Model-1 and Model-2 in structural strength under different loads. It has lower deflection, ensuring better rigidity and stability. Its lower equivalent stress allows it to handle higher loads with minimal deformation, and reduced shear stress improves load distribution and durability. Overall, it is the most reliable choice for heavy-duty applications, offering longer service life, lower maintenance costs, and better operational efficiency in demanding conditions

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