Truck Chassis Analysis using Finite Element Method for Steel and Carbon Fiber Components

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Abstract – *The foundation of any vehicle, referred to as its frame or chassis, plays a pivotal role in the automotive industry. Much like the skeletal system of a living organism, it serves as a sturdy structure that holds together all major components. Its primary objective is to provide secure support, ensuring the vehicle can bear the maximum load across diverse operating conditions. The chassis must possess ample strength to withstand both heavy loads and sudden shocks. Being the central component of an automobile, the chassis acts as a framework to uphold the vehicle body. Therefore, it must exhibit exceptional rigidity and robustness to endure the dynamic forces, vibrations, and stresses encountered during vehicle motion.*

Traditionally, steel has been the predominant material used in chassis manufacturing, gradually giving way to aluminum over time. However, this study delves into the exploration of replacing conventional materials with ultra-lightweight carbon fiber composites. The extraordinary strength and lightweight nature of carbon fibers render them highly suitable for producing automotive chassis. The study specifically focuses on conducting modal and static structural analyses of the Tata LPT 3118 truck chassis frame, comparing the performance of both steel and carbon fiber materials. The analysis encompasses a comprehensive evaluation of stress, strain, and total deformation values for each material. Employing the finite element method, the chassis is modified using SOLIDWORKS 2016, followed by Finite Element Analysis and Modal Analysis performed on a dedicated workbench.

Key Words: FEM, Composite material

1. Introduction

The essence of an automobile lies in its two vital elements: the Body and the Chassis. The chassis, specifically, pertains to the vehicle's structure in the absence of the body. It serves as the bedrock upon which an assortment of chassis units find their place, connecting to the axles through springs and other components that transfer or absorb the axle's force and rotational power. In the formative years of the automotive industry, chassis frames came into being using a medley of materials, including tubular steel, rolled steel sections, wood, and fortified wooden sills featuring steel flitch plates.

The chassis assumes the role of the fundamental framework in a commercial vehicle. In the days preceding the 1930s, nearly all motorized vehicles boasted a distinct structural frame, known as the body-on-frame design, which stood apart from the vehicle's body itself. In subsequent years, the majority of passenger cars transitioned to a monobody construction, seamlessly integrating the chassis and bodywork. However, trucks, buses, and pickups have continued to embrace a separate frame as their dedicated chassis. This chassis frame provides support to an array of vehicle components, encompassing the engine, transmission system (consisting of the clutch, gearbox, propeller shaft, and rear axle), wheels and tires, suspension system, as well as control mechanisms such as braking, steering, and electrical components. Therefore, it is often referred to as the "carrying unit." The principal functionalities fulfilled by a frame in motor vehicles are as follows:

Providing support for the vehicle's mechanical components and body.

Shaping the vehicle body.

Dealing with static and dynamic load conditions without excessive deflection or distortion. These loads include:

Weight of the body, passengers, and cargo.

Vertical and torsional forces transmitted while traveling on uneven surfaces.

Transverse lateral forces resulting from road conditions, side winds, and steering.

Torque from the engine and transmission.

Longitudinal tensile forces during acceleration and compression during braking and collisions.

The automotive chassis, a crucial element, bestows strength and stability upon a vehicle across diverse conditions. Serving as the sturdy framework that unites the engine, body, axles, powertrain, and suspension system, it relies on tie bars as connectors for all automobile components. Among the oldest chassis designs, the ladder chassis reigns supreme with its exceptional load-carrying capacity. SUVs and heavy commercial vehicles commonly embrace ladder chassis due to their ability to bear substantial loads, delivering commendable driving dynamics and ride comfort. Consequently, ladder chassis enjoy widespread preference over unibody and backbone frames.

The ladder chassis frame exhibits longitudinal side bars interconnected by cross members. Additional brackets lend support to the body, while the dumb iron assumes the role of a bearing for spring shackles. The fusion of chassis components is achieved through riveted joints, weld joints, or bolts. Notably, the ladder frame adopts an upsweep at both the front and rear, accommodating the springing action of the suspension system. To enhance steering lock, the frame narrows at the front. Frame construction employs diverse cross sections, such as channel, box, hat, double channel, and I-section, offering versatility and adaptability

The automobile chassis serves as the foundation of the vehicle, encompassing essential elements such as tires, engine, frame, driveline, and suspension. Within this assemblage, the frame plays a pivotal role in providing crucial support. It must possess ample strength to endure shocks, torsion, vibrations, and other forms of stress. The chassis frame consists of interconnected side members and cross members. To detect vulnerable areas prone to fatigue failure, stress analysis utilizing Finite Element Method (FEM) can be employed. By assessing the stress magnitude, it becomes possible to predict the lifespan of the truck chassis, with the accuracy of this prediction relying on stress analysis outcomes.

Conducting stress analysis on the chassis helps identify critical points exhibiting elevated stress levels [3]. These critical points are vital components that can trigger fatigue failure in the chassis frame. Consequently, the longevity of the fire truck chassis is heavily contingent upon the magnitude of stress it endures. In this study, both modal and static structural analyses are conducted on the ladder chassis. Modal analysis involves determining natural frequency and mode shape.

To effectively manage the vibrations generated by the engine, suspension, and driveline, the chassis must possess rigidity and strength. Steel and aluminum have long been used as conventional materials for chassis construction. However, carbon fibers offer numerous advantages over these traditional options. Carbon fibers exhibit superior strength and stiffness while remaining lightweight. Furthermore, they can be easily molded into various shapes. The utilization of a lightweight chassis reduces the vehicle's fuel consumption, thereby enhancing fuel efficiency. Consequently, manufacturers favor ultra-lightweight carbon fiber chassis to bolster the strength and stability of vehicles.

The emergence of computer aided design and computer aided engineering has been primarily driven by advancements in computer technology, making powerful tools more affordable and accessible. These tools offer predictive capabilities and valuable insights into complex engineering processes. Consequently, engineers across various disciplines now require numerical solution tools to investigate problems that were previously only solvable through experiments. In many instances, the modeling of engineering problems leads to ordinary and partial differential equations, often of a nonlinear nature. Over the past 50 years, the finite element method has emerged as a powerful solution tool for addressing these differential equations. Roslan Abd Rahman and his colleagues (2008) delved into the stress analysis of a robust chassis used in heavy-duty trucks. Stress analysis plays a vital role in fatigue studies and predicting the lifespan of components by identifying critical points with the highest stress levels. In their analysis, they focused on a specific truck model and utilized the ABAQUS software, a commercial finite element package. The dimensions of the model were 12.35 meters in length and 2.45 meters in width. The chassis material employed was ASTM Low Alloy Steel A 710 C (Class 3) with a yield strength of 552 MPa and a tensile strength of 620 MPa. Their findings revealed that the critical point of stress was located at the chassis opening where it came into contact with the bolt. The stress magnitude at this critical point reached 386.9 MPa. This critical point indicated an initial stage of potential failure, as fatigue failures tend to initiate from areas experiencing the highest stress.

Romulo Rossi Pinto Filho [30] presented a relevant case study that focused on optimizing the design of off-road vehicle frames. The primary objective of this research was to achieve an optimized chassis design with appropriate dynamic and structural behavior. The study consisted of three main steps. Firstly, a software based on the finite element method (FEM) was used to model the chassis of a commercial off-road vehicle. Secondly, a series of tests were conducted to collect data for modeling and validation purposes. Finally, with the validated model, the researchers performed structural optimization to improve torsion stiffness while maintaining the overall mass of the structure. Another notable case study, led by Wesly Linton at Cranfield University (34), focused exclusively on a chassis provided by Luego Sports Cars Ltd. The initial assessment of the chassis revealed a torsion value of approximately 1330 Nm/deg and a mass of 120.1 kg. To bolster the torsion stiffness, the research team implemented a series of adjustments and enhancements. These included the strategic incorporation of additional cross bar structures and the utilization of advanced structural materials. As a result, the overall torsion stiffness experienced a staggering increase, reaching an impressive 337% of its initial value. These modifications yielded substantial improvements to the overall chassis structure, leading to enhanced performance in terms of ride quality, vibration reduction, and more.

Therefore, based on the literature survey, in this study, Modal Analysis and Finite Element analyses were used to study and understand the characteristics of a truck chassis (truck TATA LPT 3118). The analysis results were combined to create a virtual model using Finite Element Method (FEM) tools, which was then refined through a correlation process. Further analyses were conducted to identify the most suitable material for the truck chassis design. To facilitate the study, the truck chassis was modeled using SolidWorks software while maintaining the original dimensions of the structure. The model was then imported into ANSYS Simulation software to determine the natural frequencies and mode shapes. For accurate representation of the solid chassis, 10 node-tetrahedral elements were selected for the meshing analysis. The next step involved conducting Experimental Modal Analysis on the actual truck chassis structure to obtain the natural frequencies, mode shapes, and damping ratio. The analyses were performed on the ANSYS simulation bench to ensure the quality of the results. The findings from the finite element analysis and experimental modal analyses were then compared to identify the most suitable material for the truck chassis.

A correlation analysis was conducted to assess the agreement between the finite element analysis and the model testing. The experimental data served as a reference for the model updating analysis. Based on the overall results, appropriate material selection was carried out to enhance the strength of the truck TATA LPT 3118 chassis. The subsequent section provides a detailed description of the steps required for each method employed to establish a valid representative FE model.

2. Numerical details

Detailed procedure of numerical simulation is discussed in this section.

2.1 Identification of problem

The fundamental structure of the truck is its chassis frame, which plays a vital role in securely carrying heavy loads in various operational situations. Its main function is to absorb the torque generated by the engine and axles, while enduring the impact of challenging road conditions when the vehicle is in motion.

For this specific project, the truck's chassis falls under the category of a ladder frame type. A typical ladder frame chassis for commercial vehicles is illustrated in Figure 7. Structurally, a ladder frame can be compared to a series of interconnected grillages. The side members of the frame act as a barrier against shear forces and bending loads, while the cross members provide torsional rigidity. Light commercial vehicle chassis commonly feature sturdy box section steel frames, which offer both vertical and lateral strength, as well as resistance to torsional stress.

The use of a ladder frame chassis offers both advantages and disadvantages. One notable advantage is the ease of mounting and dismounting the body structure. A wide range of body types, such as flat platforms, box vans, tankers, and detachable containers, can be easily adapted to a standard ladder frame chassis. Moreover, the design of rubber chassis effectively isolates the noise generated by the drive train components from the passenger compartment. This design approach not only proves relatively inexpensive but also simplifies the manufacturing process compared to other chassis types.

However, ladder frames do come with some drawbacks. Torsional rigidity is a notable concern for ladder frames due to their two-dimensional structure. They exhibit lower torsional rigidity compared to other chassis types, particularly when subjected to vertical loads or bumps. Additionally, ladder chassis designs tend to be heavier than alternative chassis designs. Another drawback is the suboptimal condition of the chassis structure being analyzed in this case. Corrosion in several parts of the chassis could impact its strength, especially in the welding areas, which may affect the analysis results. The table provides the specifications of the materials used for analyzing the truck chassis.

Table 1: *Specification of TATA LPT 3118 truck*

Truck Model Used	Tata LPT 3118
Suspension Type	Parabolic leaf Spring @ Front & Rear
No. of Gears	G750, 6F-Synchromesh, 1R- Constant mesh
Max Engine Output	177 HP@2500 rpm
Max Engine Torque	700 Nm@1300-1800 rpm
Kerb Weight	10000 Kg
Max Speed	80 km/hr
Overall Length (chassis)	9.0 m
Overall Width (chassis)	1.125/.860 m
Wheel Base	5.20 m
Front Overhang	1.50 m
Rear Overhang	2.30 m

Table 2: *Properties of material*

Material Properties	Steel	Carbon Fiber
Density (kg/m3)	7850.00	1570.00
Young's Modulus (MPa)	200.00	190000.00
Poisson's Ratio	0.30	0.25
Yield Stress (MPa)	250.00	220.00

2.2 Solid Modeling

The Fem technique is employed to conduct static structural analysis on the chassis of a truck using ANSYS simulation software. Initially, a three-dimensional model of the truck chassis is created using SOLIDWORKS 3D modeling software. Subsequently, the frame model is imported into the Solidwork Simulation Workbench to facilitate the analysis process.

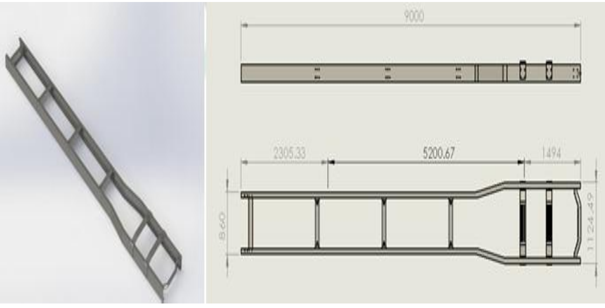

Figure 1: *Solid model of chassis modelled in SOLIDWORKS*

2.3 MESHING OF CHASSIS FRAME

The model undergoes meshing, employing a total of 76,399 nodes and 40,378 Tetrahedral elements. To enhance the accuracy of the outcome, a more refined meshing technique is employed specifically in the area believed to experience the greatest stress.

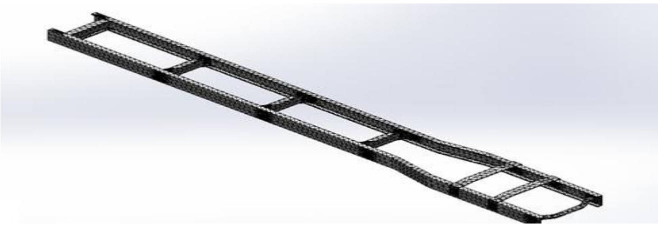

Figure 2: *Meshing of truck chassis model*

2.4 MATERIAL PROPERTIES

Table 3: *Properties of material applied during analysis*

Material Properties	Steel	Carbon Fiber
Density (kg/m3)	7850.00	1570.00
Young's Modulus (MPa)	200.00	190000.00
Poisson's Ratio	0.30	0.25
Yield Stress (MPa)	250.00	220.00

2.5 Loading and boundary conditions

The role of the load application is of utmost importance when conducting component analysis. One encounters various load types, including the Uniformly Distributed Load (UDL), Uniformly Varying Load, and Point Load. The current framework incorporates the UDL spanning its entire length. The truck chassis model experiences static forces exerted by the truck body and cargo, thereby applying pressure.

Let's delve into the specifics of the truck's capacity. The truck has a maximum capacity of 8 tons, which can be translated to 8000 kg or 78,480 N. Taking into account a 1.25% increment, the truck capacity becomes 98,100 N. Additionally, the weight of the body and engine amounts to 2 tons, equivalent to 2000 kg or 19,620 N.

Consequently, the total load acting on the chassis comprises the sum of 10,000 kg and 2000 kg, or 98,100 N and 19,620 N, respectively, totaling 117,720 N. As the chassis consists of two beams, each beam bears half the load imposed on the chassis. Therefore, the load on a single beam can be calculated as 117,720 N divided by 2, resulting in 58,860 N per beam.

In this analysis, static forces are employed as the loads on the chassis model. We assume that the maximum weight of the loaded truck and body is 10 tonnes. Moreover, we consider the load to be uniformly distributed across the chassis model. Consequently, a net force of 117,720 N is applied to the upper side of the chassis frame. Both side bars equally withstand this net load, with each side bar carrying a load of 58,860 N. The connection type employed in this analysis involves rivets, which join the cross bars, side bars, and brackets.

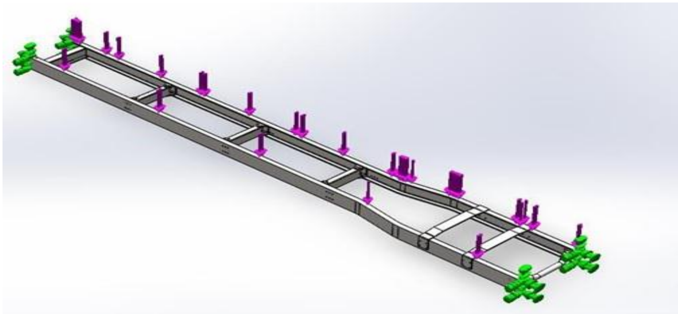

Figure 3: *Loading and boundary condition*

2.6 PROCEDURE

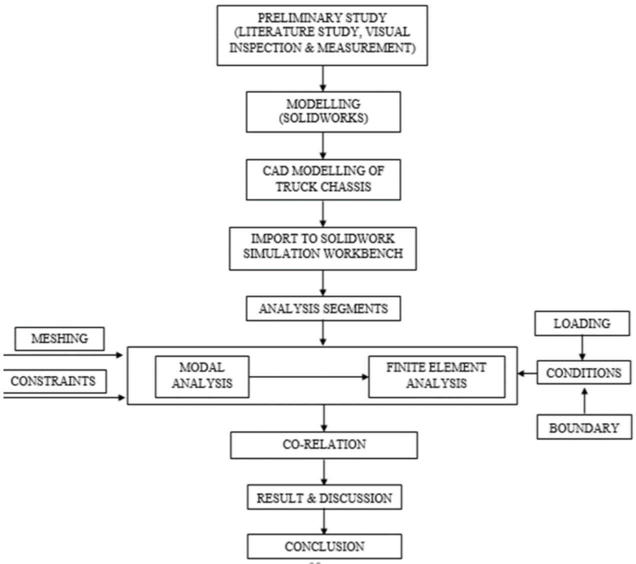

Figure 4: *Schematic of flow chart explaining procedure of simulation*

3. Result and discussion

Mode shapes refer to the varying shapes of a structure at different natural frequencies. These mode shapes are determined by utilizing the Eigen values derived from vibration equations.

Modal analysis holds significant importance as a fundamental aspect of dynamic character analysis. This contemporary approach allows for the identification of natural frequencies and mode shapes of structures. By analyzing rigidity, the occurrence of resonance vibrations can be mitigated. Through modal analysis, one can discern the distinctive characteristics exhibited by each mode of the structure, while also predicting the actual vibration response within the frequency range. The insights gained from modal analysis serve as valuable reference points for other dynamic analyses, such as random analysis and harmonic analysis. In the specific context of this study, a 3D finite element analysis is conducted on the modal analysis of the chassis frame, utilizing the ANSYS SIMULATION WORKBENCH software.

In the modal analysis of the frame, only fixed support boundary conditions are applied, thereby eliminating the need for other conditions like loading and gravitational acceleration. Consequently, the modal analysis is performed on a structural steel frame, yielding the following mode shape.

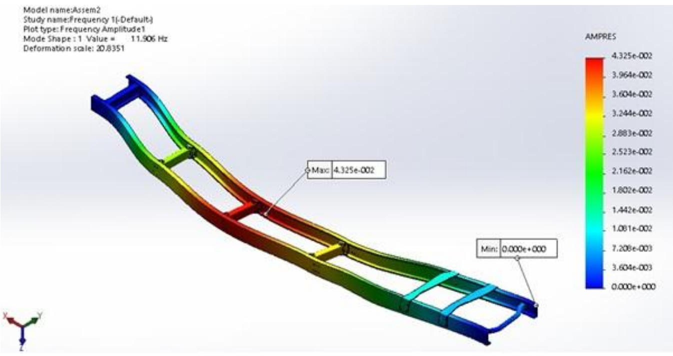

Figure 5: *Modal analysis of the chassis with material as structural steel*

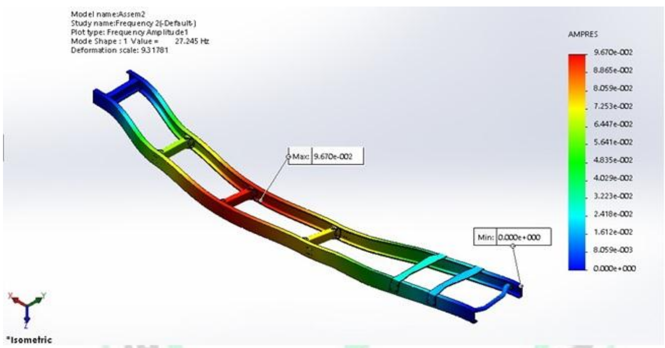

Figure 6: *Modal analysis of the chassis with material as carbon fiber*

Table -4: P*ercentage increase in the frequency*

DEFORMATION	STEEL	CARBON Fiber	% INCREASE
1	11.906	27.245	128.83
2	17.901	40.973	128.88
3	22.396	51.244	128.80
4	24.996	57.457	129.86
5	36.605	83.69	128.62

Table-5: Analyzed static structural results

PARAMETER	STEEL	CARBON FIBER
EQUIVALENT STRESS (MPa)	207.10	207.10
EQUIVALENT STRAIN	0.0007119	0.0006325
TOTAL DEFORMATION (m)	0.009567	0.009134

3. CONCLUSIONS

The ladder chassis of the Tata LPT 3118 truck underwent modal analysis and static structural analysis. The results revealed that when comparing steel and carbon fibers, the von equivalent stress for carbon fibers increased while the total deformation decreased. This indicates that the stress values of carbon fibers remain within acceptable limits. Consequently, carbon fiber emerges as an ideal material for vehicle chassis due to its remarkable strength and lightweight nature. In fact, when considering the same load carrying capacity, carbon fibers are preferable over steel for constructing ladder frames. This is because the carbon fiber frame weighs significantly less (54.28 kg) compared to the steel frame (170.45 kg), resulting in a weight reduction of 60-68% while simultaneously enhancing the stiffness of the chassis frame. However, it's important to note that carbon fiber materials are relatively more expensive than steel from an economic standpoint.

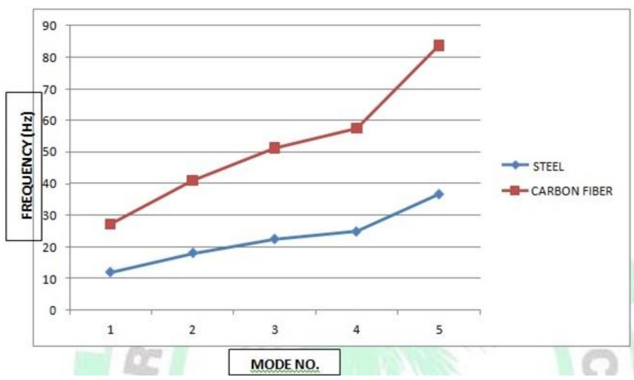

Figure 7: *Frequency v/s mode no. comparison of steel and carbon fiber*

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