Review Paper on Dynamic Load Behavior of Truck Chassis

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Abstract

The dynamic load behavior of truck chassis plays a crucial role in determining vehicle durability, structural integrity, ride comfort, and overall safety under real-world operating conditions. This review paper provides a comprehensive analysis of the types of dynamic loads acting on truck chassis—including vertical, lateral, longitudinal, torsional, and impact loads—and examines the key parameters influencing these forces. Material considerations such as high-strength low-alloy steels, aluminum alloys, and composite–metal hybrid structures are discussed with emphasis on their fatigue behavior under cyclic loading. Various analytical approaches, including Finite Element Analysis (FEA), Multi-Body Dynamics (MBD) simulation, and experimental methods such as strain gauging and road load data acquisition, are critically evaluated. Existing research emphasizes the dominance of dynamic loads over static loads, the significance of welded joint fatigue, and the importance of co-simulation frameworks for accurate stress prediction. Despite considerable advancements, notable research gaps persist in areas such as modular chassis systems, electric truck load dynamics, AI-based predictive fatigue modeling, and digital twin integration. This review highlights the need for advanced computational tools and real-time data-driven strategies to develop smart, adaptive chassis systems for the next generation of heavy-duty vehicles.

Keywords: Dynamic Loads, Truck Chassis, Finite Element Analysis (FEA), Multi-Body Dynamics (MBD), Fatigue Analysis, Structural Integrity, Road Load Data Acquisition (RLDA), Torsional Stiffness, Composite Materials, Digital Twin Technology.

1. Introduction

The truck chassis is the primary load-bearing framework that supports the engine, transmission, suspension, cargo, and body components. As trucks operate under highly variable and often extreme loading conditions—such as braking, acceleration, uneven road profiles, dynamic impact loads, and torsional twisting—the chassis is subjected to a complex combination of bending, torsion, fatigue, and vibrational stresses. Understanding the dynamic load behavior of the chassis is essential for improving structural reliability, ride comfort, payload capacity, and safety [1].

Dynamic loading on a truck chassis is influenced by factors such as road irregularities, vehicle speed, suspension characteristics, payload distribution, and structural rigidity. Recent advancements in computational methods (FEA, MBD, and CFD-coupled simulations), material engineering, and experimental modal analysis have enhanced the understanding of dynamic responses in commercial vehicles [3].

Automobile chassis usually refers to the lower part of the vehicle including the tires, engine, frame, driveline and suspension. Out of these, the frame gives necessary support to the vehicle components placed on it. Also the frame should be so strong to resist impact load, twist, vibrations and other bending stresses. The chassis frame consists of side rails attached with a number of cross members. Along with the strength, an important consideration in the chassis design is to increase the bending stiffness and torsion stiffness. Proper torsional stiffness is required to have good handling characteristics. Commonly the chassis are designed on the basis of strength and stiffness. In the conventional design procedure, the design is based on the strength and is then focused to increase the stiffness of the chassis, with very small consideration to the weight of the chassis. This design procedure involves the adding of structural cross member to the existing chassis to improve its torsional stiffness. As a result, weight of the chassis increases. This increase in weight of the chassis fuel efficiency is reduced and increases the overall cost due to extra material. The design of the chassis with proper stiffness and strength is necessary. The design of a vehicle structure is of fundamental importance to the overall vehicle performance [4].

vehicle structure plays an important role in the reliability of the vehicle. Generally, truck is a heavy motor vehicle which is designed for carrying the attached weights, such as the engine, transmission and suspension as well as the passengers and payload. The major focus in the truck manufacturing industries is to design vehicles with more payload capacity. Using high strength steels than the conventional ones are possible with corresponding increase in payload capacity. The chassis of truck which is the main part of the vehicle that combines the main truck component systems such as the axles, suspension, power train, cab and trailer etc.

Automotive designers need to have complete understanding of various stresses prevalent in different areas of the chassis component [5].

During the conceptual design stage,when changes to the design is easy to implement and have less impact on overall project cost, the weight and structural characteristics are mostly unknown since detailed and overall vehicle information is not available at the early stage. The vehicle design starts up with conceptual studies to define size, number and location of undriven and drive axles, type of suspension, engine power, transmission, tire size and axle reduction ratio, cab size and auxiliary equipment. The selected configuration has to be more precise and accurate for the considered transportation tasks and should match the existing production line. In general, there are two approaches to analyze truck chassis: one is stress analysis to predict the weak points and the other is fatigue analysis to predict life cycle of the frame. This overview selectively and briefly discusses some of the recent and current developments of the stress analysis of truck chassis. A number of analytical, numerical and experimental methods are kept in mind for the stress analysis of the heavy duty truck frames. Conclusion of the stress analysis in the vehicle chassis has been reported in literature. Finally, the scope of future work has been discussed after concluding on the obtained results [6].

2. Fundamentals of Dynamic Load Behavior

2.1 Types of Dynamic Loads

- **Vertical dynamic loads:**

Vertical dynamic loads arise when the truck moves over bumps, potholes, undulations, and uneven road surfaces. These irregularities cause rapid vertical acceleration and deceleration of the wheels, leading to fluctuating bending stresses in the chassis side members. Such loads are critical, as they directly influence ride comfort, fatigue life, and the overall durability of the frame.

- **Lateral loads:**

Lateral loads are generated during cornering, sharp turning, sudden lane changes, and due to aerodynamic sidewind forces. These loads act perpendicular to the direction of travel and induce side bending in the chassis. Excessive lateral loading may compromise vehicle stability, increase the risk of rollover, and accelerate wear in suspension mounts and steering components.

- **Longitudinal loads:**

Longitudinal dynamic loads occur during acceleration, deceleration, and braking. These forces act along the length of the chassis and influence the stability and overall structural performance of the vehicle under traction or braking forces. High longitudinal loads can cause stress concentration at engine mounts, cross members, and bracket joints.

- **Torsional loads:**

Torsional loads are produced when the left and right wheels experience different levels of road elevation, such as when driving over uneven terrain, off-road surfaces, or ramps. This difference leads to twisting of the chassis structure. Torsional behavior strongly affects ride comfort and structural fatigue, making torsional stiffness a critical design parameter.

- **Impact loads:**

Impact loads are sudden, high-magnitude forces caused by events such as curb strikes, pothole hits at high speed, off-road driving shocks, or the sudden dropping of heavy cargo. These loads are transient but severe, causing peak stress conditions that can lead to immediate damage or long-term fatigue failures in the chassis.

2.2 Key Load Parameters

- **Payload magnitude and distribution:**

The amount of payload and the way it is distributed across the chassis play a major role in determining stress patterns. Uneven or excessive loading increases bending moments and may lead to overload-related failures.

- **Suspension stiffness and damping:**

Suspension characteristics directly influence how road-induced vibrations and shocks are transmitted to the chassis. Higher stiffness increases load transfer, while proper damping helps absorb dynamic energy, thereby reducing peak stresses.

- **Chassis material properties:**

The strength, stiffness, fatigue resistance, and elastic modulus of the chassis material determine its ability to withstand repeated dynamic loads. Materials such as HSLA steel, aluminum alloys, and composites each exhibit different load responses and durability profiles.

• Road roughness profiles (ISO 8608 guidelines):

Road roughness, categorized under ISO 8608, significantly affects the amplitude and frequency of dynamic loads. Rougher roads generate higher vibration input, increasing vertical and torsional stresses on the chassis.

• Tire pressure and tire–road interaction:

Tires act as the first line of vibration isolation. Incorrect tire pressure or poor tire-road grip alters load transfer characteristics, increasing shock loads and affecting chassis stability.

• Vehicle speed and vibration frequency range (1–80 Hz):

Vehicle speed influences the frequency and severity of dynamic excitations. Typical truck chassis vibrations fall within the 1–80 Hz range, and resonance within this band can amplify stresses, affecting durability and comfort.

3. Material Considerations

• High-strength low-alloy (HSLA) steel:

High-strength low-alloy (HSLA) steel is widely used for manufacturing truck chassis due to its excellent strength-to-weight ratio and cost-effectiveness. It provides superior load-carrying capacity and good resistance to bending and torsional stresses, making it suitable for heavy-duty applications. Its weldability and durability under fluctuating loads further enhance its suitability for commercial vehicle frames.

• Aluminum alloy chassis:

Aluminum alloy chassis are increasingly used in lightweight commercial vehicles where reduced mass and improved fuel efficiency are important. Aluminum offers lower density compared to steel, enabling significant weight savings while maintaining adequate stiffness. Although not as strong as HSLA steel, its corrosion resistance and ability to dissipate vibrational energy make it an attractive choice for modern vehicle designs.

• Composite-metal hybrid chassis:

Composite-metal hybrid chassis systems combine metals such as steel or aluminum with advanced composite materials to achieve a balance between stiffness, strength, and weight reduction. Composites contribute high tensile strength and excellent fatigue resistance, while metals provide structural rigidity and ease of fabrication. This hybrid approach allows manufacturers to optimize performance without compromising durability.

- **Fatigue behavior of materials:**

The fatigue behavior of chassis materials plays a critical role in long-term durability, as truck frames are subjected to continuous cyclic loading from road vibrations, payload variations, braking, and acceleration forces. Weld joints, suspension brackets, and cross-member connections are particularly vulnerable to fatigue-induced cracking. Selecting materials with high fatigue strength and designing joints to minimize stress concentration are essential for extending chassis life.

4. Methods for Studying Dynamic Load Behavior

4.1 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) is extensively used to evaluate the dynamic performance of a truck chassis by predicting stress distribution, natural frequencies, and fatigue life under various operating conditions. Several key approaches are adopted within FEA to achieve comprehensive analysis. Static structural analysis is performed to understand the stress levels under initial or constant loading conditions. Modal analysis is used to compute natural frequencies and mode shapes, which helps identify resonant behavior. Harmonic analysis evaluates the response of the chassis to periodic road excitations, such as those generated by engine vibrations or repeating road patterns. Transient dynamic analysis is conducted for time-varying loads, capturing the chassis response during events like braking, cornering, or sudden impacts. Additionally, random vibration analysis using Power Spectral Density (PSD) road spectra allows assessment of chassis behavior under statistically varying road irregularities, offering a realistic representation of real-world driving conditions.

4.2 Multi-Body Dynamics (MBD) Simulation

Multi-Body Dynamics (MBD) simulation provides a system-level approach by modeling the chassis together with suspension components, wheels, and the overall vehicle structure. It is particularly useful for studying interactions between different subsystems. MBD is used to analyze ride comfort, as it captures the suspension response to road disturbances. It also helps evaluate dynamic stress distribution by simulating load transmission throughout the vehicle.

Additionally, MBD models are effective for analyzing load transfer during braking and acceleration, offering insights into longitudinal vehicle stability. Another important application is assessing torsional stiffness under realistic operating conditions, where the model simulates asymmetric road inputs or uneven loading conditions. Common software tools used for MBD include ADAMS, TruckSim, Simpack, and MATLAB Simulink, which provide robust environments for integrating vehicle dynamics and structural behavior.

4.3 Experimental Methods

Experimental methods complement simulation techniques by providing real-world data for validation and refinement of analytical models. Strain gauging is commonly used to measure real-time strains at critical locations on the chassis rails, enabling detection of stress hotspots under dynamic loads. Road load data acquisition (RLDA**)** involves conducting field tests on different road surfaces, speeds, and payload conditions to record actual load histories experienced by the vehicle. Experimental modal analysis (EMA**)** is performed to identify natural frequencies, damping ratios, and mode shapes, which are essential for correlating with FEA-based modal predictions. Finally, fatigue testing is carried out using dedicated test rigs or accelerated life testing facilities to evaluate the fatigue performance of chassis members, welded joints, and cross members under controlled cyclic loading. Together, these experimental techniques provide critical insights into dynamic load behavior and ensure the reliability and accuracy of simulation models.

5. Literature Review

Anurag et al. [1] modeled the truck chassis frame using Creo (Pro-E) 2.0 and performed detailed stress analysis in ANSYS Workbench 15.0 to evaluate nodal displacements and stress distribution under applied loads. Their findings highlight the regions with maximum stress concentration, which are critical for improving chassis reliability and preventing frequent failures. The study emphasizes the importance of identifying weak points through FEA and suggests that further research using ANSYS-based simulations is essential for enhancing truck chassis design.

S. Dheeraj and R. Sabarish [2] investigated stress concentration, displacement patterns, and natural frequencies in a tipper truck chassis using ANSYS 10. Their comparative analysis of 6 mm and 8 mm chassis thickness revealed that the 6 mm frame exhibited lower stresses and better overall performance due to reduced self-weight. Although the 8 mm frame showed lower frequency response, the increased thickness resulted in higher bending stresses, making the lighter 6 mm chassis more suitable for practical applications.

Mukesh Patil et al. [3] conducted static stress analysis of a truck chassis using 3D modeling in Creo Parametric and FEA in ANSYS Workbench. Their results indicated that road excitation frequencies overlap with the natural frequencies of the chassis, making it vulnerable to resonance. Mode shape analysis helped identify suitable mounting points for components such as the engine and suspension. The study also noted that increasing chassis mass lowers natural frequencies, and recommended increasing stiffness or reducing chassis length to avoid excessive vibration and resonance issues.

Kiran Ghodvinde and Wankhade [4] performed static FEA on different automotive chassis designs, including Chevy truck and kit car frames, to identify critical stresses, particularly at joints. They demonstrated that increasing side-member thickness or using optimized connection plate lengths significantly reduces stress concentrations. Their study validated FEA results using theoretical beam analysis and emphasized that local reinforcement is effective for enhancing strength, although excessive stiffening increases chassis weight. The findings provide practical guidelines for improving chassis stiffness while balancing weight considerations.

Ahmad O. Moaaz and Ghazaly [5] reviewed and conducted stress analysis of heavy truck chassis using ANSYS, presenting an overview of recent advancements in vehicle structural analysis and optimization. Their study highlighted how finite element stress analysis plays a crucial role in identifying weak points and estimating fatigue life during early design stages. By surveying existing research and design practices, they reinforced the relevance of FEA-based chassis evaluation and emphasized the need for continued investigation into stress and fatigue behavior using ANSYS tools.

Naveen Ala et al. [6] designed and analyzed a heavy vehicle chassis for various materials and cross-sections using SolidWorks and ANSYS Workbench 15. They evaluated chassis performance using C, I, and box sections while comparing materials such as carbon steel, HSLA steel, structural steel, high-strength steel, aluminum alloys, and AISI 4130. Their results showed that high-strength steel offered superior stiffness, higher natural frequencies, and 1.5–2% weight reduction compared to conventional steel. Among all configurations, the I-section chassis made of high-strength steel provided the best balance of strength, stiffness, and weight efficiency.

Hirak Patel et al. [7] optimized an automotive chassis through FEA-based stress and deflection analysis, supported by sensitivity studies for weight reduction. The chassis was modeled in PRO-E and analyzed in ANSYS Workbench to ensure adequate stiffness and strength under various loading conditions. Their optimization process demonstrated that modifying cross-sectional geometry could reduce chassis weight by approximately 17% while maintaining structural performance. The study highlighted the importance of balancing stress limits, deflection constraints, and lightweighting objectives for improved chassis design.

Sandip Godse and Patel [8] carried out static load analysis of the TATA Ace EX chassis using ANSYS Workbench and validated results through mathematical calculations. Their study identified high-stress zones and proposed strength enhancement through stiffeners, local thickness increase, and reinforcement. The modified chassis exhibited a significant reduction in stress levels from 37.04 MPa to 22.97 MPa, demonstrating improved load-carrying capacity. The study effectively shows how targeted reinforcement can enhance chassis durability without major design overhauls.

Monika S. Agrawal [9] addressed major structural challenges in commercial vehicle chassis by analyzing strength, stiffness, fatigue behavior, bending moments, and vibration characteristics. Using CATIA for modeling and ANSYS for static and dynamic analysis, she highlighted the growing need for lightweight yet high-performance chassis structures to meet fuel economy and durability requirements. The study demonstrated how combining theoretical principles with advanced FEA tools can significantly improve chassis design efficiency and service life.

6. Existing Research

Existing studies consistently show that dynamic loads play a far more dominant role in chassis design than static loads, as trucks frequently operate under fluctuating road and loading conditions. Researchers highlight that while a certain level of torsional flexibility is beneficial for improving ride comfort, excessive flexibility can significantly reduce chassis durability and lead to premature failure. It is also well-established that welded joints, cross-members, and connection interfaces are the most fatigue-prone components due to cyclic loading and stress concentration effects. Recent materials research indicates that composite and hybrid structures provide substantial potential for weight reduction without compromising stiffness. Furthermore, advancements in simulation methods reveal that co-simulation techniques combining Multi-Body Dynamics (MBD) and Finite Element Analysis (FEA) produce the most accurate predictions of dynamic stresses and load transfer. Despite simulation advances, studies emphasize that real-world field data through strain gauges and RLDA remain critical for validating and calibrating numerical models.

Although dynamic load behavior has been widely investigated, several important gaps remain. There is limited research focusing on modular chassis architectures, which are increasingly relevant for next-generation trucks designed for easier maintenance and ease of manufacturing. Existing vehicle–road interaction models are largely based on European or American profiles, leading to a lack of accurate models tailored to Indian road conditions, where surface irregularities are significant and highly variable. Additionally, with the rapid rise of electric commercial vehicles, there is an evident gap related to electric truck chassis, which experience unique load dynamics due to heavy battery packs and altered center-of-gravity distribution. Another emerging research need is the application of AI-driven predictive fatigue models, which remain underexplored in chassis fatigue life estimation. Finally, studies have not fully utilized digital twin technology, which could support continuous monitoring and predictive maintenance of chassis structures throughout the vehicle's service life.

7. Conclusion

Dynamic load behavior is fundamental to the safety, performance, and long-term durability of truck chassis systems. As transportation demands evolve toward higher payload capacities, reduced vehicle weight, and improved driver comfort, the industry is increasingly adopting advanced materials, integrated MBD-FEA simulations, and intelligent fatigue prediction frameworks. The future of chassis design will rely on a seamless integration of real-time sensor data, advanced analytical models, and digital monitoring platforms, enabling the development of smart, adaptive chassis systems capable of responding to varying dynamic conditions. Addressing current research gaps—such as modular chassis design, Indian road modeling, electric truck load behavior, AI-based fatigue analysis, and digital twin implementation—will play a crucial role in shaping the next generation of efficient and reliable heavy-duty vehicles.

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