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ПРОЕКТИРОВАНИЕ И РАСЧЕТ СТАТИЧЕСКОЙ ПРОЧНОСТИ РАМЫ ГРУЗОВИКА ГРУЗОПОДЪЕМНОСТЬЮ 3,5 ТОННЫ

DESIGN AND STATIC DURABILITY SIMULATION OF A 3.5-TON TRUCK FRAME

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В настоящее время автомобильный транспорт является неотъемлемой частью логистической цепочки, обеспечивая почти 80 % грузоперевозок. Однако качество дорожного покрытия во Вьетнаме еще не полностью гарантировано, и транспортные средства часто эксплуатируются на неровных дорогах с многочисленными дефектами, что подвергает раму грузовика постоянным изгибающим и крутящим нагрузкам, представляющим опасность как для людей, так и для имущества. В связи с этим данное исследование посвящено анализу рамы грузовика посредством ее проектирования и расчетов прочности в условиях *статической полной нагрузки с использованием метода конечных элементов (FEM). Результаты моделирования показывают, что спроектированная рама грузовика обладает достаточной прочностью.*

Currently, road transport is an indispensable part of the supply chain, accounting for nearly 80 % of freight transportation. However, the quality of road surfaces in Vietnam is not yet fully guaranteed, and vehicles frequently operate on rough roads with numerous irregularities, subjecting the truck frame to continuous bending and torsional loads that may pose risks to both people and property. Therefore, this paper focuses on analyzing a truck frame by designing and conducting durability simulations under static full-load condition using the Finite Element Method (FEM). The simulation results show that the designed truck frame maintains sufficient strength.

Ключевые слова*: статическая нагрузка, статическая прочность, шасси, рама грузовика 3,5 т, HyperMesh, метод конечных элементов, МКЭ.*

Keywords*: static load, static durability, chassis, 3,5 tons truck frame, HyperMesh, finite element method, FEM.*

INTRODUCTION

In recent years, the rapid growth of urban freight demand has significantly increased the role of medium- and light-duty trucks in city logistics, as they are commonly used for their flexibility and operational efficiency [1]. However, road transport infrastructure in many developing countries, including Vietnam, faces challenges such as degraded and uneven pavements, which negatively affect vehicle performance, durability, and reliability [2]. Therefore, accurately assessing vehicle behavior under realistic road conditions is essential for improving vehicle dynamics and ensuring operational safety.

FEM is widely recognized as the most effective approach for evaluating truck frame design, especially for identifying stress concentrations and deformations to predict service life and optimize structural performance [3, 4]. Accordingly, this paper presents the design and static durability analysis of a 3,5-ton truck frame using FEM.

RESEARCH METHODOLOGY

The paper presents the method of designing and evaluating the durability of a truck frame using the FEM (fig. 1). The truck frame is designed based on the theory of strength of materials and simulated for durability under static full-load condition.

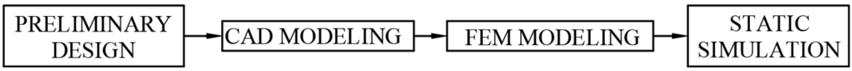

Figure 1 – Research Methodology Diagram

TRUCK FRAME DESIGN

In this section, the truck frame is designed to ensure sufficient bending and torsional strength. Based on the specifications of 3,5-ton trucks, the frame is simplified into a 2d model (fig. 2), with C-shaped longitudinal beams selected as shown in fig. 3. The strength of materials theory is then applied to calculate the maximum bending and shear stresses according to Equation (1) (tab. 1).

Table 1 – Component Masses

Components	Frame	Cabin	Powertrain	3 people in cabin	Unsprung mass	Other components	Maximum cargo load
Masses (kg)	200	350	700	210	600	250	2190

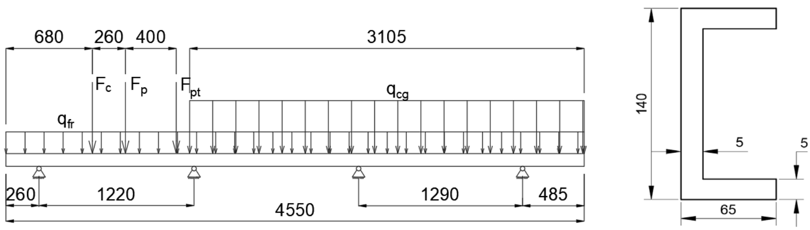

Figure 2 – Simplified 2D+ truck frame model and beam cross-section:
F_c, F_p, F_{pt} – loads of the cabin, peoples, and powertrain (N);
q_{cg}, q_{fr} – distributed loads of the cargo and truck frame (N/mm)

During operation, the vehicle is subjected to complex dynamic effects from uneven road surfaces. Therefore, this study conducts calculations and simulations using static loads multiplied by a Dynamic Load Factor (DLF). Since the DLF value varies depending on the type of road [5, 6], this paper adopts a DLF value of 2 to represent the road conditions in Vietnam.

Determination of σ_{max} and τ_{max}:

$$\sigma_{\max} = \frac{|M_x|_{\max}}{J_x} \cdot y_{\max}^k \quad \text{and} \quad \tau_{\max} = \frac{|Q_y|_{\max} \cdot S_x^c}{J_x \cdot b^c} \tag{1}$$

Applying the Distortion Energy Theory (von Mises yield criterion):

$$\sigma_v = \sqrt{\sigma^2 + 3 \cdot \tau^2} \le [\sigma] \tag{2}$$

Table 2 – Results of Stress

Parameter	σ_{max}	τ_{max}	σ_v
Value (MPa)	90,50	12,98	93,26

From tab. 2, σ_v is 93,26 MPa, much lower than the yield strength of the frame material, S500MC steel (620 MPa) [7]. Hence, the truck frame is considered safe with the selected dimensions of the longitudinal beam cross-section.

MODEL CONSTRUCTION

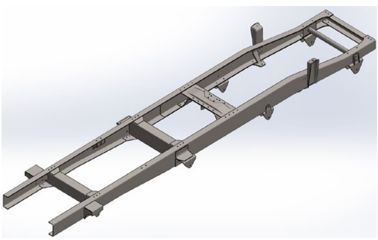

Figure 3 – CAD model of the truck frame

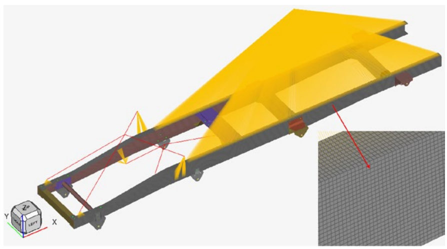

Figure 4 – FEM model of the truck frame

Fig. 3 shows the CAD model of the truck frame, with S500MC steel and dimensions obtained from actual measurements and the technical specifications of the reference vehicle, Hino 300 616 MT 2525 STD [7–9].

Fig. 4 shows the FEM-model of the truck frame using a combination of two 2D element types, quads and trias, to reduce computational time, improve accuracy, and provide flexibility for complex geometries such as the truck frame. The element size was set to 5 mm, and the element quality was controlled according to several built-in software criteria [10] (tab. 3).

Table 3 – Element quality of the FEM truck frame model

Parameter	Value	Result
Number of elements	194814	
Number of nodes	200768	
Warpage	Maximum deviation: 0,2518°	Pass
Aspect ratio	Maximum deviation: 2,588	Pass
Jacobian	Minimum value: 0,5004	Pass
Minimum length	3 mm	Pass
Maximum length	8,993 mm	Pass

DURABILITY ANALYSIS

To evaluate the structural performance of the truck frame, a static full-load simulation was performed using the finite element model developed in Section 4. The frame was constrained at the leaf spring bracket positions, which restricted all six degrees of freedom, effectively replicating realistic mounting conditions (fig. 5, 6).

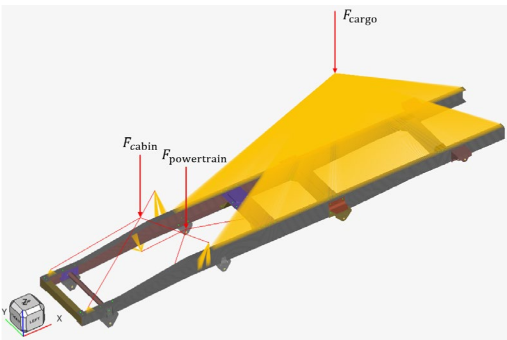

Figure 5 – Distribution of cabin, powertrain, and cargo loads on the truck frame

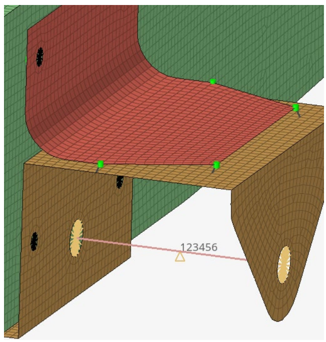

Figure 6 – Constrained at the spring bracket positions

Forces corresponding to the cabin and driver, powertrain assembly, and maximum cargo load were applied based on their respective masses multiplied by a Dynamic Load Factor (DLF) of 2. This factor accounts for road irregularities and simulates more demanding real-world conditions that vehicles experience in Vietnam (tab. 4).

Table 4 – Mass of the assemblies exerting forces on the frame

Assembly	Cabin + driver	Powertrain assembly	Cargo body
Mass x DLF (kg)	1120	1400	4380

The total applied mass, distributed across the key load-bearing regions of the frame, resulted in a structural loading scenario equivalent to approximately 6900 kg. fig. 7 illustrates the load application, while fig. 8 shows the resulting stress distribution. The analysis revealed that the maximum von Mises stress occurred near the junctions of the cross members and the longitudinal beams, reaching a value of 155,1 MPa. This stress concentration represents the most critical area of the frame under full static load.

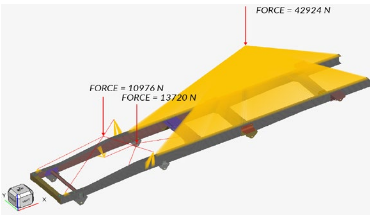

Figure 7 – Truck frame is subjected to static full-load conditions

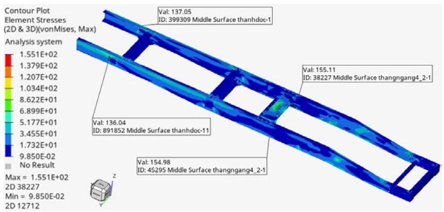

Figure 8 – Stress distribution of the truck frame under full static load

Despite these stress peaks, the maximum value remains significantly lower than the yield strength of the chosen S500MC high-strength structural steel (620 MPa). This provides a safety factor of approximately 4, indicating that the frame can withstand loading conditions far beyond the rated operational capacity. Furthermore, no excessive deformations or local instabilities were observed, confirming that the frame possesses robust stiffness and structural integrity. The results demonstrate that the designed frame is not only capable of supporting the nominal load but also has reserve capacity to accommodate occasional overloads and challenging operating environments.

CONCLUSION

This study presented the design and durability evaluation of a 3,5-ton truck frame using the Finite Element Method. By applying static full-load conditions with an additional dynamic load factor, the analysis simulated realistic operating environments typical of Vietnamese road conditions.

The results indicated that the maximum stress of 155,1 MPa was well below the yield strength of S500MC steel (620 MPa), ensuring structural safety and reliability.

In conclusion, the durability analysis confirmed that the designed frame maintains sufficient strength with a high safety margin, making it suitable for practical operation under heavy load and rough road conditions. Future research should extend this work to include dynamic load simulations, fatigue life prediction, and optimization of weight-to-strength ratio to further enhance the performance of the truck frame.

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