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Comparative Structure Performance Analysis of a Vehicle Chassis Frame. A Case of Nyumbu Trucks

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Abstract: The vehicle chassis frame is the primary structural component that supports all major vehicle systems and transfers static and dynamic loads during operation. The selection of an appropriate chassis cross-section significantly influences structural strength, stiffness, safety, weight, and durability. This study evaluated the structural performance of three chassis frame cross-sections, namely Rectangular Hollow Section (RHS), C-channel, and I-beam, using Nyumbu trucks as a case study. The objective was to identify the most structurally efficient cross-section under identical loading conditions. Three-dimensional chassis models were developed in SolidWorks Premium 2023 using identical dimensions and material properties (AISI 1018 mild steel). Finite Element Analysis (FEA) was performed under static and equivalent dynamic loading conditions using identical boundary conditions and mesh settings. Structural performance was evaluated based on equivalent (von Mises) stress, resultant displacement, factor of safety (FOS), and structural weight. The I-beam exhibited the best overall structural performance. Under static loading, it recorded the lowest von Mises stress (1.227×10^8 N/m²), the smallest displacement (2.9 mm), and the highest FOS (3.0). Under the equivalent dynamic loading case, the I-beam again demonstrated superior performance with the lowest stress (1.84×10^8 N/m²), lowest displacement (4.4 mm), and FOS of 2.0. The RHS exhibited satisfactory static performance but its FOS decreased to 0.9 under the equivalent dynamic case. The C-channel produced the highest stresses and displacements, with FOS values below unity under both loading conditions. The study concludes that the I-beam provides the most favorable simulated combination of strength, stiffness, and safety within the investigated configurations.

Keywords: Vehicle chassis, Structural performance, Finite element analysis, RHS, C-channel, I-beam, SolidWorks, Dynamic loading.

I. INTRODUCTION

Vehicle chassis frames are fundamental structural components that support major vehicle systems and transfer loads during operation. In developing countries, trucks play an important role in transportation because of their flexibility, reliability and ability to operate under challenging infrastructure conditions. Chassis design therefore requires an appropriate balance between strength, stiffness, durability, safety, weight and manufacturability.

Different cross-sectional shapes, including Rectangular Hollow Sections (RHS), C-channels and I-beams, are used in chassis construction. RHS sections provide high torsional stiffness and relatively uniform stress distribution, while C-channels are comparatively simple to fabricate and assemble. I-beams are efficient under bending because material is distributed away from the neutral axis. However, each section has limitations related to torsional behaviour, fabrication, weight and structural stability (Beer et al., 2017; Megson, 2014).

Tanzania Automotive Technology Centre (TATC) Nyumbu has developed locally manufactured Nyumbu trucks for applications including troop carrying, water bowser and tipper operations. Such vehicles may experience static loads from vehicle weight and payload as well as amplified loads associated with uneven roads, potholes and other operating conditions. Accurate prediction of stress and deformation is therefore important for chassis design and improvement.

Previous chassis studies have commonly evaluated different cross-sections under static loading. This creates a need for a controlled comparison that also considers an equivalent amplified dynamic loading condition. The present study

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addresses this gap by comparing RHS, C-channel and I-beam chassis sections using FEA under identical modelling assumptions.

A. Research Objective

The main objective was to compare the structural performance of C-channel, RHS and I-beam sections of a vehicle chassis frame under static and equivalent dynamic loading using finite element analysis. Specifically, the study developed three-dimensional chassis models using common envelope dimensions and material properties; simulated their responses under identical loading conditions using SolidWorks Premium 2023; and compared maximum von Mises stress, resultant displacement, factor of safety and structural weight.

II. MATERIAL AND METHODS

A. Chassis Model Development

Three-dimensional chassis frame models were developed using SolidWorks Premium 2023. The Nyumbu truck chassis envelope dimensions were maintained consistently for the three configurations so that the influence of cross-sectional geometry could be compared. Each model used four cross members. The three investigated longitudinal-member sections were RHS, C-channel and I-beam.

TABLE I COMMON CHASSIS DIMENSIONS USED IN THE MODELS

Parameter	***Value***
Chassis length	5020 mm
Chassis width	1130 mm
Number of cross members	4
RHS outer height	180 mm
RHS outer width	100 mm
RHS wall thickness	5 mm

B. Material Definition

AISI 1018 mild steel was assigned to the chassis models. The material properties used in the simulations were Young's modulus of 205 GPa, Poisson's ratio of 0.29, density of 7800 kg/m³, yield strength of 370 MPa and tensile strength of 440 MPa.

TABLE II AISI 1018 MATERIAL PROPERTIES

Property	**Value**
Young's modulus	205 GPa
Poisson's ratio	0.29
Density	7800 kg/m³
Yield strength	370 MPa
Tensile strength	440 MPa

C. Finite Element Analysis

FEA was conducted in SolidWorks Premium 2023. The models were discretized using a solid mesh with a blended curvature-based mesher. The mesh was set to high quality, with a maximum element size of 253.635 mm and minimum element size of 12.6817 mm. The resulting mesh contained 132,082 elements and 267,892 nodes.

TABLE III MESH INFORMATION

Parameter	***Value***
Mesh type	Solid mesh
Mesher	Blended curvature-based mesh
Mesh quality	High
Maximum element size	253.635 mm
Minimum element size	12.6817 mm
Total elements	132,082
Total nodes	267,892

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Four boundary conditions were applied at the front and rear axle attachment locations. The static load represented the vehicle body and permissible payload. The total vehicle load used in the static case was 6,874 kg, equivalent to 67,365.2 N using g = 9.81 m/s². The equivalent dynamic-load case was represented using a Dynamic Amplification Factor (DAF) of 1.5, giving an applied load of 101,047.8 N. This dynamic case is an amplified-load static-equivalent assessment and not a transient dynamic simulation.

D. Performance Indicators

The structural response was evaluated using maximum equivalent (von Mises) stress, maximum resultant displacement, factor of safety and structural weight. The same geometry envelope, material, support conditions, mesh settings and loading assumptions were used for the three sections to isolate the effect of cross-sectional geometry.

III. RESULTS AND DISCUSSION

A. Static Loading Results

Under static loading, the RHS chassis produced a maximum von Mises stress of 2.766×10^8 N/m², a maximum displacement of 3.5 mm and a factor of safety of 1.34, with a model weight of 295.22 kg. The C-channel produced a higher maximum stress of 4.338×10^8 N/m² and displacement of 4.590 mm, with a factor of safety of 0.85 and a model weight of 197.05 kg. The I-beam produced the lowest maximum stress of 1.227×10^8 N/m², the lowest displacement of 2.9 mm and the highest factor of safety of 3.0, with a model weight of 297.8 kg.

TABLE IV SUMMARY OF FEA RESULTS UNDER STATIC LOADING

Section	*Weight (kg)*	*Max. stress (N/m²)*	*Max. displacement (mm)*	*FOS*
RHS	295.22	2.766×10^8	3.5	1.34
C-channel	197.05	4.338×10^8	4.590	0.85
I-beam	297.8	1.227×10^8	2.9	3.0

The I-beam therefore showed the most favourable static response. Its lower stress and displacement are consistent with efficient material distribution for bending-dominated loading. The C-channel had the lowest weight but developed the highest stress and a factor of safety below unity, indicating that the analysed loading condition may produce yielding or permanent deformation. The RHS provided an intermediate response and retained a factor of safety above unity under static loading.

B. Equivalent Dynamic Loading Results

For the equivalent dynamic-load case using DAF = 1.5, the RHS produced a maximum von Mises stress of 4.112×10^8 N/m², a maximum displacement of 5.3 mm and a factor of safety of 0.9, with a model weight of 295.22 kg. The C-channel produced the highest stress of 6.5×10^8 N/m² and the highest displacement of 6.9 mm, with a factor of safety of 0.6 and a model weight of approximately 197 kg. The I-beam produced the lowest stress of 1.84×10^8 N/m², displacement of 4.4 mm and a factor of safety of 2.0, with a model weight of approximately 298 kg.

TABLE V SUMMARY OF FEA RESULTS UNDER EQUIVALENT DYNAMIC LOADING

Section	*Weight (kg)*	*Max. stress (N/m²)*	*Max. displacement (mm)*	*FOS*
RHS	295.22	4.112×10^8	5.3	0.9
C-channel	197	6.5×10^8	6.9	0.6
I-beam	298	1.84×10^8	4.4	2.0

The equivalent dynamic results reinforce the static-loading comparison. The I-beam retained the lowest stress and displacement and the highest factor of safety. The RHS response became critical because its factor of safety reduced below one, while the C-channel remained the least favourable configuration. The results indicate that cross-sectional geometry has a strong influence on stress, deformation and safety margin under the adopted loading conditions.

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C. Comparative Structural Performance

TABLE VI OVERALL COMPARISON OF STRUCTURAL PERFORMANCE

Section	*Loading*	*Stress (N/m²)*	*Displacement (mm)*	*FOS*	*Overall finding*
I-beam	Static	1.227×10^8	2.9	3.0	Best simulated static performance
I-beam	Dynamic	1.84×10^8	4.4	2.0	Best simulated dynamic performance
RHS	Static	2.76×10^8	3.5	1.34	Satisfactory under static loading
RHS	Dynamic	4.112×10^8	5.3	0.9	Requires attention/reinforcement for dynamic case
C-channel	Static	4.3×10^8	4.6	0.85	Lowest safety margin
C-channel	Dynamic	6.5×10^8	6.9	0.6	Poorest dynamic performance

Overall, the I-beam exhibited the most favourable simulated structural performance under both loading cases. The RHS provided acceptable static performance but its factor of safety fell below one in the equivalent dynamic case. The C-channel had the lowest mass but also the highest structural demand and factors of safety below one under both loading conditions. A factor of safety below unity indicates that the predicted von Mises stress exceeds the adopted yield strength, implying the possibility of yielding or permanent deformation under the analysed case.

IV. CONCLUSION

This study compared the structural response of RHS, C-channel and I-beam chassis frame sections for a Nyumbu truck using SolidWorks Premium 2023 FEA. Under static loading, the I-beam produced the lowest reported maximum von Mises stress (1.227×10^8 N/m²), lowest resultant displacement (2.9 mm) and highest FOS (3.0). The RHS produced 2.766×10^8 N/m², 3.5 mm and FOS 1.34, while the C-channel produced 4.338×10^8 N/m², 4.590 mm and FOS 0.85. Under the equivalent amplified-load case using DAF = 1.5, the I-beam again produced the lowest stress (1.84×10^8 N/m²), displacement (4.4 mm) and highest FOS (2.0). The RHS reached 4.112×10^8 N/m² and FOS 0.90, while the C-channel reached 6.50×10^8 N/m² and FOS 0.60.

The I-beam therefore demonstrates the most favourable simulated structural response among the three investigated geometries for the adopted modelling conditions. This conclusion is conditional: it does not establish universal chassis superiority because the I-beam is approximately 51.1% heavier than the C-channel and approximately 0.9% heavier than the RHS, while torsional stiffness, lateral-torsional buckling, fatigue, joints, manufacturability, corrosion and road-service behaviour were not fully assessed. The equivalent dynamic case is an amplified-load screening analysis rather than a transient dynamic simulation.

V. RECOMMENDATIONS

a) The I-beam configuration may be considered for further engineering evaluation because it produced the lowest simulated stress and displacement and the highest FOS within the investigated cases. This is a preliminary design-screening result and not an approval for production.
b) For the existing RHS configuration, the equivalent dynamic case should be treated as a critical screening condition because the model reaches a stress above the adopted 370 MPa yield strength. The critical front-axle/lower-surface region should receive particular attention in future detailed analysis and inspection.
c) For the C-channel configuration, possible redesign measures include increased web/flange thickness, increased flange width, local reinforcement around suspension and cross-member connections, and additional cross-members. Each modification should be re-analysed because reinforcement changes mass and stiffness.
d) Finite Element Analysis should be included during the design stage to improve chassis safety and reduce development costs.
e) Future dynamic studies should model suspension stiffness and damping, tyre compliance, bump geometry and vehicle speed using transient or multibody methods. Modal analysis should also be added to identify natural frequencies and possible resonance conditions.

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f) Future studies should include fatigue analysis, torsional loading, vibration analysis and experimental validation of the simulation results.

VI. CONTRIBUTION OF THE STUDY

The study provides a Nyumbu-specific comparative finite element assessment of RHS, C-channel and I-beam chassis sections under common modelling assumptions. It provides quantitative evidence on stress, displacement, factor of safety and structural weight and offers a preliminary engineering basis for selecting and further evaluating chassis cross-sectional configurations. The results can also support future prototype testing, torsional assessment, fatigue evaluation and chassis design optimisation at TATC and related Tanzanian automotive institutions.

DECLARATIONS

Funding: No specific external funding was reported for this study.

Conflict of interest: No competing interest was reported.

Data availability: The numerical results and modelling information are derived from the finite element simulation study and are subject to the applicable institutional requirements.

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