Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Design and Analysis of a Ladder Chassis Frame for use in the Construction of a Lightweight Utility Vehicle

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Article Info

Keywords:
Ladder Chassis, Lightweight Utility Vehicle, von Mises Stress, Finite Element Analysis.

Received 21 October 2021
Revised 16 November 2021
Accepted 16 November 2021
Available online 12 December 2021

https://doi.org/10.37933/nipes/3.4.2021.21

https://nipesjournals.org.ng

Abstract

The chassis of a lightweight utility vehicle was designed and fabricated from readily available material in a low-technology environment. The chassis made from mild steel (AISI 1018) sections, was analysed using load deflection method and finite element modelling. The results show that mild steel material with yield strength of 370MPA is suitable for chassis construction of lightweight utility vehicle.

1. Introduction

In June 2002, the United Nations Industrial Development Organization (UNIDO) in collaboration with the Federal Ministry of Industry held a symposium in Lagos, on the “Development of an Economically Viable and Environmentally Sound 2- and 3-Wheeler Sector in Nigeria”. The report stated that under the Country Service Framework for Nigeria, and at the request of the Federal Government of Nigeria and with major financial support from the government of Japan, UNIDO’s interest was to help build up local capacity to develop safe, environmentally sound, low-cost motorized vehicles for transport and economic development, to support indigenous small parts producers, to enter into emerging supply chains in the industry. UNIDO was also examining how a sustainable, private sector led growth could be achieved and how, in reasonable time, the industry could be made fully indigenous [1]. As reported by Addis Engineering Limited, Nigeria’s automobile industry dates back to 1959 when the United African Company (UAC) established the first assembly plant to assemble Bedford trucks among others [1]. Since then, other motor vehicle and motorcycle assembly plants have been established. Despite this long period, the automotive industry in Nigeria has not made much progress beyond mere assembly. The above report indicated that local content barely reached 30 percent in 2002.
In line with UNIDO’s thinking on “how a sustainable private-sector-led growth could be achieved and how, in reasonable time, the industry could be made fully indigenous”, it is important to set up mechanisms for acquiring the skills for auto components production, especially engines, suspension and chassis components. The chassis of an automobile is a major structural component

which constitutes the platform upon which other parts for example, the engine, suspension systems etc., of the vehicle are built. It is considered as a part that determines both static and dynamic load-carrying capacity vehicle performance and safety of the vehicle. [2,3] Also, the handling of a vehicle is grossly affected if for any reason its chassis has poor bending stiffness [3,4].

In designing a chassis for a light weight utility vehicle with a carrying capacity of about one tonne for the conveyance of goods, it is expected that the chassis be light to help the vehicle performance but must also be strong to serve its purpose; i.e. to bear the impact of forces acting on it including the weight of components built on it and the payload that the utility vehicle is expected to carry. Therefore, the solidity of the chassis must be such that the chassis has necessary rigidity to resist expected static and dynamic loads not limited to twist, shock and vibration without failure. More also it is vital for a chassis to possess the required bending stiffness to allow for proper handling of the vehicle. The solidity of a chassis is very important since an unstable chassis will be very unsafe [4].

Patil and Deore [5] and Darlon et al. [6] classified chassis as follows: ladder frame chassis; monocoque chassis; backbone chassis; space frame chassis; and tub design chassis. Selecting the best but simple type of chassis design appropriate for use in a lightweight vehicle becomes a very vital choice to make. The ladder chassis, is simple in its design and consists of two parallel beams and several cross sections, which could be of I, C and box type section [3]. It is believed by many to be the oldest form of chassis in the history of automobile [5,6], and therefore most common and still found in many utility vehicles such as buses and trucks e.g. Eicher E2 TATA truck [3].

Utility vehicles are very important in the distribution chain of any economy. Current utility vehicles such as pickups, hatchbacks, etc. are far too expensive for Nigerian rural farmers, tradesmen and micro/small scale entrepreneurs. These persons resort to manual and motorcycle transportation, which are bedevilled with low carrying capacities. Manual transportation is associated with fatigue while motorcycles are inherently hazardous. The use of the imported tricycles is unsafe and too costly for the function. In order to possibly overcome these problems, a lightweight utility vehicle was designed and fabricated with readily available materials. The purpose of this paper is to present the design of the ladder chassis (shown in Figure 1), for a utility vehicle.

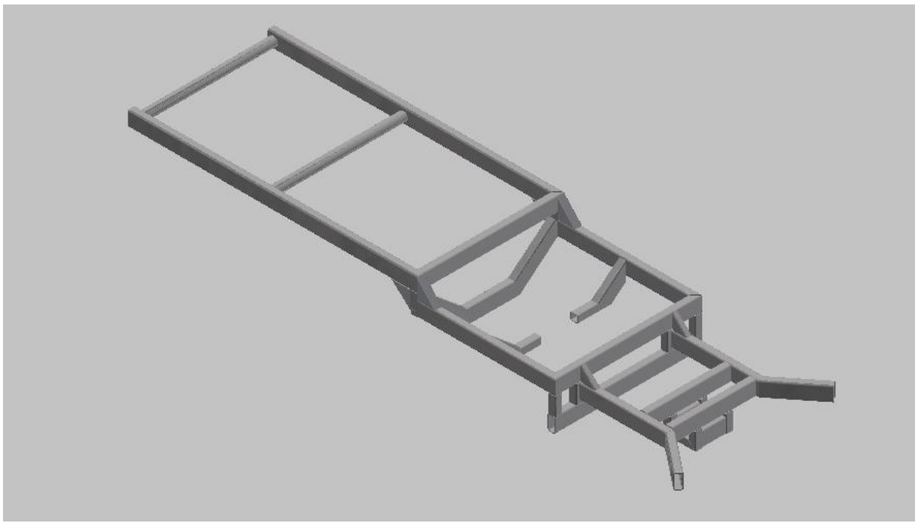

Figure 1: CAD model of chassis in Autodesk Inventor

The methodology of this study covers the materials and methods used in achieving the aim of this study.

2.1 Methodology

Most ladder chassis frames for trucks and buses are built on I and C cross sections which are made from steel alloy (austenitic) material. Although other materials such as ASTM A710 steel, ASTM A302 alloy steel and aluminium alloy 6063-T6 have been subjected to test under the same load conditions to ascertain their suitability for use in a Eicher E2 TATA truck [5]. All these materials proved to be adequately strong enough but among them ASTM A302 alloy steel was found to provide better strength for a ladder chassis frame.

In a low technology environment such as Nigeria where the automobile industry is still in its infancy, the use of these materials for chassis construction is unattainable. Therefore, a readily available mild steel material, AISI 1018 with a rectangular box cross section was used for the ladder chassis frame construction due to its advantages [7]. From Table 1, the comparison of sections made, it can be seen that a chassis constructed from a rectangular box cross sections provides more strength and minimum deflection over C and I cross sections assuming all sections are of the same material type [5].

Table 1: Comparison of results of analysis for various cross sections for chassis construction [7]

Cross sections	Weight (Kg)	Analytical Method		FE Analysis	
		Displacement (mm)	Stresses (N/mm^2)	Displacement (mm)	Stresses (N/mm^2)
C-Type	476	9.267	473	6.153	301
I-Type	462	6.842	319	4.786	234
Rectangular Box (Hollow) Type	631	4.017	187	2.683	127

Table 2 shows the mechanical properties of the Mild steel AISI 1018 that was used for the chassis fabrication.

Table 2: Mechanical and physical Properties of AISI 1018 (Mild Steel) [7].

Physical Properties	Metric
Density	7.87 g/cc
Mechanical Properties	**Metric**
Hardness, Brinell	126
Hardness, Knoop	145
Hardness, Rockwell B	71
Hardness, Vickers	131
Tensile Strength, Ultimate	440 MPa
Tensile Strength, Yield	370 MPa
Elongation at Break	15.0 %
Reduction of Area	40.0 %
Modulus of Elasticity	205 GPa
Bulk Modulus	140 GPa
Poissons Ratio	0.290
Machinability	70 %
Shear Modulus	80.0 GPa

2.2. Chassis Design

The design and analysis for stiffness of the ladder frame chassis was done by considering the loading configurations in Figure 2. R_b is the reaction at the front axle and R_c is the back reaction at the back axle.

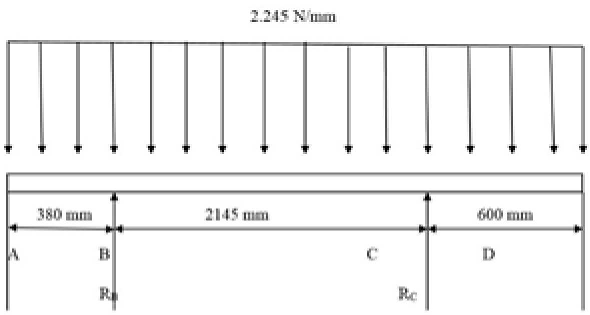

Figure 2: Load distribution on the chassis

A solid model of the chassis was created using Autodesk software, Inventor 2015, and exported to ANSYS R18.1, where finite element analysis of the chassis was performed.

2.2.1 Design Calculation for Chassis Frame

The moment distribution method is applicable in the determination of the stress produced in the chassis. This method is a displacement method of analysis, which in place of the calculation of the displacement, makes it possible to apply a series of converging corrections that allows direct calculation of the end moments. The sidebars of the chassis of the utility truck are made from rectangular cross channels of 80 x 40 x 4 mm.

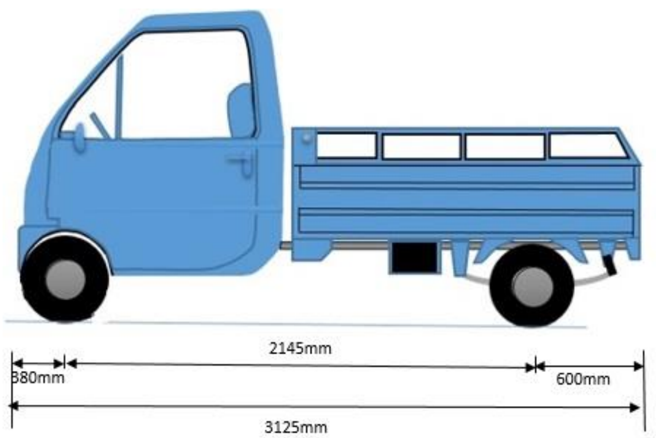

Figure 3: Side view of the front and rear overhang of the truck

Figure 3 shows the dimensions of the utility vehicle with the following major values:

(i) Front Overhang (a) = 380 mm
(ii) Rear Overhang (c) = 600 mm
(iii) Wheel Base (b) = 2145 mm

Truck's load carrying capacity is assumed to be equal to 1 ton (1000 kg), therefore, the truck load carrying capacity is 9810 N

Applying a 0.25 factor of safety, the total truck load was determined as 12262.5N.

The weight of the vehicle body and engine was assumed to 0.18 ton. This is equivalent to 180kg (i.e. 1765.8N).

The total load (T_{LC}) acting on chassis is:

T_{LC} = capacity of the utility truck (CUT) + Weight of body and engine (WBE) (1)

The T_{LC} was determined as 14028.3N.

For a chassis with two beams, it follows that the load acting on each beam is half of the total load acting on the chassis.

∴ Load acting on the single frame = $\frac{1}{2}T_{LC}$ (2)

The load acting on single frame was calculated to be 7014.15N per beam

(a) Determination of the Reactions

The beam is considered as an overhanging beam at both ends supported at B and C with a uniform distributed load since it is clamped with shock absorber and leaf spring as shown in Figure 2.

Let the load acting on the whole span of the beam = LSF = 7014.15N; and

Length of the beam (L_b) = 3125 mm

Uniformly Distributed Load (UDL) = ${LSF}/{L_b}$ (3)

Therefore, UDL was calculated to be 2.244528 N/mm.

The moment about B (Figure 2) was determined as follows:

$R_B = WL(L - 2L_{CD})$ (4)

R_B was calculated as 3147.375N.

Also, $R_C = WL(L - 2L_{AB})$ (5)

R_C was determined as 3866.775N.

(b) Determination of the Shear Force

The shear force was determined from Figure 4 as follows:

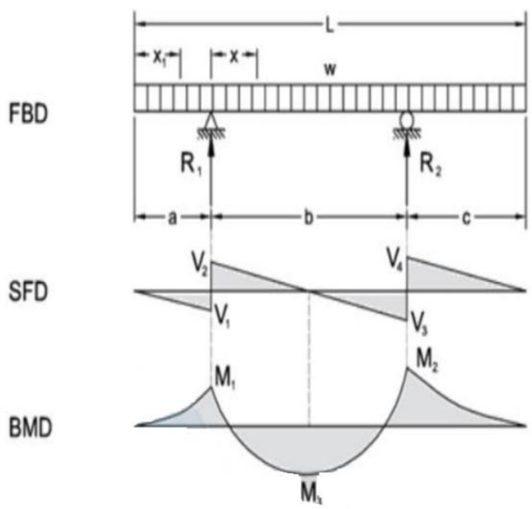

Figure 4: Shear force and bending moment diagram

If x is the distance of the section measured from the left-hand support, then the shear forces, V_1, V_2, V_3 and V_4 were calculated as follow:

$V_1 = W \times L_{AB}$ (6)

Therefore, V_1 was obtained as 852.92N.

$$V_2 = R_B - V_1 \quad (7)$$
$\therefore V_2 = 2294.45$N.

$$V_3 = R_C - V_4 = R_C - (W \times L_{CD}) \quad (8)$$
$\therefore V_3 = 2520.06$N.
$$V_4 = W \times L_{CD} \quad (9)$$
$\therefore V_4 = 1346.72$N.

(c) Determination of the Bending Moment

The bending moments M_1, M_2 and M_3were determined from the bending moment diagram in Figure 4 as follows:

$$M_1 = -W \times (L_{AB}^2/2) \quad (10)$$
M_1 was determined as -162054.92 N-mm.
$$M_2 = -W \times (L_{CD}^2/2) \quad (11)$$
M_2 was determined as -404015.04 N-mm
$$M_3 = R_B[(\frac{R_B}{2} \times W) - L_{AB})] \quad (12)$$
M_3 was determined as 1010690.71 N-mm
$\therefore M_{max} = 1010690.71$ N-mm

(d) Determination of the Bending Stresses

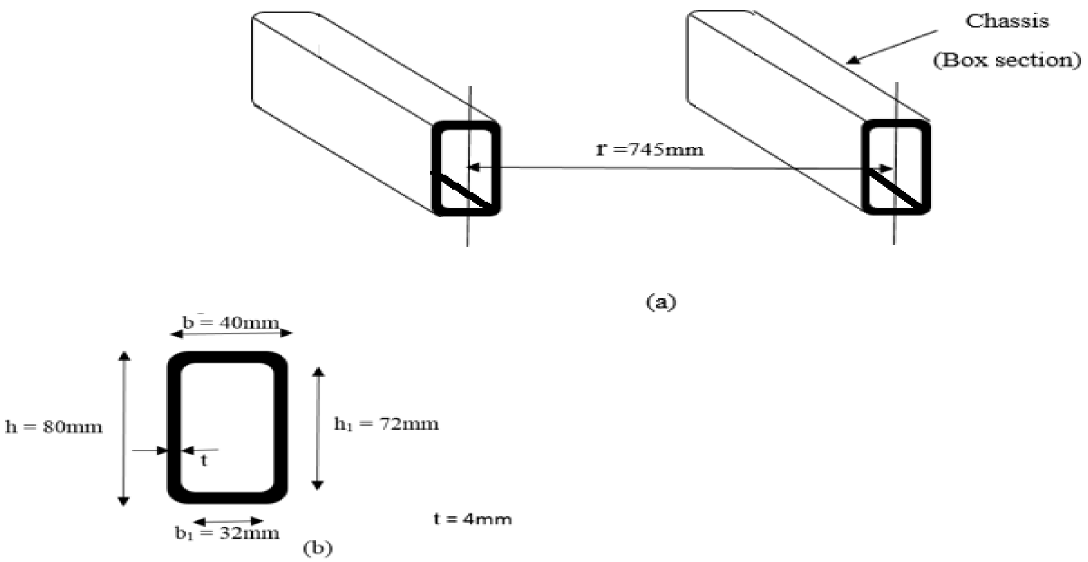

Figure 5. (a) Lateral distance between the centres of the two chassis box chassis cross section and (b) Geometry of chassis box section

The moment of inertia about x-axis (I_{xx}) was calculated as follows:

$$I_{xx} = \frac{(bh^3 - b_1h_1^3)}{12} \quad (13)$$
Where b = total width of the box section of the chassis

h = total height of the box section of the chassis

b_1 = internal hollow width of the box section (b -2t, t equals wall thickness of beam)

h_1= internal hollow height of the box section (h -2t, t equal to wall thickness of beam). (See Figure 5).

∴ I_{xx} was determined as 711338.67 mm^4.

The moment of inertia about y-axis (I_{yy}) was determined thus,

$$I_{yy} = \frac{(hb^3 - h_1 b_1^3)}{12} \quad (14)$$

∴ I_{yy} was determined as 230058.67 mm^4.

Considering the section of modules around the x–x axis (Z_{xx}),

$$Z_{xx} = \frac{(bh^3 - b_1 h_1^3)}{6h} \quad (15)$$

∴ Z_{xx} was determined as 17783.47 mm^3.

The bending stress (σ) acting on the beam was determined using the following relationship:

$$\sigma = \frac{M_{max}}{Z_{xx}} \quad (16)$$

∴ σ was determined as 56.83 N/mm^2.

(e) Determination of Shear Stresses

The angle of twist was assumed to be = 1^o, therefore,

$$\theta = 1^o \times \frac{\pi}{180} \quad (17)$$

And θ was determined as 0.017453 rad.

Width of the chassis (i.e. the lateral distance between the centres of the two chassis box sections), r = 745mm (see Figure 5).
Length of chassis, L= 3125mm
Distance between two reactions = 2145mm
Modulus of rigidity for mild steel, G = 78125 N/mm^2
The shear stress, τ was determined from the twisting moment (T_M) equation

Recall, Twisting Moment $T_M = {G\theta}/{L} = {\tau}/{r}$ (18)

$$\therefore \tau = {G\theta r}/{L} \quad (19)$$

The shear stress, τ was obtained to be 196.59 N/mm^2.

von Mises stress was determined to be 345.21MPa, using equation (20)

$$\text{von Mises stress} = (\sigma^2 + 3\tau^2)^{1/2} \quad (20)$$

(f) Determination of the Deflection of Chassis, Y

$$Y = \frac{W(b-x)}{24EI[x(b-x)+b^2-2(c^2+a^2)-2/b\{c^2x+a^2(b-x)\}]} \quad (21)$$

where, W = weight of chassis,
a, b and c = front overhang, wheel base and rear overhang respectively.
x = $\frac{1}{2}$ of total length

∴ Y was obtained as 13.74 mm, which is the maximum deflection produced in the chassis frame.

2.3 Finite Element Analysis of Chassis

The finite element analysis (FEA) computational technique was used to analyse the load-carrying capacity of the chassis.

2.3.1 Modelling of the Chassis Frame

The model of the chassis as per the dimensions was created in Autodesk Inventor, as shown in Figure 6. The model was then imported into ANSYS workbench. Figure 7 shows the imported model in ANSYS workbench. Figures 8 – 11 show the various finite element operations on the chassis frame.

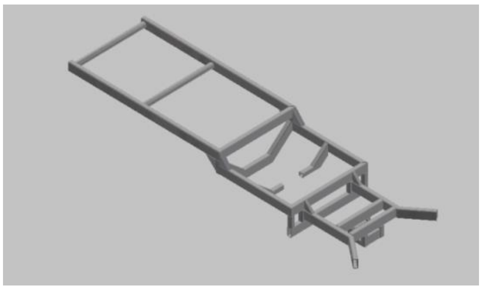

Figure 6: CAD model of chassis in Autodesk Inventor

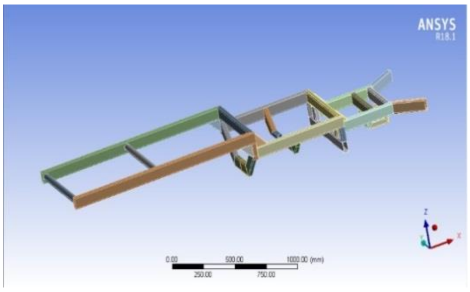

Figure 7. Geometry of chassis frame in ANSYS

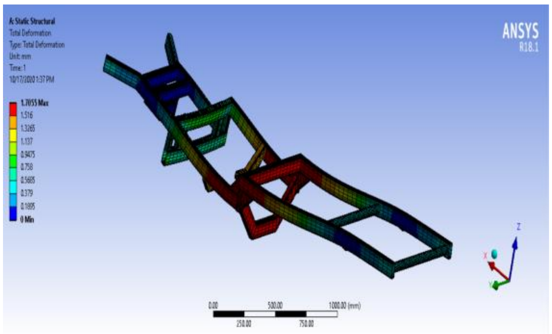

Figure 8: Deformation of the chassis frame

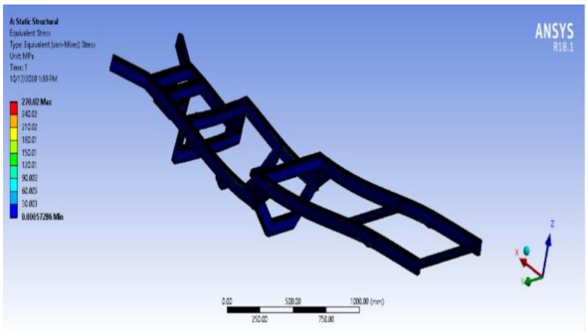

Figure 9: von Mises stress on the chassis frame

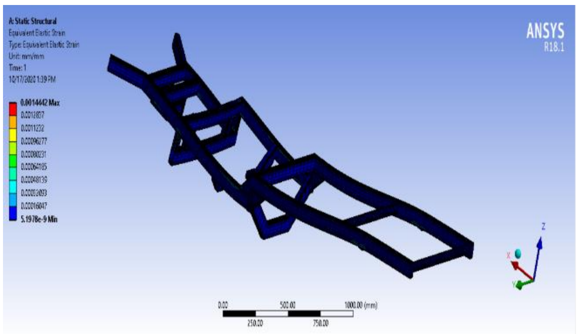

Figure 10: Equivalent elastic strain on chassis frame

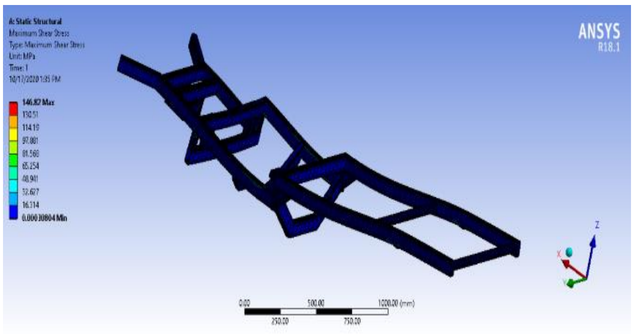

Figure 11: Shear stress on the chassis frame

3.0. Results and Discussion

The results of the finite element analysis and the theoretical calculations of the stress on the ladder chassis frame, showed that the manually calculated maximun von-Mises stresses gave a value of 345.21 MPa, which is about 27.84% higher than the maximum von-Mises stress obtained from the FEA analysis (shown in Figure 9), which gave a value of 270.02MPa. Therefore, the chassis made of mild steel is safe for it intended use in the construction of a lightweight truck, since both the calculated and FEA values of von Mises stresses are less than the permissible value of 370MPa of the chassis material. The FEA shown in Figures 8, 10 and 11 also gave maximum values of the total deformation stress of chassis as 1.1800mm, equivalent elastic strain as 0.00139mm/mm and the maximum shear stress of 146.82MPa, that are within the desired limits. The sidebar stresses generated were more than that of the whole chassis frame because of the addition of series of crossbars. The addition of crossbars makes chassis less prone to bending and twisting.

4.0 Conclusion

This work shows that the mild steel (AISI 1018) material is suitable for the design of ladder chassis for a lightweight utility vehicle. The stress analyses show that the operating forces are within safe stress limits.

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