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Design Considerations for Ladder Chassis of a Lightweight Vehicle

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Abstract

The chassis supports the body, the payload and other components linked to the body and forms the structural backbone of vehicles. This paper presents the design and static analysis of a lightweight utility vehicle chassis. The static analysis was conducted on a model of the ladder chassis developed from solid works. The ANSYS workbench was employed for the Finite Element Analysis. The results obtained show that deformation of the chassis was found to be within the safe limits according to deflection span ratio for the simply supported beam. The von Mises and maximum shear stresses obtained was found to be lower than the yield strength of the material.

Keywords: Chassis, Deformation, Maximum Shear Stress, Utility Vehicle, Von Mises.

1. Introduction

The chassis is the principal part of a vehicle that gives strength and stability to vehicular components and the payload placed on it. It is mainframe that carries all the vehicle components and supports all the loads. The components available in most vehicle chassis include the engine, the steering system, the suspension system, the braking system and the seats (Begum & Murty, 2016b; Mohamad et al., 2017; Ravi Chandra, Sreenivasulu, & Syed Altaf, 2012). The load supported by the chassis are the weight of each component and the forces involved during cornering, acceleration and deceleration (Cavazzuti & Splendi, 2011; Hema Kumar, 2009; Kumar & Deepanjali, 2016; Mat & Ghani, 2012). The performance, safety and roadworthiness of any vehicle are dependent on the chassis design of the vehicle. The chassis is designed to withstand shock, twist, vibrations and other stresses.

Vehicle chassis should be able to absorb impact during a crash to protect the driver or occupant from serious injuries. Automobile chassis is usually made of light sheet metal or composite plastics. The automobile chassis are designed to rigid as to withstand vibration, twist, buckling, shock and many other stresses (Mohamad et al., 2017). According to ("Automotive Frames, Automotive Chassis, Automobile Frames, Automobile Chassis, Auto Frame, Automotive Frames Supplier," n.d.; Ravi Chandra et al., 2012), there are three main types of chassis and they include:

i. **Ladder Chassis:** Ladder chassis is generally regarded as the oldest form of automobile chassis. It is still used by most of the SUVs. The ladder chassis takes the shape of a ladder having two longitudinal rails interlinked by several lateral and cross braces.

ii. **Monocoque Chassis:** Monocoque Chassis is a one-piece structure that prescribes the overall shape of a vehicle. It is manufactured by welding floor pan and other pieces together. It is cost effective and suitable for robotized production, most of the vehicles today make use of steel plated monocoque chassis.

iii. **Backbone Chassis:** Backbone chassis has a rectangular tube-like backbone, usually made up of glass fibre that is used for joining the front and rear axle together. It is very strong and it is used in the sports car. Backbone chassis is easy to make and cost-effective.

The ladder chassis is very popular for utility vehicles. The most common ladder chassis channels used are the C-Channel and I-Channel chassis. The Finite Element Method (FEM) was employed in the structural analysis of automobile chassis to determine the various critical stresses on the chassis. The critical point is the stress with the highest magnitude. They are used to predict the critical points that may lead to fatigue failure (Begum & Murty, 2016a, 2016b; Mat & Ghani, 2012; Ravi Chandra et al., 2012).

2. Materials and Method

2.1 Materials

The chassis designed in this work is a ladder chassis developed for a lightweight utility vehicle by the Federal University of Petroleum Resources, Nigeria. The ASTM A710 Steel was used for the Chassis design.

Detailed design calculations were made for the chassis. Table 1 shows the material properties of the ASTM A710 steel.

Table 1. Material Properties of ASTM A710 Steel

Property	**Value**
Young's Modulus(GPa)	205
Shear Modulus (GPa)	80
Mass density (g/cm^3)	7.85
Yield strength (MPa)	450
Ultimate Tensile strength(MPa)	515
Poisons ratio	0.29

Table 2. Design Specifications of the Ladder Chassis and Vehicle

Parameter	**Value**	**Units**
Chassis profile	76.2 x 38.1 x 4	mm^3
Front Overhang (a)	480	mm
Rear Overhang (c)	730	mm
Wheel Base (b)	1490	mm
The width of the chassis	550	mm
Length of chassis	2700	mm
Capacity of Truck	1000	kg
The capacity of Truck with 1.25% design allowance	12262.5	N
Body weight	1962	N
Engine weight	475.79	N
The weight of the body and engine	2437.79	N
The total load acting on chassis = Capacity of the Chassis + Weight of body and engine	14700	N
The load acting on the single frame	7350	N

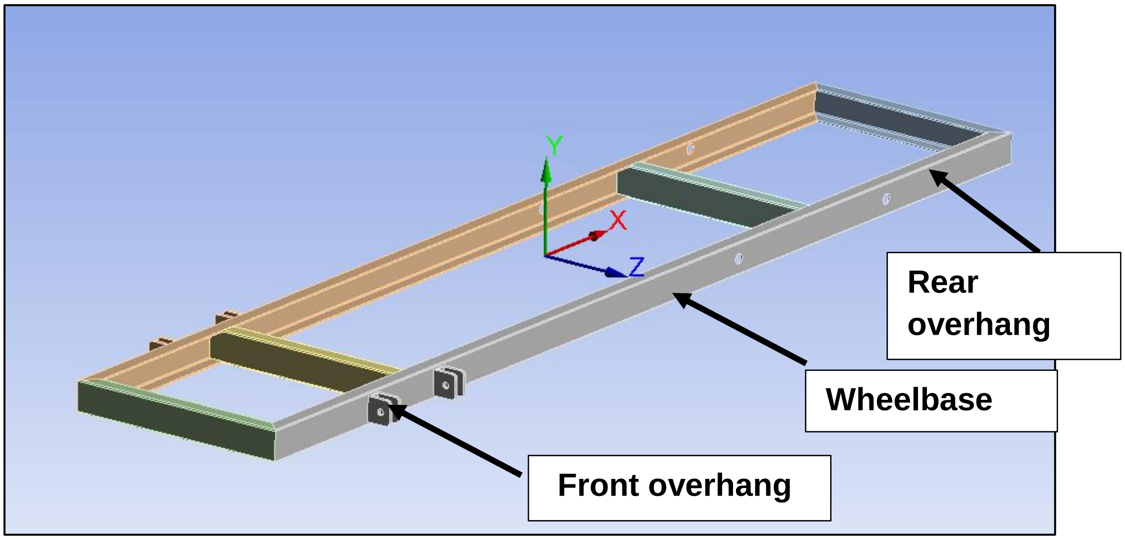


Figure 1. CAD Model of the Ladder Chassis

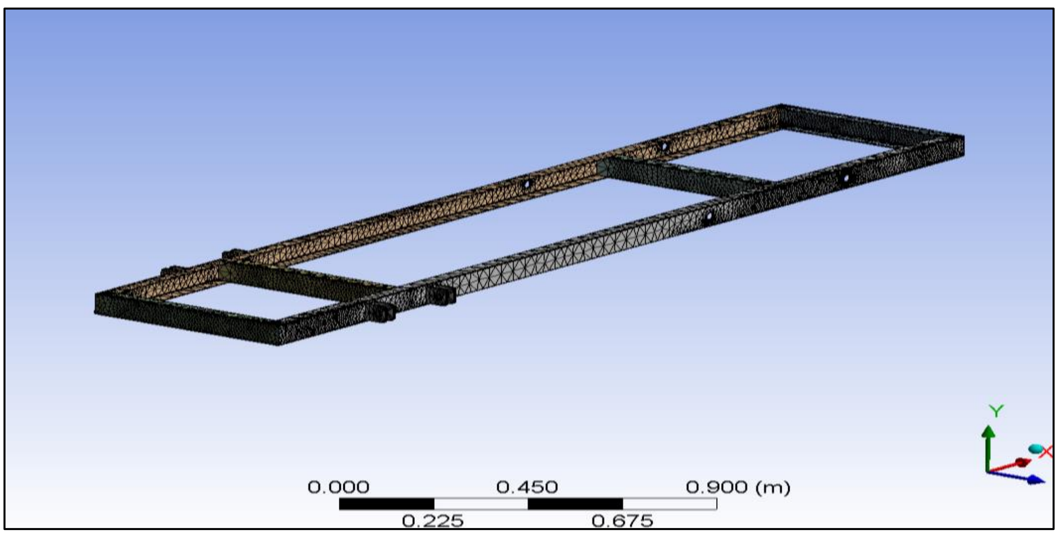


Figure 2. Meshed Model of the Ladder Chassis

2.2 Methods

A combination of methods was employed in the design and structural analysis of the ladder chassis. Firstly, detailed design calculations were made to determine the reactions, shear force, bending moments and deflection with a view to achieving a lightweight utility vehicle with a curb weight of 1 ton. The chassis design specifications are shown in Table 2. Lastly, a static structural analysis was conducted for the ladder frame chassis to determine the various stresses and total deformation on the chassis

2.2.1 Calculation for the Reactions, shear force, bending moments and deflection

The beam is simply clamped with shock absorber and leaf spring. Therefore, the beam is supported at C and D with varying distributed load. Figure 4 shows the shear force and bending moment diagram of the ladder chassis. Figure 5 depicts the C-Channel profile.

Load acting on the entire span of the beam = 7350 N

Length of the beam = 2700 mm

Varying Distributed Load = 7350 / 2700 = 2.72 N/mm

Therefore, Moment about C:

$2.72 \times 480 \times 480/2 = (2.72 \times 1490 \times 1490/2) - (R_d \times 1490) + (2.72 \times 730 \times 1855)$

$313344 = 3019336 - 1490 R_d + 3683288$

$R_d = 6389280/1490$

$R_d = 4288.1$ N

Total load acting on the beam = $2.72 \times 2700 = 7344$ N

$R_c + R_d = 7344$ N

$R_c = 7344 - 4288.1$

$= 3055.9$ N

Shear force calculations:

$F_a = 0$ N

$F_c = (-2.72 \times 480) + 3055.9$

$= 1750.3$ N

$F_d = (-2.72 \times 1970) + 3055.9 + 4288.1$

$= 1985.6$ N

$F_b = 0$ N

Bending moment calculations:

M_a = 0 Nmm

M_c = (-2.72 × 480 × 480/2) = -313344 Nmm

M_d = (-2.72 × 1970 × 1970/2) + 3055.9 × 1490

= -5278024 + 4553291

= - 724733 Nmm

M_b = 0 Nmm

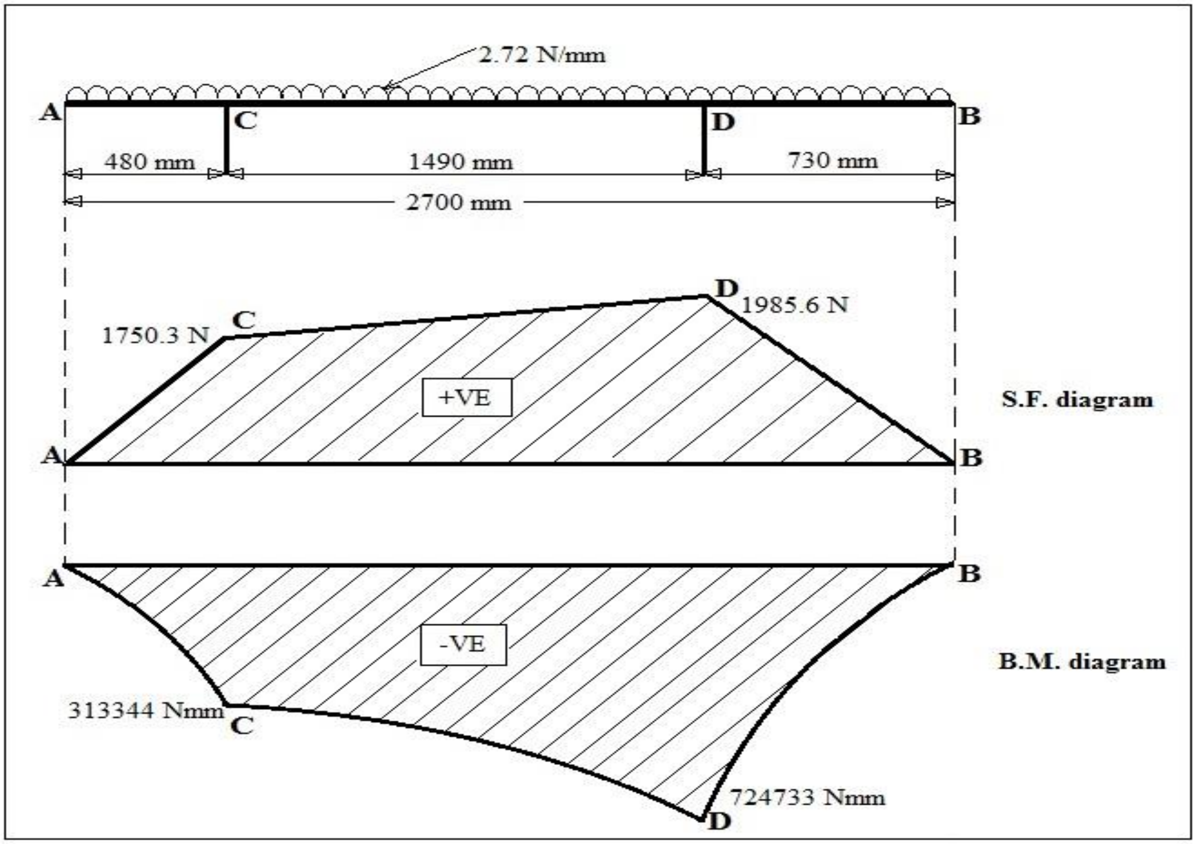


Figure 4. Bending moment and shear force diagram

Deflection of Chassis calculations:

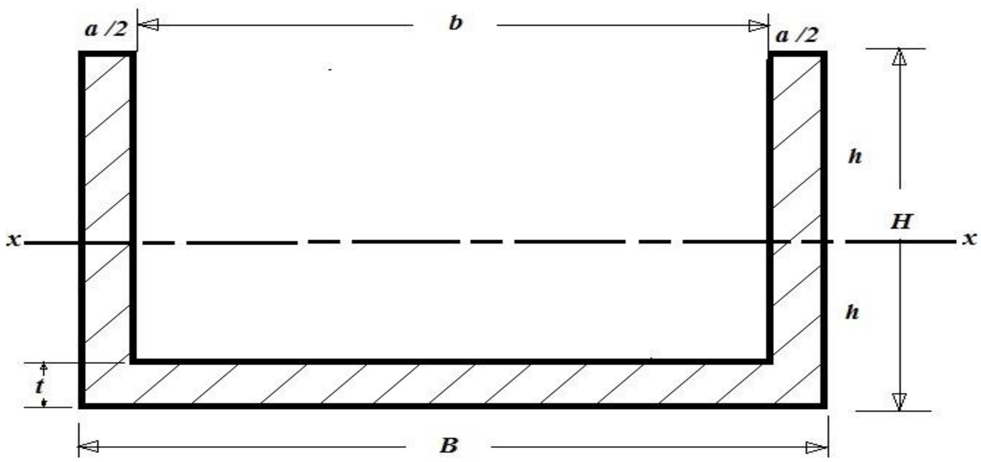


Figure 5. C-channel profile

Moment of inertia about x-x axis of a C-channel is represented below

$$I_{xx} = \frac{Bh^3 - b(h-t)^3 + ah_1^3}{3} \qquad (1)$$

Where, B = 3' = 76.2mm; H = 1.5' = 38.1mm; t = 4mm; B = B – 2t = 68.2mm; h + h₁ = H; $\frac{1}{2}H = h_1 = 19.05mm$

$I_{xx} = \frac{76.2\ (19.05)^3 - 68.2(19.05-4)^3 + 8(19.05)^3}{3} = 349614.8\ mm^4$

The deflection of chassis can be calculated from the equation,

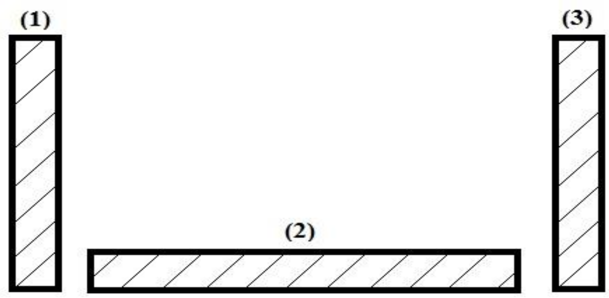
$$\frac{W \times (b-x)}{24EI}\left[x(b-x) + b^2 - 2(c^2 + a^2) - \frac{2}{b}[xc^2 + a^2(b-x)]\right] \qquad (2)$$

Where, $a = 480$ mm (front overhang); b = 1490 mm (wheel base); c = 730 mm (rear overhang); x = Total length/2 = 2700/2 = 1350 mm; E = Modulus of elasticity = 210000 N/mm^2; I = Moment of inertia = 349614.8 mm^4; $\rho =$ Density = 7.85 g/cm^3 = 7850 kg/m^3; W = Weight of chassis.

However, $W = mg$ (3)

But, $m = \rho V$ (4)

Consider the cross-section of the C channel, as if it were partitioned by separate rectangular bars as shown below.



Total length = 2700 +2700 +550 +550 +550 +550 =7600 mm

Hence Volume (V) = $V_1 + V_2 + V_3 = 2V_1 + V_2$

$= 2\,(0.0381 \times 0.004 \times 7.6) + (0.0682 \times 0.004 \times 7.6) = 4.39 \times 10^{-3}\ m^3$

Therefore,

Mass of entire chassis, $\boldsymbol{m} = \rho V$

$= 7850 \times 4.39 \times 10^{-3}\ m^3 = 34.46\ kg$

Weight of chassis, $W = m\,g = 34.46 \times 9.81 = 338$ N

Deflection of chassis =

$$\frac{338\,(1490-1350)}{24EI}\left[1350(1490-1350) + 1490^2 - 2(730^2+480^2) - \frac{2}{1490}[1350(730)^2 + 480^2(1490-1350)]\right] = \boldsymbol{-3.89x10^{-3}\ mm}$$

2.2.2 Structural Analysis of the Ladder Chassis

The design parameters and specifications used for the structural analysis of the chassis were stated in Tables 1 and 2. A model of the chassis was developed using Solid works as shown in Figure 1. The meshed model of the chassis contains 1359982 nodes and 869961 elements as shown in Figure 2. Finite Element Analysis was conducted on the model using ANSYS R15.0 to determine the various stresses and deformations on the chassis. Figure 6 depicts the boundary and load conditions of the ladder chassis. The contour plots of Von Mises stress distribution, Maximum Stress and total deformation for the ladder chassis are shown in Figures 7-9.

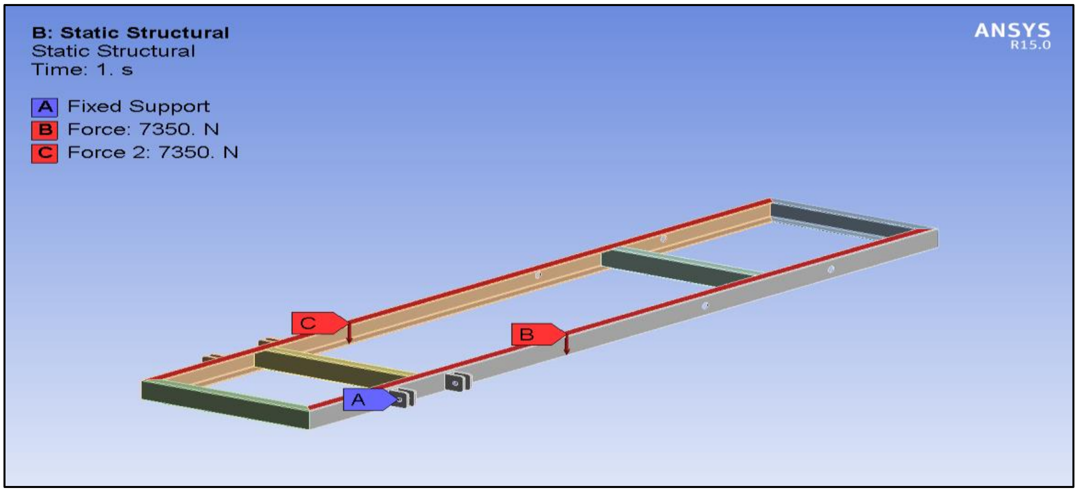


Figure 6. Fixed support and load on chassis

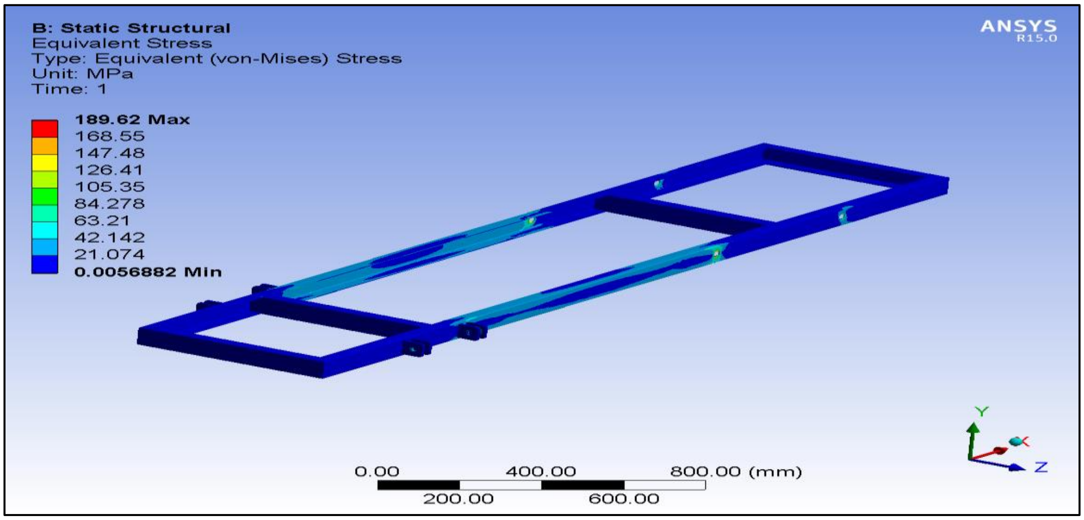


Figure 7. Equivalent Stress of the ladder chassis

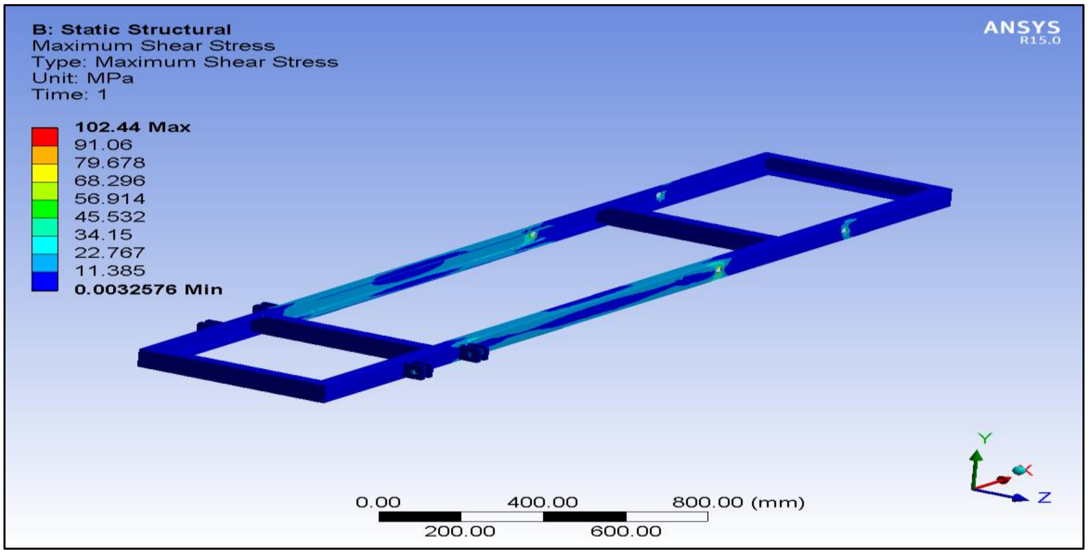


Figure 8. Maximum Shear Stress of the ladder chassis

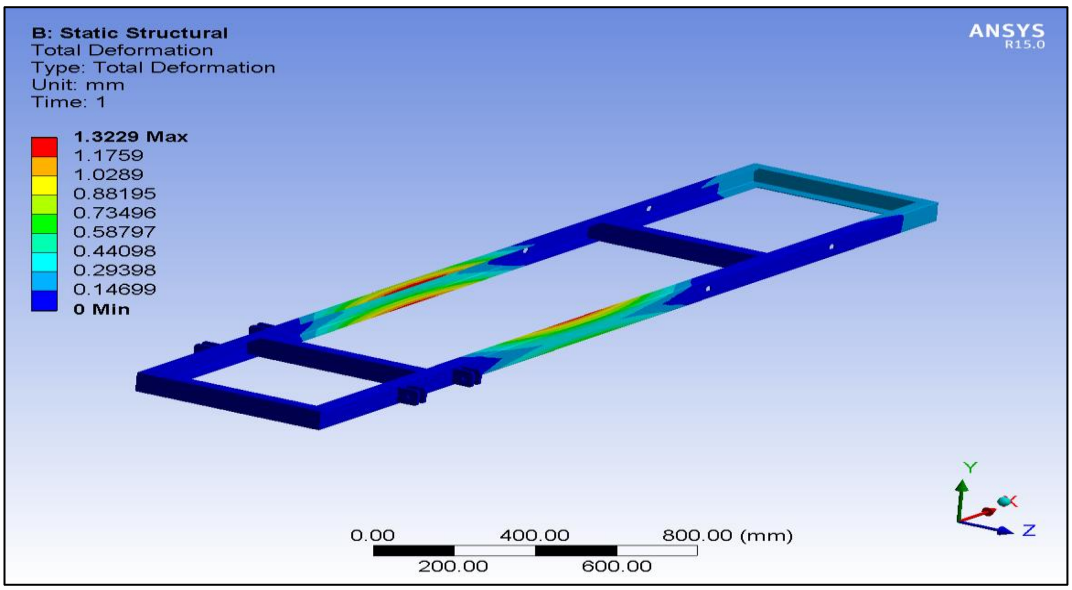


Figure 9. Total Deformation

3. Results and Discussion

3.1 Reactions, shear force, bending moments and deflections

Figure 3 shows the summary of the results obtained for the reactions, shear force and bending moments of the ladder chassis developed. The load along the ladder chassis is assumed to be varying distributed. The load acting on the entire span of the beam is 7350N. Point C and D are the front and rear overhangs respectively. The reactions on point C and D were obtained as R_c = 3055.9N and R_D= 4288.1N. The shear force acts perpendicular to the longitudinal axis of the ladder chassis. The shear forces acting on points C and D were obtained as 1750.3N and 1985.6N respectively. For design purposes, the ability of the chassis to resist shear forces is more important than its ability to resist axial forces ("Shear Force and Bending Moment," n.d.).

The bending moments characterize the behaviour of the ladder chassis when an applied load is subjected to it perpendicularly to along its longitudinal axis. The bending moment, M_c at point C was obtained as -313344Nmm. This is largely due to close bracing on the ladder chassis while the bending moment, M_D at point D was obtained as -724733Nmm which can be attributed to the bracing at the rear overhang.

The maximum deflection obtained for the Chassis frame is $-3.89x10^{-3}$ mm which is within the safe limit according to deflection span ratio for the simply supported beam.

3.2 Static Structural Analysis of the Chassis

3.2.1 Von Mises stress of the Chassis

The von-Mises stress of the chassis is shown in Figure 7 and was found to be 189.62MPa. The von Mises obtained is below the yield strength of the material which is 450MPa.

3.2.2 Maximum Shear Stress of the Chassis

The shear stress connotes the chassis endurance under external load and it is an important factor considered in the chassis design. In this study, the maximum shear stress obtained is 102.44MPa as shown in Figure 8.

3.2.3 Total Deformation of the Chassis

The total deformation of the ladder chassis and the magnitude of shape displacement is shown in figure 9. The maximum deformation is 1.3 mm and this occurs within the wheelbase of the chassis.

Conclusion

In this study, a ladder chassis was designed and analyzed for a lightweight utility vehicle. The following conclusion was made for the chassis model developed from solid works and analyzed using ANSYS Workbench

i. The maximum shear and von Mises stresses obtained were less than the yield stress.

ii. The deformation obtained was found to be within the safe limits for the simply supported beam.

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