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Structural Design and Optimization of Chassis for Transport Vehicle

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Abstract- In this study, design analysis and shape optimization of ladder chassis frame is analyzed. Static analysis is performed on ladder chassis frame to find out the stress, strain and displacement in a ladder chassis due to acting loads. Solid Works software is used for the modelling of ladder chassis frame and ANSYS is used for the static analysis of ladder chassis fame. Coming to shape optimization, the cross-section of cross-members will be changed accordingly C, T & I and tested for the same. The main goal of the work is to study the different types of chassis, find out the stress, strain and displacement under acting loads on ladder chassis, design and optimize the shape of the chassis towards the weight optimization and to study the effect of changing cross-section of cross members of ladder chassis frame with different material. It is found that the generated stresses are within the permissible limit as yield strength of A710 steel is 455 MPa so design is safe. Deformation is minimum in ladder chassis with C- section and maximum in ladder chassis with T- section. Stress is maximum in ladder chassis with T- section and minimum in ladder chassis with C- section. For weight reduction analysis, minimum weight of Ladder chassis with I-section is 749.47 kg and maximum weight of Ladder chassis with box-section is 1034.1 kg. So with regard to different cross-section of cross-member in ladder chassis, C- section is suitable for trucks.

Keywords: - Ladder chassis, t-section, Stress, Strain, box-section, Weight, cross-members, ANSYS, Solid Works.

I. INTRODUCTION

Automotive industry is one of the major industries around the globe [1]. Chassis is a central part of automotive vehicle and it carry the load of components such as engine, gearbox, clutch, fuel tank etc. These loads include the weight of each component. Therefore, chassis should be rigid enough to absorb the shock, twist, vibration and other stresses. Bending and torsional stresses are the main design consideration for the chassis apart from this it has better handling characteristics [2]. Therefore, the chassis must provide the strength needed for supporting the components to keep the ride safe. Chassis is the skeleton of vehicle and it is the load carrying structure, so it has to be designed [3].

One of the major challenges is of designing of the chassis. Design of chassis is begins with analysis of load cases [1]. There are four loads acting on chassis to be considered namely: (1) bending loads (2) torsion loading (3) combine bending and torsion loading (4) lateral loading (5) inertia forces when vehicle accelerates and decelerates.

These loads are important considerations in design of chassis because of ride safety and comfort of passengers. Nowadays automotive engineers are more interested in reducing the weight of chassis without compromising its performance. Apart from this many scholars have done the optimization of chassis. For instance, Cavazzuti et. al. [7] optimized the design of chassis. Sobieski et al. [8] have done the optimization of chassis using bending and torsion loading as a constraint. Sklad [9] addressed the optimization of chassis towards light weight. Sethupathi et al. [10] have done the optimization of FSAE chassis using FEA. Yasar and Brian [11] studied the effect of design parameters on chassis of car.

Design was analyzed by using FEA tools with three materials namely aluminum alloy, magnesium alloy and carbon fiber. Further, design optimization was carried out by using Taguchi methodology. Paramar and Morabiya [12] analyzed the stress distribution of truck frame. Results indicate that stress intensity is minimum in "I" section than "C" section.

II. LITERATURE REVIEW

Gaikwad and Ghawade [18] performed the static structural analysis of truck chassis. Chassis is modelled in Pro-E and FEM analysis has been done in ANSYS. Highest stress is found as 106.08 MPa. Further, the result of numerical simulation is bigger than 5.92% than analytical one.

Muthyala [19] made the comparative analysis of steel and CFRP ladder chassis. Further, crash analysis has been performed. Thickness optimization is performed on ladder chassis. It is observed that 7.91% weight is reduced in the combination of chassis.

Garud et al. [20] had changed the web height and thickness to study their effects on weight. CFRP was showing better results as compared to original chassis. Further, with increase in thickness, deformation and stress value decreases.

Mishra [21] designed the truck chassis with different materials. Ladder chassis is modelled in Solid Works and FEM analysis has been done in ANSYS. Result reveals that shear stresses are maximum in alloy steel chassis as compared to aluminum chassis.

Kumar et al. [22] performed the FEM analysis of truck chassis. Results indicate that highest stress occurred is 106.08 MPa. The calculated maximum stress is 95.43 MPa. The result of FEM analysis is 10% higher than that of analytical one.

Francis et al. [23] calculated the von mises stress and shear stress for chassis frame. Mild steel, aluminum alloy and titanium alloy are selected for analysis. Result indicates that von mises stress is found minimum in aluminum alloy.

Darlong et al. [24] had done the FEM analysis of ladder chassis frame under static and dynamic conditions. Result indicates that 15.22% weight reduction is achieved with a von-mises stress of 31.69 MPa.

Goel et al. [25] studied the deformation, natural frequency, and stress induced in an automotive chassis under different cross-section of cross members. Chassis is modelled in Solid Works and FEM analysis has been done in ANSYS.

III. RESEARCH METHODOLOGY

1. Geometry of Chassis:
The geometry of chassis is shown in fig 1 Further, SOLID WORKS 2016 is used for 3D modeling of chassis.

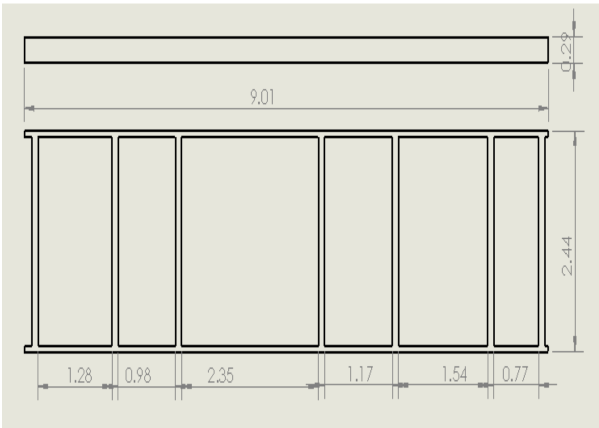

Fig 1. Geometry of chassis (Top view) (All dimensions are in m).

2. Chassis Material:
To achieve light weight construction, chassis is built with carbon steel and aluminum alloys [17]. Currently, material used for the chassis is A710 steel. However, in this study A710 steel is selected for analysis and optimization of chassis.

Table 1. Alloys Properties.

Material	Modulus of elasticity (GPa)	Density (Kg/m^3)	Tensile strength (MPa)	Yield strength (MPa)
A710 steel	200	7767	510	455

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Table 2. Specification of ladder Chassis. [17]

S.No.	Parameters	Value
1	Total length of chassis	9010 mm
2	Width of chassis	2440 mm
3	Front overhang	1260 mm
4	Rear overhang	2155 mm
5	Capacity (GVW)	25 Ton
6	Kerb weight	5750 Kg
7	Pay load	19250 Kg

Existing dimension of side bar made from C-section is have dimension of Height H=285 mm, Width (B) = 65 mm and thickness (t) = 7mm

3. Modelling of Chassis:

A 3-D model of ladder chassis is built in SOLIDWORKS 2016. In order to build the model accurately, the design specifications have been taken from Fig. 3.

By following the rules of designing, CAD model is designed. Side (C-Section) and cross members (T, I and box) are modeled in single geometry.

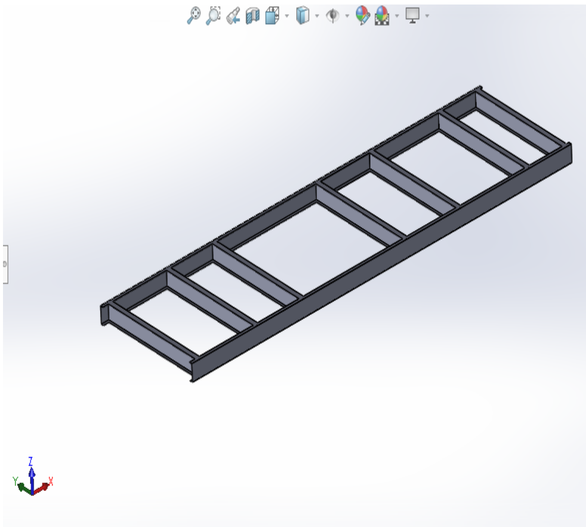

Fig 2. C-Section chassis frame with C-Section cross members.

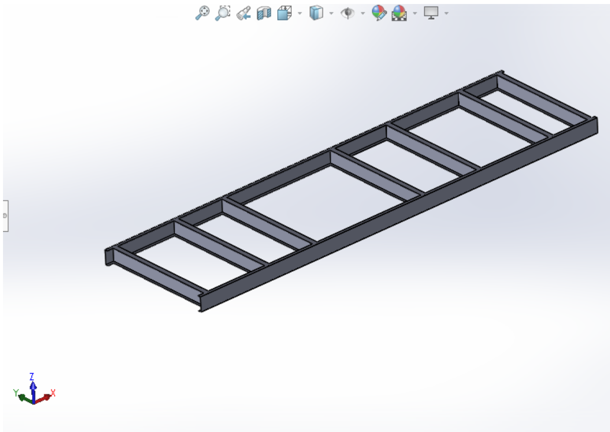

Fig 3. C-Section chassis frame with T-Section cross members.

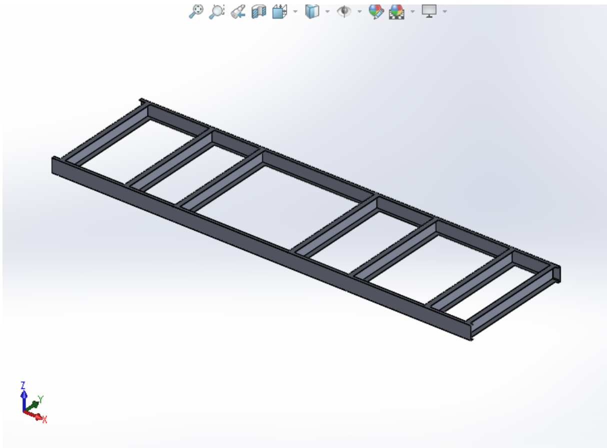

Fig 4. C-Section chassis frame with T-Section cross members.

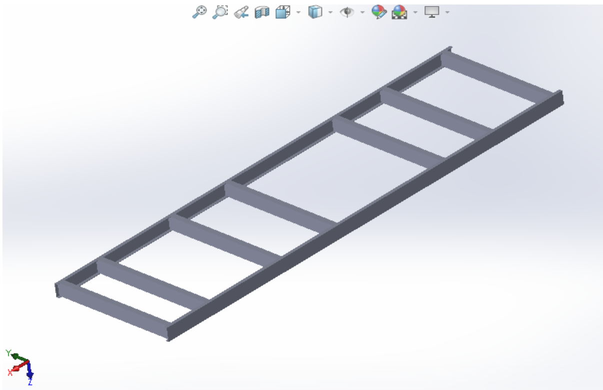

Fig 5. C-Section chassis frame with box-section cross members.

Using the dimension of side and cross members, CAD model of C-section chassis frame with I, T, and box section of cross-members have been modeled using SOLIDWORKS 2016. The solid model generated has been shown in Fig. 4 to Fig. 7. Further, CAD model is converted into IGES format and then imported for analysis in ANSYS 2016.

4. Loads and Boundary Conditions:

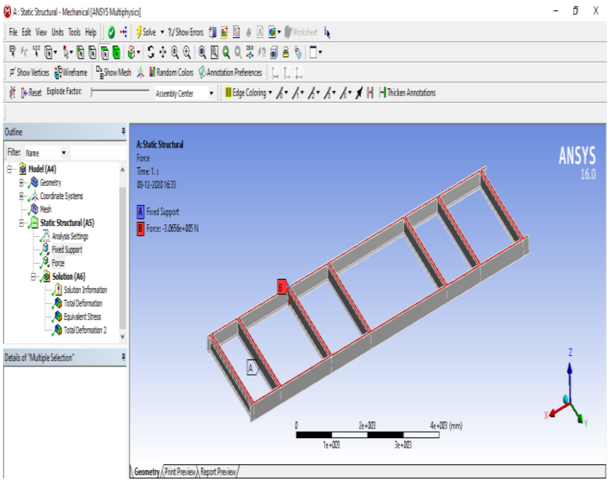

Fig 6. Boundary conditions for C-Section chassis frame with C-Section cross members.

IV. RESULTS AND DISCUSSION

1. FEM Results:

FEM analysis has been performed on CAD model of C-section chassis frame with I, T, and box section of cross-members and results are discussed based on stress, strain and deformation.

1.1 Deformation: Static structural analysis has been performed on ladder chassis frame with different shapes of cross members. The contour plots of deformation are shown in Fig.7-10.

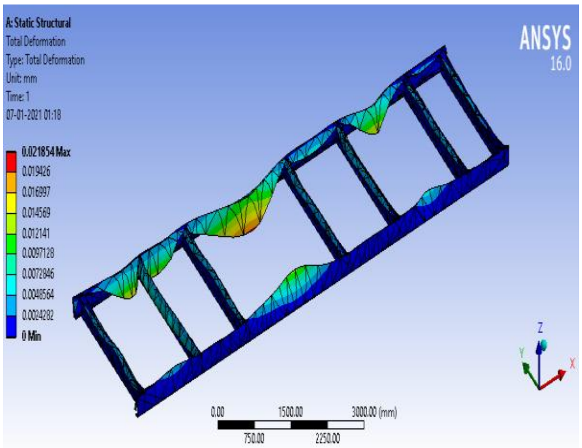

Fig 7. Deformation plots of ladder chassis with C-section.

In fig.1, it is observed that max. deformation is 0.0218 mm in case of ladder chassis with C-section but when the shape of cross-member is changed from C- section to I-section, deformation is increased to 0.0238 mm as shown in fig. 8.

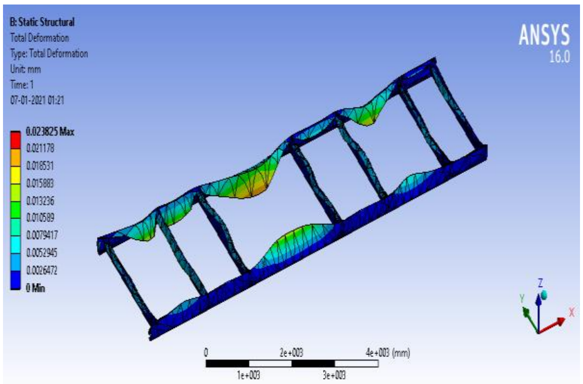

Fig 8. Deformation plots of ladder chassis with I-section.

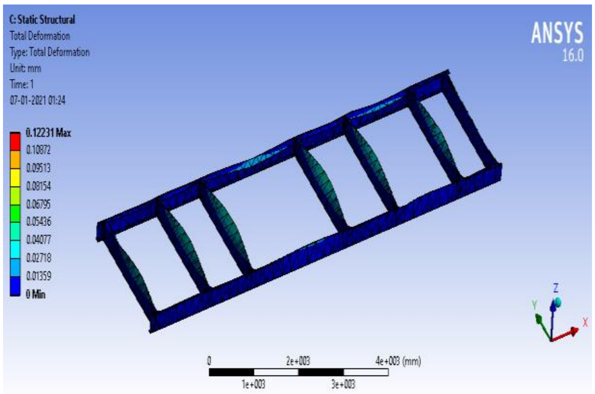

Fig 9. Deformation plots of ladder chassis with T-section.

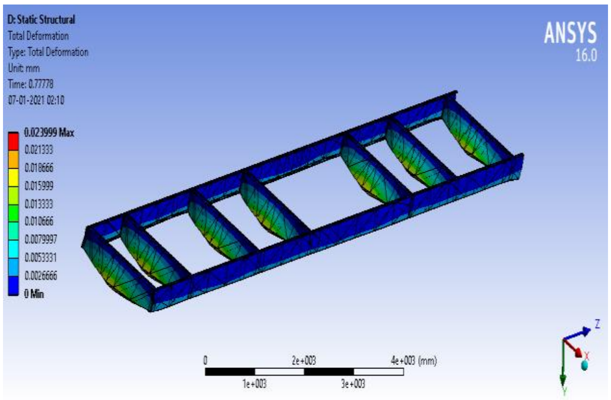

Fig 10. Deformation plots of ladder chassis with box-section.

In fig. 3, it is observed that max. deformation is 0.122 mm in case of ladder chassis with T-section but when the shape of cross-member is changed from T-section to box-section, deformation is decreased to 0.0239 mm as shown in fig 10.

Therefore, it is concluded that max. deformation is found in ladder chassis withT-section and min. deformation is found in ladder chassis with C-section.

Table 3. Deformation Results.

Type	Deformation, mm	Remark
Ladder chassis with C-section	0.0218	Min.
Ladder chassis with I-section	0.0238	
Ladder chassis with T-section	0.122	Max.
Ladder chassis with box-section	0.0239	

1.2 Stress: Static structural analysis has been performed on ladder chassis frame with different shapes of cross members. The contour plots of stress are shown in Fig. below.

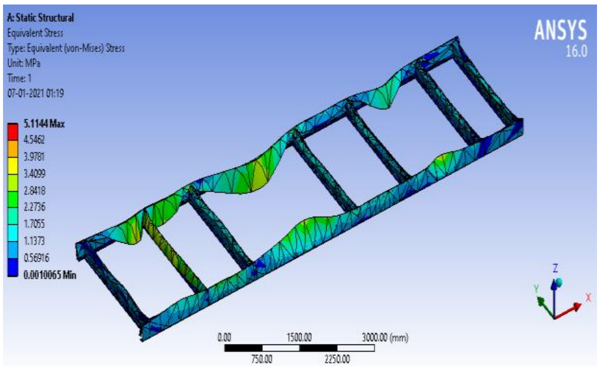

Fig 11. Stress plots of ladder chassis with C-section.

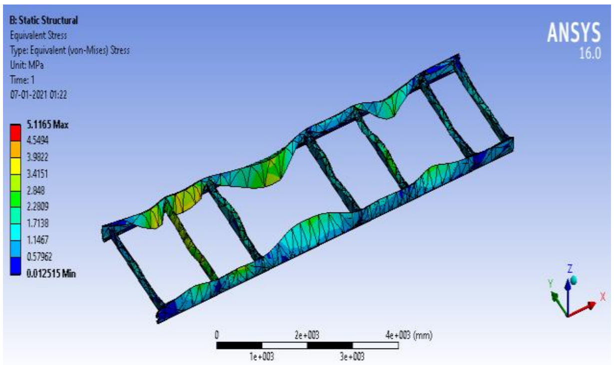

Fig 12. Stress plots of ladder chassis with I-section.

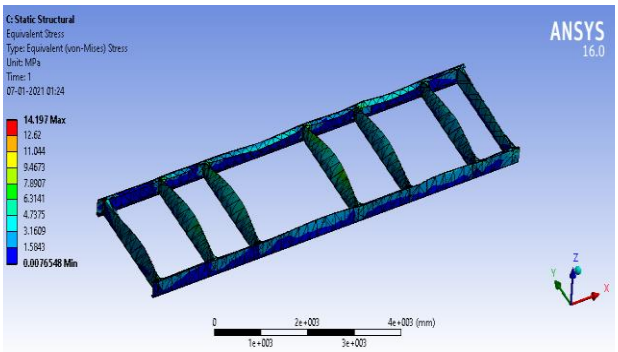

Fig 13. Stress plots of ladder chassis with T-section.

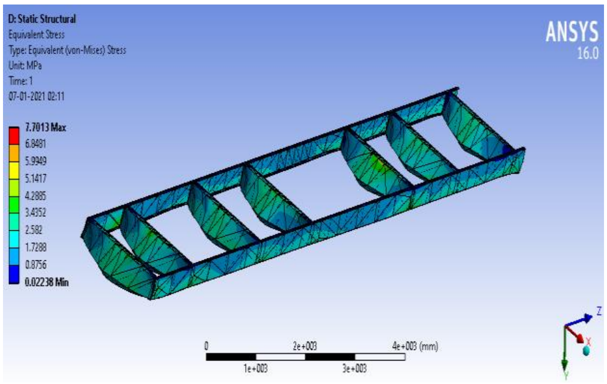

Fig 14. Stress plots of ladder chassis with box-section.

Stress obtained is shown in fig. 11-14. In case of ladder chassis with C-section stress obtained as 5.114 MPa, in case of ladder chassis with I-section stress obtained as 5.116 MPa, in case of ladder chassis with T-section stress obtained as 14.19 MPa and in case of ladder chassis with box-section stress obtained as 7.70 MPa. From the Table 5.2, max. Stress is found in ladder chassis with T-section and min. stress is found in ladder chassis with C-section.

Table 4. Stress Results.

Type	Stress, MPa	Remark
Ladder chassis with C-section	5.114	Min.
Ladder chassis with I-section	5.116	
Ladder chassis with T-section	14.19	Max.
Ladder chassis with box-section	7.70	

1.3 Strain: Static structural analysis has been performed on ladder chassis frame with different shapes of cross members. The contour plots of strain are shown in Fig. 15-18

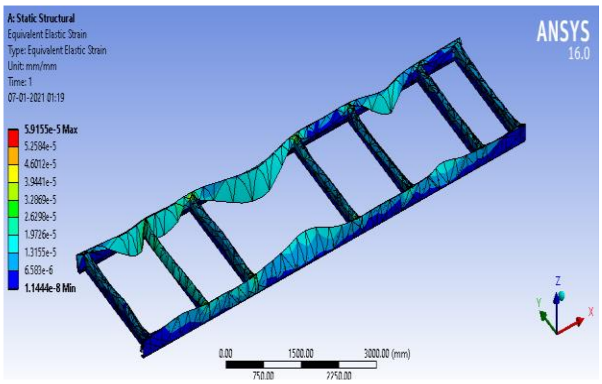

Fig 15. Strain plots of ladder chassis with C-section.

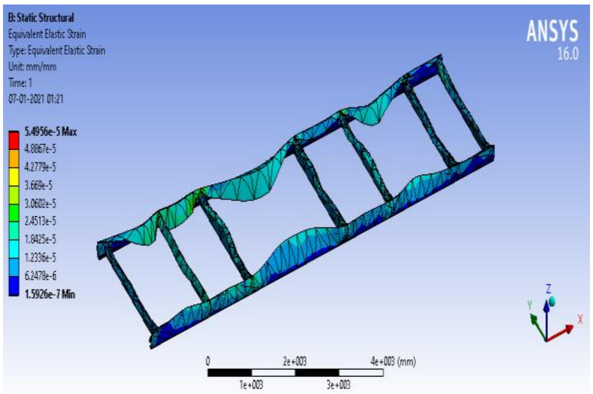

Fig 16. Strain plots of ladder chassis with I-section.

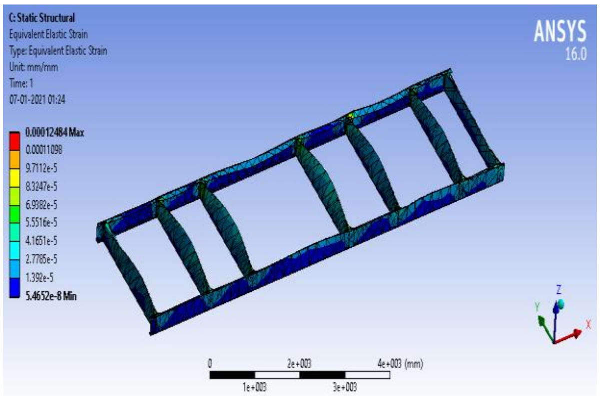

Fig 17. Strain plots of ladder chassis with T-section.

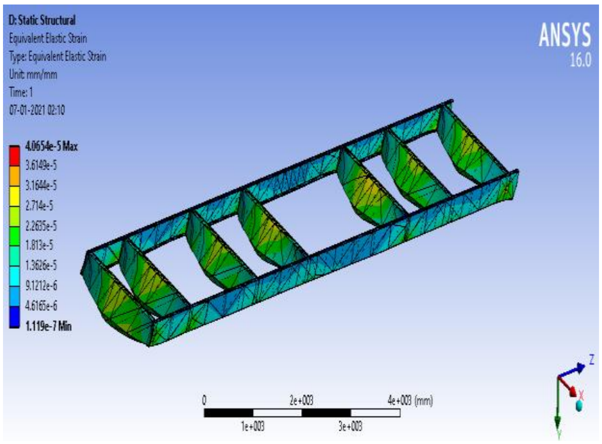

Fig 18. Strain plots of ladder chassis with box-section.

Strain obtained is shown in fig. 15-18. In case of ladder chassis with C-section stress obtained as 5.91 x 10-5, in case of ladder chassis with I-section stress obtained as 5.49 x 10-5, in case of ladder chassis with T-section stress obtained as 0.00012 and in case of ladder chassis with box-section stress obtained as 4.06x 10-5.

From the Table 4.3, max. Strain is found in ladder chassis with T-section and min. strain is found in ladder chassis with C-section.

Table 5. Strain Results.

Type	Strain	Remark
Ladder chassis with C-section	5.91×10^{-5}	-
Ladder chassis with I-section	5.49×10^{-5}	-
Ladder chassis with T-section	0.00012	Max.
Ladder chassis with box-section	4.06×10^{-5}	Min.

2. Weight Reduction:

For weight reduction analysis, weight of ladder chassis is directly obtained from ANSYS as shown in Table 4.

Table 6. Weight Results.

Type	Weight, Kg	Remark
Ladder chassis with C-section	836.55	
Ladder chassis with I-section	749.47	Min.
Ladder chassis with T-section	836.6	
Ladder chassis with box-section	1034.1	Max.

In case of ladder chassis with C-section weight obtained as 836.55 kg, in case of ladder chassis with I-section stress obtained as 749.47 kg, in case of ladder chassis with T-section stress obtained as 836.6 kg and in case of ladder chassis with box-section stress obtained as 1034.1 kg. From the Table 4, max. weight is found in ladder chassis with box-section and min. weight is found in ladder chassis with I-section.

V. CONCLUSION

In this study, design analysis and shape optimization of ladder chassis frame is performed. Static analysis is performed on ladder chassis frame to find out the stress, strain and displacement in a ladder chassis due to acting loads. Solid Works software is used for the modelling of ladder chassis frame and ANSYS is used for the static analysis of ladder chassis fame.

Coming to shape optimization, the cross-section of cross-members will be changed accordingly C, T & I and tested for the same. A710 steel is considered and tested for performance.

Following conclusion is summarized as follows:

- The generated stresses are within the permissible limit as yield strength of A710 steel is 455 MPa so design is safe.
- Deformation is minimum in ladder chassis with C-section and maximum in ladder chassis with T-section.
- Stress is maximum in ladder chassis with T- section and minimum in ladder chassis with C- section.
- For weight reduction analysis, minimum weight of Ladder chassis with I-section is 749.47 kg and maximum weight of Ladder chassis with box-section is 1034.1 kg.
- So with regard to different cross-section of cross-member in ladder chassis, C- section is suitable for trucks.

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