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Analysis of the Cross Member Designs Used For Improving the Tensional Stiffness of Heavy Commercial Vehicle Chassis Frame

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Abstract **:***The chassis frame is the most important part of a heavy duty vehicle. Its main function is to safely carry the maximum load under all designed operating conditions. Hence it should be rigid enough to withstand various forces coming on it like bending forces, twisting forces, vibrations and other forces. An important factor in chassis frame design is to have adequate strength as well as torsional stiffness for better handling characteristics. Therefore, maximum shear stress induced in the frame and deflections during various operating conditions are important criteria for the chassis frame design. Cross-member assist the side rails to overcome lateral, bending and mainly torsional loads.In this paper, analysis of25 tonne capacity truck chassis frame is presented. Finite element analysis of various cross member designs is performed with the help of Hypermesh software. This work involves static analysis to determine the torsional and lateral stiffness of the chassis frame by using different types of cross sections namely C-section, hollow square and tubular. Weight and stiffness of various sections are compared to suit the best section for the chassis frame for torsional as well as lateral stiffness improvement.*

Keywords:*Heavy Vehicle Chassis, Torsional Stiffness, Static Analysis, Cross Members, Deformation*

I. Introduction

The most important structural member of any heavy commercial vehicle (HCV) is its chassis frame. It is approximately a rectangular frame resembling a ladder. This type of chassis frame is often referred to as a ladder frame. It comprises of two side members also called long members joined by a series of cross members. Along with the strength, an important consideration in the chassis design is to have adequate bending and torsion stiffness. Adequate torsional stiffness is necessary to have good handling characteristics. Commonly the chassis frames are designed on the basis of strength and stiffness. As per the conventional design procedure, the stiffness of the chassis is increased by adding cross members which results in overall increase of weight of chassis. This increase in weight of the chassis results inlowering fuel efficiency and increase in the overall cost due to extra material. Hence the design of the chassis with adequate stiffness and strength is necessary. Fig.1 illustrates a chassis of HCV:

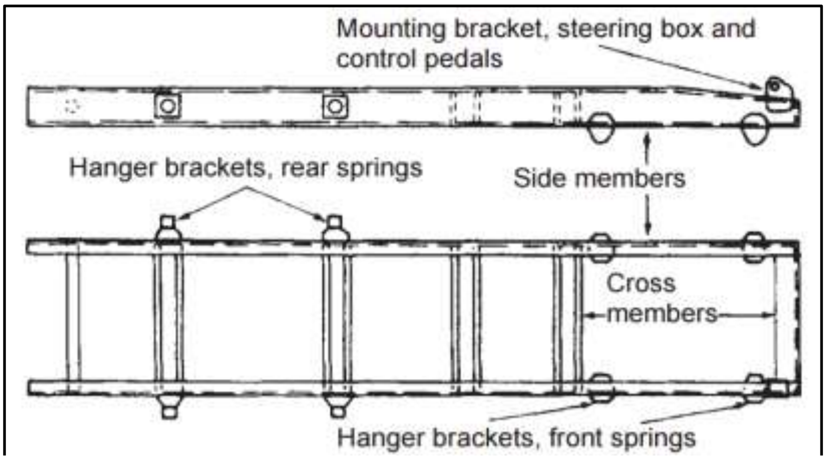

Fig.1: HCV ladder chassis frame [14]

The loads acting on the frame are:

1. Weight of the body, passengers, and cargo loads.
2. Vertical and twisting load due to uneven road surfaces.
3. Lateral forces caused by road camber, side wind and steering the vehicle.
4. Torque transmitted from engine and transmission.

OjoKurdiet.al [1] worked on the optimization of Hino model truck chassis frame for high torsional stiffness by simple modifications in shape. Torsional stiffness is dependent on property of a structure and independent ofmagnitude of applied load. Chassis torsional stiffness depends upon the types of cross section used and material of the chassis frame. Raghu [2] worked on the effect of stiffness parameters on the crashworthiness of the ladder frame. Optimized cross section of side member of chassis is obtained by considering the specific energy absorption as the objective function to be maximized. Akash and Jaideep [3]worked on the design and analysis of TATA 2518 TC chassis frame with constraints of maximum stress induced and deflection of chassis under maximum load. S.Prabakaran and Gunasekar [4] worked on the optimization of chassis frame of Eicher E2 model by varying the section of long member for three different cases with constraints of maximum shear stress and deflection of chassis under maximum load.

Divyesh et.al [5] worked on AMW 2523 TP truck chassis with constraints of maximum shear stress and deflection of chassis under maximum load. Chassis frame is modelled with three different cross sections namely C, I and Rectangular Box type cross sections and after analysis it is found that the rectangular cross section has the least deflection among all the three cross sections considered. Rakesh Kumar Sahu et.al [6] performed the static load analysis on a small vehicle having load carrying capacity of 1 ton. The different cross sections selected for the analysis are rectangular, square and tubular section and analysis is performed with two different materials i.e. structural steel and aluminium alloy. Prakash and M. Prabhu [7] works on the improvement of torsional stiffness based on the results obtained from FE analysis. Improvement in torsional stiffness is achieved by providing stiffener in front and rear portion of the frame. KamleshPatil and EknathDeore [8] worked on the optimization ofTATA 912 Diesel bus chassis frame with constraints of maximum shear stress and deflection of chassis under maximum load. From the analysis results, it is observed that the rectangular box section is more strength full than C and I-section. Siva Nagaraju et.al [9] worked on analysis of Innova car chassis with different cross sections. The results of the analysis show that induced stresses in C-section aremore in the box type section but it is within the ultimate strength limit, so it can be used. The C-type cross section has less weight as compare to rectangular section and also provide operational benefits. Abhishek Sharma et.al [10] worked on the design and analysis of theTATA LPS 2515 EX truck chassis. The results show that box type cross section is best in terms of deflections but the overall weight of the chassis is high as compared to other cross members.Patel Vijaykumar and R. I. Patel [11] worked on the design modification of the existing cross section by changing the dimension to optimize the chassis weight. Abhishek Singh et.al [12] analyzed the TATA LP 912 with higher strength as the main criteria. For validation the design is done by applying the vertical loads acting on the horizontal of different cross sections.Lenin Rakesh et.al [13] worked on the investigation of the structural analysis of the Ashok Leyland chassis. Analysis is performed by using three different materials namely Al-360, cast iron GFRP to select the best one.

1.1. Significance of torsional and lateral stiffness of chassis

Handling performance of vehicle is mostly accounted on torsional rigidity of chassis. Increased chassis torsional rigidity improves the vehicle handling characteristics. Higher torsional stiffness allows the suspension components to control larger percentage of vehicle kinematics. Lack of torsional stiffness of chassis frametends to magnify the effect of under steering and over steering of the vehicle. Also the front and rear axle portion of the chassis frame get twisted due to the uneven road conditions resulting in single wheel bump conditions. To overcome the failure of the chassis frame in such conditions optimum torsional stiffness of the chassis frame is necessary.

Lateral bending of chassis is due to camber of the road, side wind, centrifugal force while negotiating a turn or collision with some object. Lateral forces act along the length of the chassis. Therefore, the lateral stiffness of chassis is also important.

II. Problem Statement

Torsional stiffness of chassis frame is necessary to overcome the various load coming on it due to the uneven road surfaces, road camber, loads while negotiating a turn etc.The main disadvantage of the ladder frame is its low torsional rigidity. Since it is a two-dimensional structure, its torsion rigidity is lower than other chassis. The weight of the ladder chassis is also high compare to other types of chassis.This paper describes the stiffness analysis of the heavy commercial vehicle chassis frame by using various types of cross sections for improvement of torsional stiffness with constraints of maximum weight and deflection of chassis frame under constant load. As per the data available from benchmarking of various truck chassis frame it has been found that commonly used section in truck chassis frame for cross member are C-sections, hollow square and tubular sections. Almost 65% of HCV chassis frame has C-sections as they are good in resisting bending forces. Hence comparison of these three sections with respect to torsional and lateral stiffness and weight as a constraint is performed.

Objectives of the proposed work

1. Compare various cross section of cross member with respect to torsional stiffness.
2. To find the best type of cross section for the improvement of torsional stiffness with constraints of weight.
3. To validate the cross-member as per the acceptance criteria defined.

III. Specifications of the Existing Chassis Frame

Stiffness analysis of 25 Tonnage capacitytruck chassis frame is performed by using Hypermesh software and Optistruct as a solver. The existing material for chassis is steel with yield strength 410 MPa. Existing weight of the chassis is 610.4 Kg. Suspension brackets and other aggregates are not considered in the analysis.

Chassis frame material

The existing chassis frame material is BSK46. It is widely used automotive structural steel. Table 1 shows the physicalproperties of BSK46 and Table 2 shows the specifications of the chassis frame under consideration.

Table no 1: PhysicalProperties of BSK46. [5]

Sr. No	Parameter	Values
1	Overall Length Of Frame	9250 mm
2	Front Width of Frame	893 mm
3	Rear Width of Frame	790 mm
4	Wheel base	5305 mm

Table no 2: Specification of Existing Chassis frame

Sr. No	Parameter	Values
1	Modulus Of Elasticity	210 GPA
2	Density	7850 Kg/m^3
3	Yield strength	410 MPa
4	Poisonous Ratio	0.3

Side members of the existing chassis frame are made from C- Channels with section as 300x90x7 mm. Fig 2 shows the top view of chassis frame under consideration.

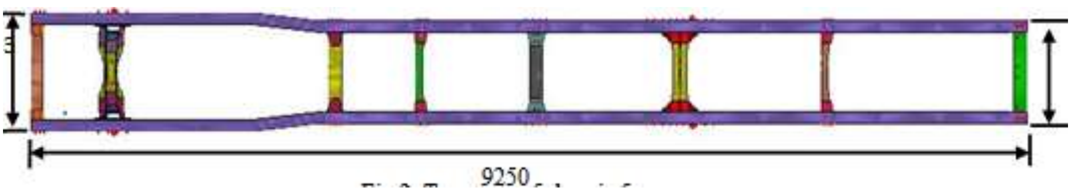

Fig.2: Top view of chassis frame

IV. FE Analysis of Existing Chassis Frame

2D meshing of the frame with element size as 10 is used. To obtain the stiffness, 10 KN load is applied on each long member at the location of shear center. The deformation of chassis frame under this load and constraints are used to calculate the stiffness of the chassis. Four different load cases are considered namely front torsion load case, rear torsion load case, front lateral load case and rear lateralload case to compare the overall stiffness of the chassis frame. Fig.3 illustrates the loads and boundary conditions used in the analysis and Table 3 shows the constraints for various load cases.

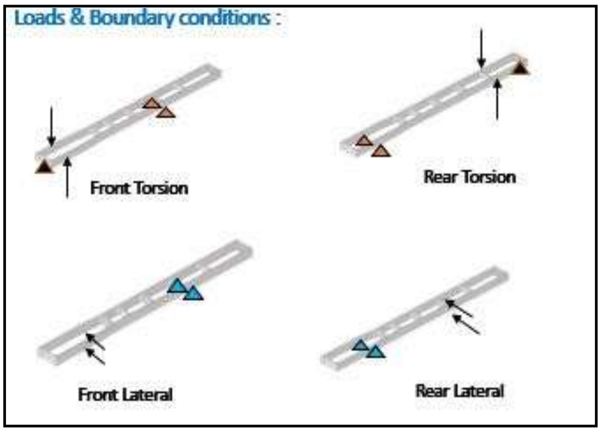

Fig.3: Loads and boundary conditions

Table no 3: Constraints for the load cases.

Symbol	Degree of freedom
	3
	123
	123456

For front torsion load case the load is applied on the front two nodes on the long member at the location of shear center. The direction of loads applied is such that it will generate a torque on the front portion of the chassis. This condition of chassis frame is same as when one of the wheel of the front axle is displaced in downward direction and the opposite wheel is in the up word direction due to the uneven road conditions. Aload of 10 KN is applied at each node at front shear center and constrainedis applied at U_x, U_y and $U_z$at rear shear center and U_z at mid of front cross members. This midpoint will act as a pivot point along which the chassis will oscillate. The deformation is measured as the maximum displacement of node where force is applied. Similarly, the deformation of chassis in rear torsion load case is found.For front lateral load case, load is applied at the front shear center point in the lateral direction of the chassis. The magnitude of load applied on each side is 10 KN and U_x, U_y, $U_{z,}$ Ro_x, Ro_y and Ro_z isconstraints at the rear side of chassis frame, so that the deformation of chassis in lateral direction can be measured.Similarly, the deformation of chassis in rear lateral load case is found.

Fig.4 to Fig.7 shows the deformation of the chassis in front torsion load case, rear torsion load case, front lateral load case and rear lateralload case respectively.

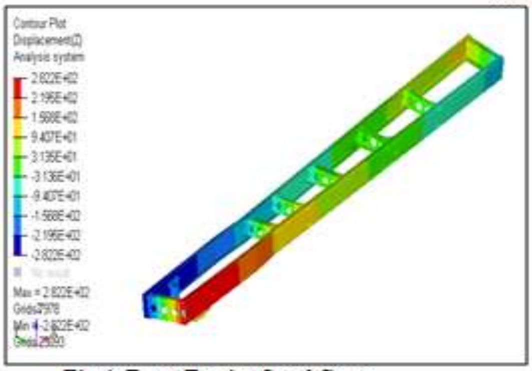

Fig 4: Front Torsion Load Case

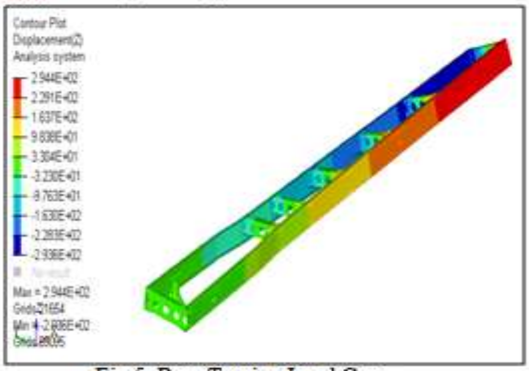

Fig 5: Rear Torsion Load Case

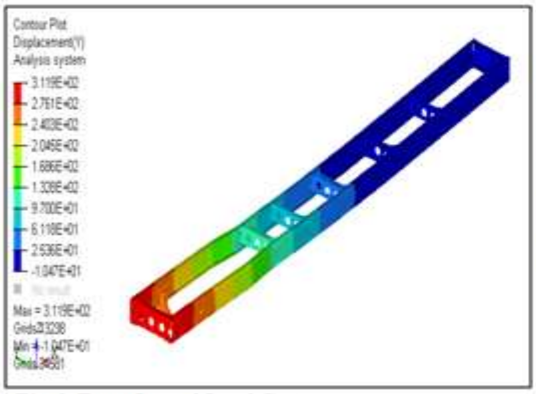

Fig 6: Front Lateral Load Case

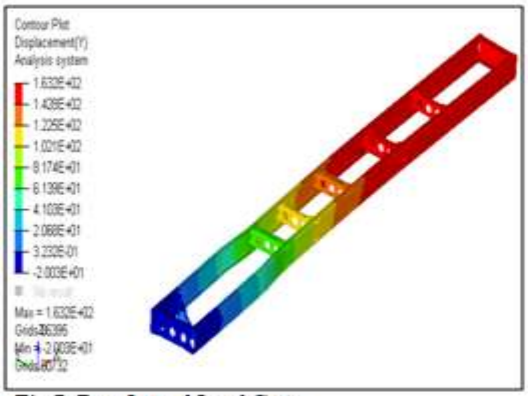

Fig 7: Rear Lateral Load Case

From the Finite Element Analysis results the values of deformation for the four load cases are obtained. Table 4 shows the deformation of chassis under the given load conditions.

Table no 4: Results of FE analysis for existing chassis frame

Sr. No	Parameter	Deformation (mm)	Weight (Kg)
1	Front Torsional deformation	268	610.4
2	Rear Torsional deformation	208	
3	Front lateral deformation	264	
4	Rear Lateral deformation	158	

4.1. Calculations for Stiffness of Chassis

1) Front Torsional Stiffness calculations:

$$\text{Tan } \theta = \frac{\text{Displacement in Z direction}}{\text{Distance between two Nodes where Load is apllied }/2}$$

$$\text{Tan } \theta = \frac{268}{920.448/2}$$

$$\theta = 30.21\,°$$

Torque = Force x Radial Distance Torque = 10 x 920.448/1000 = 9.20448 KN.m

$$\text{Front Torsional Stiffness} = \frac{\text{Torque Applied}}{\text{Angular Deflection}} = \frac{9.20448}{30.21} = 0.3046\ \text{KN.m/deg}$$

2) Rear Torsional Stiffness calculations:

$$\text{Tan } \theta = \frac{\text{Displacement in Z direction}}{\text{Distance between two points where Load is apllied }/2}$$

$$\text{Tan } \theta = \frac{208}{810.634/2} \qquad \theta = 27.16\,°$$

Rear Torsional Stiffness =(Torque Applied)/Angular Deflection = 8.10634/27.16 = 0.2984 KN.m/deg

3) Front Lateral Stiffness calculations:

$$\text{Stiffness} = \frac{\text{Force Applied}}{\text{Displacement In Y direction}} = \frac{10}{264} = 0.03787\ \text{KN/mm}$$

4) Rear Lateral Stiffness calculations:

$$\text{Stiffness} = \frac{\text{Force Applied}}{\text{Displacement In Y direction}} = \frac{10}{158} = 0.06329\ \text{KN/mm}$$

Table no 5. Stiffness Results for Existing Chassis Frame

Sr. No	Parameter	Stiffness
1	Front Torsional Stiffness	0.3046 KN.m/deg
2	Rear Torsional Stiffness	0.2984 KN.m/deg
3	Front lateral Stiffness	0.03787 KN/mm
4	Rear Lateral Stiffness	0.06329 KN/mm

4.2. FE analysis of Chassis Frame with Hollow Square Cross Member

The analysis of the existing chassis frame shows large deformation of frame in front and rear torsional load case. From Table 4 the deformation of chassis in front torsion is 268 mm and in rear torsion it is 208 mm. Torsional stiffness of chassis is influenced by thetype of cross member present at the front and rear side of the chassis. Hence to determine the effect of changing of cross member in chassis frame, 3rd cross member and 7th crossmember is replaced by hollow square cross member. Fig.8 shows the CAD model of hollow square cross member and Fig.9 meshed frame with 3rdand 7th as hollow square cross member.The replaced square cross member used for analysis is having 4 mm thickness and 80*80 mm outer dimension. Analysis is performed by applying the same load and boundary conditions as used for the existing chassis frame. Table 6 shows the deformation and stiffness of chassis frame with 3rd and 7th cross member as hollow Square.

Fig 8: CAD Model of hollow square CM

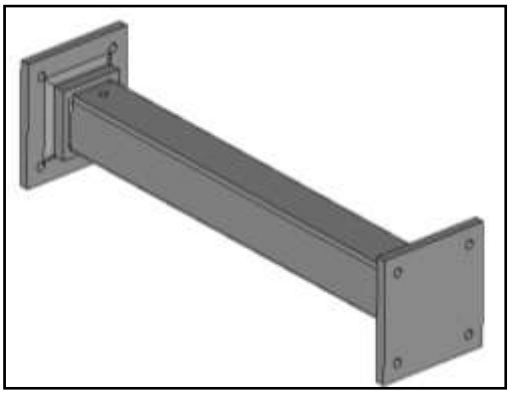

Fig 9: Meshed frame with hollow square cross member

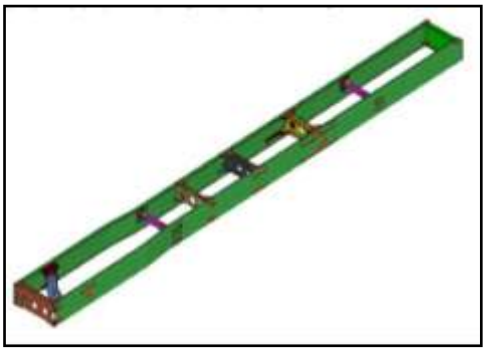

Table no 6: Deformationand Stiffness of chassis frame with 3rd and 7th cross member as hollow square

Sr. No	Load case	Deformation (mm)	Stiffness	Weight (Kg)
1	Front Torsion	182	0.4266 KN.m/deg	618.2
2	Rear Torsion	141	0.4226 KN.m/deg	
3	Front Lateral	258	0.0388 KN/mm	
4	Rear Lateral	152	0.0658 KN/mm	

4.3. FE analysis of Chassis Frame with Tubular Cross Member

In this iteration 3rdand 7th cross member is replaced by Tubular cross member. The replaced Tubular cross member used for analysis is having 4 mm thickness and 80 mm outer diameter. Fig.11 shows the CAD model of tubular cross member and Fig.12 shows meshed frame with 3rd and 7th as tubular cross member.

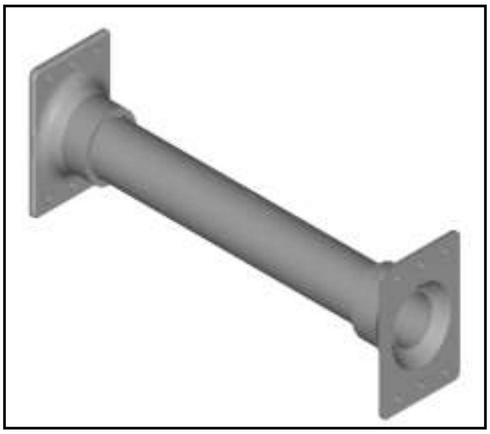

Fig 11: CAD Model of Tubular CM

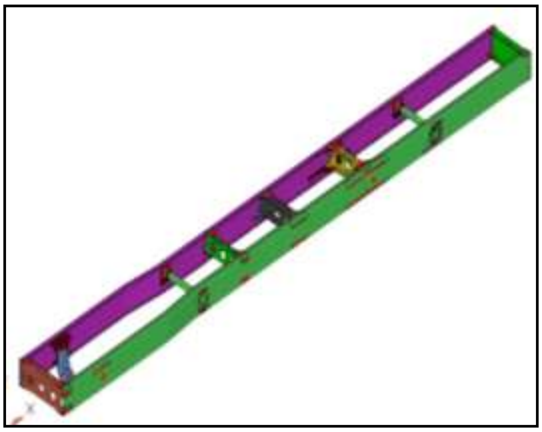

Fig 12: Meshed Frame with Tubular Cross member

Analysis is performed by applying the same loads and boundary conditions as used for the existing chassis frame. Table 7 shows the deformation and stiffness of chassis frame with 3rd and 7th cross member astubular.

Table no 7:Deformation and Stiffness of chassis frame with 3rd and 7th cross member astubular

Sr. No	Load case	Deformation (mm)	Stiffness	Weight (Kg)
1	Front Torsion	171	0.4516 KN.m/deg	611.1
2	Rear Torsion	133	0.5710 KN.m/deg	
3	Front Lateral	241	0.0415 KN/mm	
4	Rear Lateral	144	0.0694 KN/mm	

From the analysis results of Chassis frame with tubular cross member, it has been found that the deformation in front and rear torsion case is decreased significantly. Front torsional deformation of chassis is decreased by 97mm and hence the stiffness is improved considerably. Also the rear torsion deformation is decreased by 75 mm. Front and lateral deformation of the chassis is decreased by 23 mm and rear lateral deformation is decreased by 14 mm.

V. Results and Discussion

Fig.13 and 14 show the reduction in torsional deformation of the chassis and hence the improvement in torsional stiffness by changing the cross sections of the chassis. The reason behind the improvement of torsional stiffness is that the torsional stiffness of the section is directly related to the amount of material present away from center of gravity of section. Hollow square section and tubular section have more material present away from center as compared to existing C-section and hence give better results for torsional stiffness of the chassis frame. The weightof the chassis is increased by 7.8 kg by using hollow square cross member but by using tubular cross member the weight increment is very small i.e. 0.7 kg.

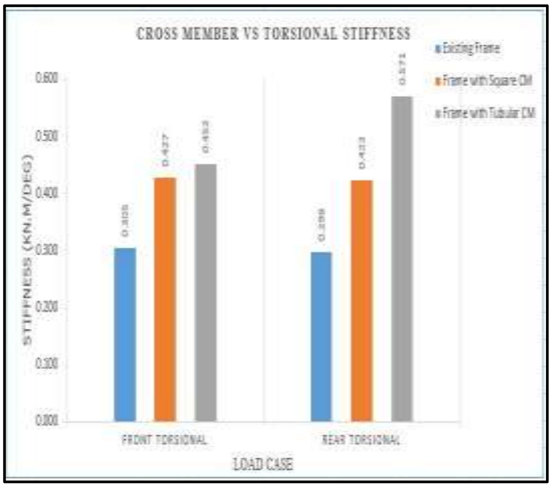

Fig.13: Comparison of Torsional Stiffness.

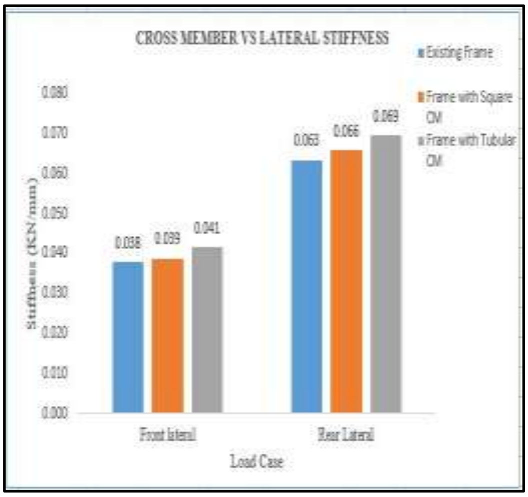

Fig.14: Comparison of Lateral Stiffness.

Fig.15 and Fig.16 show the Strain energy contribution of existing C-section cross member, hollow square cross member and tubular cross member respectively in front and rear torsion load cases.

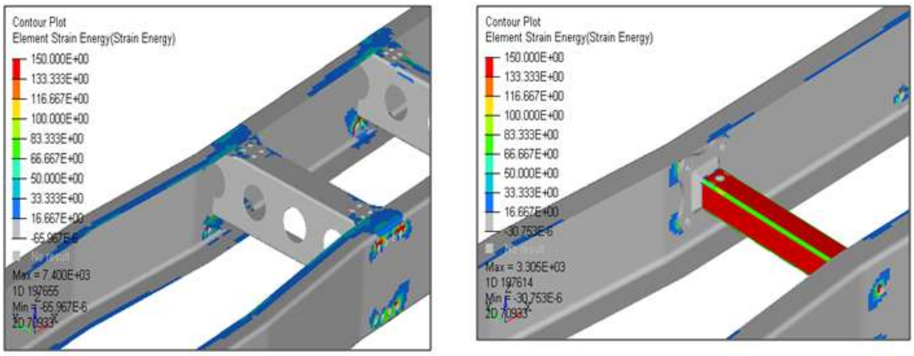

Fig 15: Strain energy contribution of 3rd cross member in front torsion load case

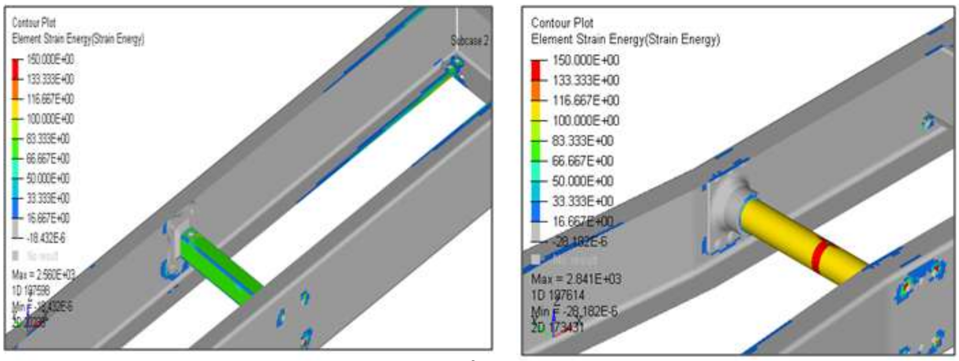

Fig 16: Strain energy contribution of 7th cross member in rear torsion load case

VI. Conclusion

The existing heavy vehicle chassis of 25 tonnage model is analyzed with different cross sections. After stiffness analysis a comparison is made between three different cross member sections with respect to torsional stiffness of the chassis. From the analysis results, it has been observed that the hollow square section and tubular sections is superior than the existing C-Section. Torsional stiffness of the chassis by using hollow square cross member is increased by 29% and lateral stiffness by 3.80%. Although this adds additional weight of 7.8 kg to the chassis frame. Chassis frame with tubular cross members provides 47% increment in torsional stiffness and 8.86% increment in lateral stiffness. Also the weight increment by using Tubular cross member is very small i.e.

0.7 kg.Hence from the analysis it is concluded that the tubular section is best for improvement of torsional stiffness of the chassis frame under consideration.

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