Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444
Volume 3, Issue 5, May-2016

Strength and rigidity analysis of heavy vehicle chassis for different frame cross section by analytically and FEA under various loading condition

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Abstract* — *The chassis frame forms the backbone of a heavy vehicle, its principle function is to safely carry the maximum load for all designed operating conditions. It should be rigid enough to withstand the shock, twist, vibration and other stresses. An important consideration in chassis design is to have adequate bending stiffness along with strength for better handling characteristics. Therefore, maximum shear stress and deflection are important criteria for the chassis design. This paper describes Structural analysis of heavy vehicle chassis with constraints of maximum shear stress and deflection of chassis under maximum load. In the present work, we have taken higher strength as the main issue, so the dimensions of an existing vehicle chassis of AMW 2523 TP truck is taken for analysis with materials namely BSK 46 Steel subjected to the same load. The three different vehicle chassis have been modeled by considering three different cross-sections. Namely C, I and Rectangular Box type cross sections. For validation the design is done by applying the vertical loads acting on the horizontal different cross sections.
Software used in this work Creo Parametric 2.0 & ANSYS 14.0.

Keywords- heavy vehicle chassis, Static Analysis, C, I and Rectangular Box type cross sections.

I. INTRODUCTION

Automotive chassis is a frame just like skeletal on which various machine parts like engine, tires, axle assemblies, brakes, steering etc. are bolted. It gives strength and stability to the vehicle under different conditions. Frames provide strength as well as flexibility to the automobile. Automotive frames are generally manufactured from steel alloys. Frame holds the body and motor of an automotive vehicle. According to the structure of chassis, the body of a vehicle is flexibly molded at the time of manufacturing. Automobile chassis is generally made of light sheet metal. It provides strength needed for supporting vehicular components and payload placed over it.

Automotive chassis or automobile chassis helps keep an automobile rigid, stiff and unbending. Auto chassis ensures low levels of noise, vibrations and harshness throughout the automobile. The different types of automobile chassis include:

Ladder Chassis: Ladder chassis is considered to be one of the oldest forms of automotive chassis or automobile chassis that is still used by most of the SUVs till today. As its name connotes, ladder chassis resembles a shape of a ladder having two longitudinal rails inter linked by several lateral and cross braces.

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

Backbone Chassis: Backbone chassis has a rectangular tube like backbone, usually made up of glass fiber that is used for joining front and rear axle together. This type of automotive chassis or automobile chassis is strong and powerful enough to provide support smaller sports car. Backbone chassis is easy to make and cost effective.

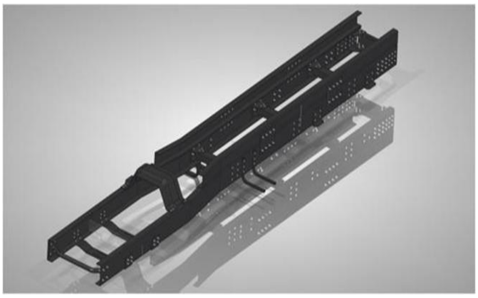

Figure 1 Heavy Vehicle Chassis

II. LITERATURE REVIEW

Cicek Karaoglu et al [1] have does stress analysis of heavy duty truck chassis with riveted joints by utilizing a commercial finite element package ANSYS version 5.3. During this study, he examine the effect of the side member thickness and connection plate thickness with length change, the side member thickness is varied from 8 to 12 mm, and the thickness of the connection plate is also varied from 8 to 12 mm by local plate, the connection plate thickness is varied from 7 to 10 mm, and the length of the connection plate (L) is varied from 390 to 430 mm. From this he concluded that if the change of the side member thickness using local plates is not possible, due to increase weight of chassis then choosing an optimum connection plate length (L) seems to be best practical solutions for decreasing the stress values.

Sairam Kothari et al [2] have studied the analysis of chassis frame for improving its payload by adding stiffener and c channel at maximum stress region of chassis frame. Analyzed was carried out for both dynamic and static load condition with the stress deflection bending moment on the Tetra chassis frame using software-Ansys. We found that with limited modifications like suitable reinforcement, increase in thickness, adding stiffeners and c channel, present payload of the Tetra can be improved from 10.4 tons to 14 tones and stress levels can be reduced from 737.3 N/mm^2 to 173.38 N/mm^2. It is less than yield stress 410 N/mm^2.

Table 1 Material property of chassis

No	Material	Yield Strength (σ_y)	Ultimate Tensile Strength (σ_u)	Young's Modulus (E)	Poisson's Ratio (ν)
1	High Strength Structural Steel	410 N/mm^2	540 N/mm^2	2,00,000 N/mm^2	0.3

Table 2 Specifications of the chassis

No	Description	Dimension (mm)
1	Length of Chassis	10208
2	Width of Chassis	1000

Sharad D. Kachave et al [3] have studied stress analysis and effect of web and flange's thickness on bending stiffness of a ladder type low loader truck chassis structure consisting of C-beams as a cross member. Structural analyses carried out by changing the thickness of web and flange by 1mm. The commercial finite element package ANSYS was used to analyze the stress and deflection for the solution of the problem. Web and flange thickness was optimized for bending stiffness.

The maximum deflection and stress was found to be 1.201 mm & 124.02 N/mm^2 in case 2 whereas minimum deflection and stress was found to be 0.97404 mm & 100.31 N/mm^2 in case 3. The maximum bending stiffness found to be 12011.83 N/mm in case 3 and minimum bending stiffness is found to be 9741.88 N/mm in case 2. The maximum weight found to be 557.56 kg in case 3 whereas minimum weight found to be 533.35 kg in case 4. Bending stiffness to weight ratio is found to be maximum 21.54 N/Kg.mm in Case 3 and minimum 18.13 N/Kg.mm in case 2. From bending stiffness to weight ratio it was clear that increase in flange thickness is more beneficial to increase bending stiffness as compared increase in web thickness.

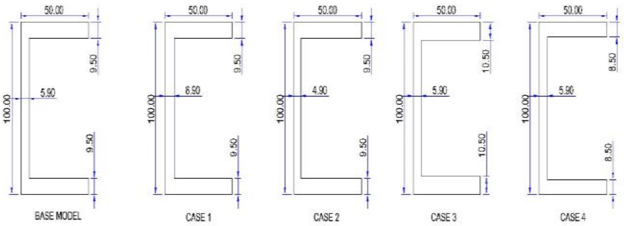

Figure 2 Dimensions of section consider for analysis

III. PROBLEM STATEMENT

In present the Ladder chassis which are uses for making buses and trucks are C and I cross section type, which are made of Steel alloy. In India no of passengers travel in the bus is not uniform, excess passengers are travelling in the buses daily due to which there are always possibilities of being failure/fracture in the chassis/frame. Therefore Chassis with high strength cross section is needed to minimize the failures including factor of safety in design. Basically C cross section type of chassis is used in buses and I cross section type in heavy trucks where high strength is required. So we have taken Rectangular Box type cross section for making ladder chassis by fabricating it which is used in small trucks. It will give best strength among all above three.

IV. OBJECTIVES

The aim of this work is to achieve good strength of automotive ladder chassis. The component should withstand all the forces acting on it without rupture or failure. Static analysis of truck chassis is carried out to analyze strength and rigidity by changing the frame cross section. The key objectives for this work:

1) Identify and study using software tools.
2) Evaluate the influence of the loads over the stresses.
3) Review the existing design and consider improvement.

V. METHODOLOGY

A finite element stress analysis need to be carried out at the failure region to determine the stress distribution and possible design improvement. Since suitable software like Pro E, Catia, Solid Works etc. are normally utilized for creating the geometry of the component. A final design review can be employed for verifying the analytical results.

5.1 Analytical calculation for chassis

Specification of heavy vehicle chassis used for analysis is described below:

- Wheel Base : 4300 mm
- Front Overhang : 1350 mm
- Rear Overhang : 1435 mm
- Overall Length : 7085 mm
- Overall Height (cab) : 2700 mm
- Overall Width (cab) : 2475 mm
- Overall Width (Rear Tyres) : 2494 mm
- Wheel Track (Front) : 2020 mm
- Wheel Track (Rear) : 1856 mm
- Weight (Kg) : 25000
- Material used : BSK 46 Steel

A. Basic Calculation

Side bar of the chassis are made from “C” Channels with 270 mm × 82 mm × 7 mm

$$Capacity\ of\ Truck = 25\ ton$$
$$= 245250\ N$$
$$Capacity\ of\ Truck\ with\ 1.25\ \% = 245250\ N$$
$$= 306562.5\ N$$
$$Weight\ of\ the\ body\ and\ engine = 7.23\ ton$$
$$= 70926.3\ N$$
$$Total\ Load = Capacity\ of\ the\ chassis + Weight\ of\ the\ body\ and\ engine$$
$$= 306562.5 + 70926.3$$
$$= 377488.8\ N$$

Chassis has two beams. So load acting on each beam is half of the total load acting on the chassis.

$$Load\ acting\ on\ the\ single\ frame = \frac{Total\ load\ acting\ on\ the\ chassis}{2}$$
$$= \frac{377488.8}{2}$$
$$= 188744.4\ N/Beam$$

B. Calculation for Reaction

Chassis is simply clamp with Shock Absorber and Leaf Spring. So Chassis is a Simply Supported Beam with uniformly distributed load. Load acting on entire span of the beam is 188744.4 N. Length of the Beam is 7085 mm.

$$Uniform\ Distributed\ Load = \frac{188744.4}{7085}$$
$$= 26.64\ N\ /\ mm$$

Beams has a supported by three wheel axles. Rear two axles converted in one axle by considering intermediate reaction point which is 1435 form rear end. Hence two reaction points are considered during loading condition. Static load is considered during beam analysis. Total load reaction generated on the beam is as under:-

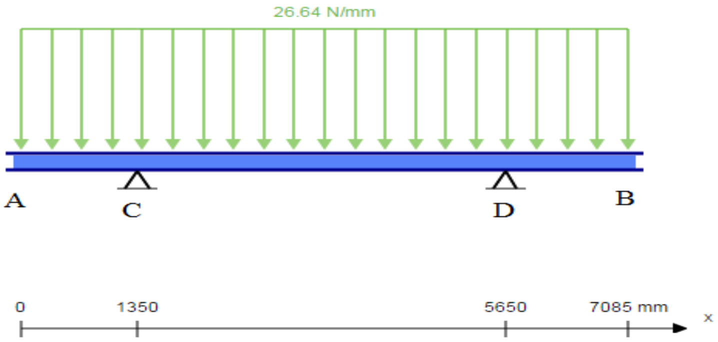

Figure 3 Total load generated on the beam

For getting the load at reaction C and D, taking the moment about C and we get the reaction load generate at the support D. Calculation of the moment are as under.

Moment about C:-

$$\frac{26.64 \times 1350 \times 1350}{2} = \frac{26.64 \times 4300 \times 4300}{2} - (4300 \times D) + (26.64 \times 1435 \times 5017.5)$$

$$24275700 = 246286800 - (4300 \times D) + 191810997$$

$$(4300 \times D) = 413822097$$

$$D = 96237.7\ N$$

Total load acting on the beam is 188744.4 N. So load acting on the reaction C is as under:-

$$C = 188744.4 - D$$

$$= 188744.4 - 96237.7$$

$$= 92506.7\ N$$

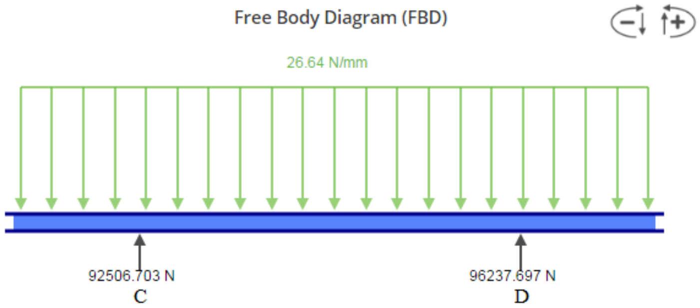

Figure 4 Reaction generated on the beam

C. Calculation for Shear Force Diagram and Bending Moment Diagram

Shear Force Diagram:-

$$F_A = 0\ N$$

$$F_C = (-26.64 \times 1350) + 92506.7$$

$$= 56542.7\ N$$

$$F_D = (-26.64 \times 5650) + 92506.7 + 96237.7$$

$$= 38228.4\ N$$

$$F_B = 0\ N$$

Figure 5 Shear Force Diagram

Bending Moment Diagram:-

$$M_A = 0$$

$$M_C = -\left(\frac{26.64 \times 1350 \times 1350}{2}\right)$$

$$= -24275700\ Nmm$$

$$M_D = -\left(\frac{26.64 \times 5650 \times 5650}{2}\right) + (92506.7 \times 4300)$$

$$= 27428877\ Nmm$$

$$M_B = 0$$

Maximum bending moment occurs at 3472.47 mm from the front overhang.
So,

$$M_{max} = R_1\left[\frac{R_1}{2w} - a\right]$$

$$= 92506.7\left[\frac{92506.7}{2 \times 26.64} - 1350\right]$$

$$= 35729497.51\ Nmm$$

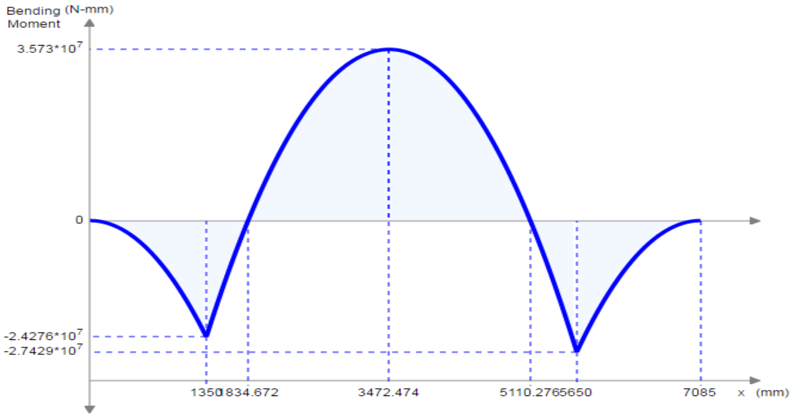

Figure 6 Bending Moment Diagram

5.1.1 Existing "C" Section Chassis

A. Calculation for the DEFLECTION

$$M_{max} = 35729497.51\ Nmm$$

Material of the chassis is BSK 46 Steel.
Property of the material:-

Ultimate Tensile Strength = 500 N/mm^2
E (Young's Modulus) = 2.10×10^5 N/mm^2
Poisson Ratio = 0.31
Radius of Gyration R = $\frac{270}{2}$
= 135 mm

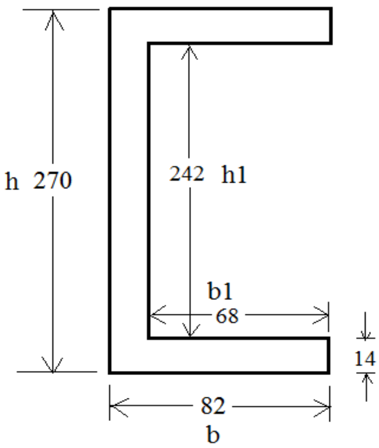

Figure 7 Existing "C" Section Chassis

Moment of Inertia around the X-X axis:-

$$I_{XX} = \frac{bh^3 - b_1h_1^3}{12}$$
$$= \frac{82 \times 270^3 - [68 \times 242^3]}{12}$$
$$= 54189734.67\ mm^4$$

Section of Modulus around the X-X axis:-

$$Z_{XX} = \frac{bh^3 - b_1h_1^3}{6h}$$
$$= \frac{82 \times 270^3 - [68 \times 242^3]}{6 \times 270}$$
$$= 401405.44\ mm^3$$

Basic Bending equations are as follow:-

$$\left(\frac{M}{I}\right) = \left(\frac{\sigma}{y}\right) = \left(\frac{E}{R}\right)$$

Maximum Bending Moment acting on the Beam:

$$M_{max} = 35729497.5\ Nmm$$
$$I = 54189734.67\ mm^4$$
$$Y = 135\ mm$$

Stress produced on the Beam is as under:-

$$\sigma = \left(\frac{M}{Z}\right)$$
$$= \left(\frac{35729497.5}{401405.44}\right)$$
$$= 89.01\ N/mm^2$$

Now check the Deflection and Slope of the Beam with all assembly of Chassis:-

Maximum bending moment is 35729497.5 Nmm

Mass moments of inertia of side members are:-

$$I_{b1} = 54189734.67\ mm^4$$
$$I_{b2} = 54189734.67\ mm^4$$

Mass moments of inertia of cross members are:-

$$I_{b3} = 28309114\ mm^4$$
$$I_{b4} = 11725785\ mm^4$$
$$I_{b5} = 23756075\ mm^4$$

$$Mass\ moment\ of\ inertia\ of\ cross\ member = [28309114 \times 3] + [11725785 \times 2] + [23756075]$$
$$= 132134987\ mm^4$$
$$Total\ mass\ moment\ of\ inertia = [54189734.67 \times 2] + 132134987$$
$$= 240514456.3\ mm^4$$

Deflection of chassis

$$Y = \left[\frac{2 \times w \times X}{384 \times E \times I}\right] \times [L^3 - 2LX^2 + X^3]$$
$$Y = \left[\frac{2 \times 26.64 \times 3472.47}{384 \times 2.10 \times 10^5 \times 240514456.3}\right] \times [7085^3 - 2 \times 7085 \times 3472.47^2 + 3472.47^3]$$
$$= 2.162\ mm$$

B. Calculation for Shear stress generated in chassis:-

Reaction generated on Beam at the center of wheel alignment

= 26.64 × 4300

= 114552 N

With the consideration of at the rate of angle of twist = 1°

$$\theta = \left(\frac{1^\circ \times \pi}{180}\right) = 0.017444$$

By considering the whole system as a one rotational body as per following data when in twist from its support

Width of the chassis	=	864 mm
Length of chassis	=	7085 mm
Distance between two reactions	=	4300 mm
Modulus of rigidity for BSK 46 Steel	=	80000 N/mm^2

Now basic rule for Twisting Moment is:-

$$\left(\frac{T}{J}\right) = \left(\frac{\tau}{r}\right) = \left(\frac{G \times \theta}{L}\right)$$

Now equating

$$\left(\frac{T}{J}\right) = \left(\frac{G \times \theta}{L}\right)$$

For the rotational shaft J is 2 times higher the Mass Moment of Inertia:-
Mass moment of inertia for chassis body = 240514456.3 mm^4
So, Polar Moment of Inertia

$$J = 2 \times I$$
$$J = 2 \times 240514456.3$$
$$J = 481028912.6\ mm^4$$

Now,

$$T = \frac{G \times \theta \times J}{L}$$
$$T = \frac{80000 \times 0.017444 \times 481028912.6}{7085}$$
$$T = 94747419.6\ Nmm$$

Shear stress generated in Chassis body:-
Take width of body as a radius of rotational body r = 864 mm

$$\left(\frac{T}{J}\right) = \left(\frac{\tau}{r}\right)$$
$$\tau = \left(\frac{T \times r}{J}\right)$$
$$= \left(\frac{94747419.6 \times 864}{481028912.6}\right)$$
$$= 170.18\ N / mm^2$$
$$Equivalent\ Stress = \sqrt{4\tau^2 + \sigma_b}$$
$$= \sqrt{(4 \times 170.18^2) + 89.01^2}$$
$$= 351.80\ N / mm^2$$

Similarly, we can find out the values of deflection and stress for I and Box section.
For I section,

$$Deflection\ Y = 2.162\ mm$$
$$Shear\ Stress\ \tau = 170.18\ N/mm^2$$
$$Equivalent\ Stress = 351.80\ N/mm^2$$

For Rectangular Box section,

$$Deflection\ Y = 1.901\ mm$$
$$Shear\ Stress\ \tau = 170.18\ N/mm^2$$
$$Equivalent\ Stress = 347.13\ N/mm^2$$

5.2 Solid Model and Finite Element Model of Chassis

Solid model of heavy vehicle chassis is done in Creo Parametric 2.0 design software. For further analysis of chassis design is imported into ANSYS 14.0 in STEP file format. The meshing is done of Auto Fine Mesh element method.

A. Existing "C" Section Chassis

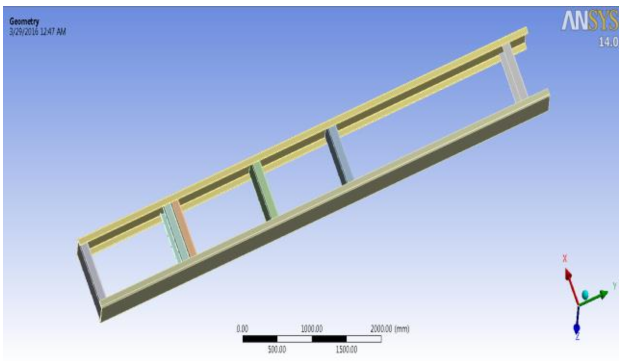

Figure 8 Solid Model

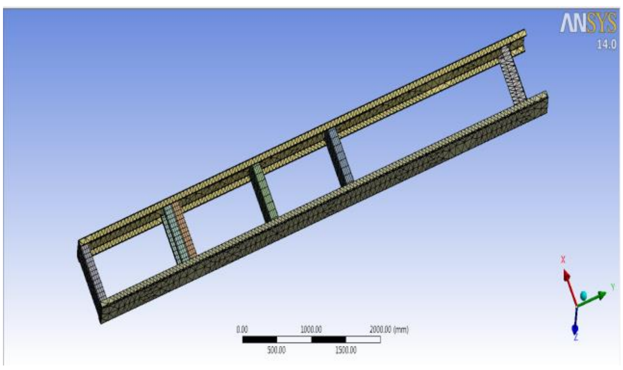

Figure 9 Meshed model

B. Modifies "I" Section Chassis

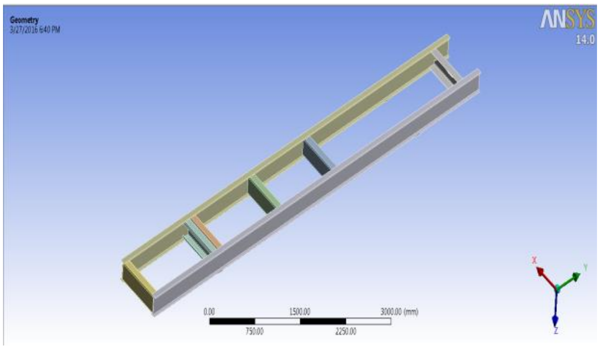

Figure 10 Solid Model

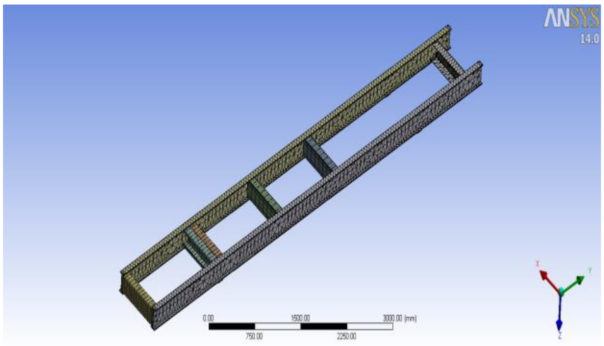

Figure 11 Meshed Model

C. Modified "Box" Section Chassis

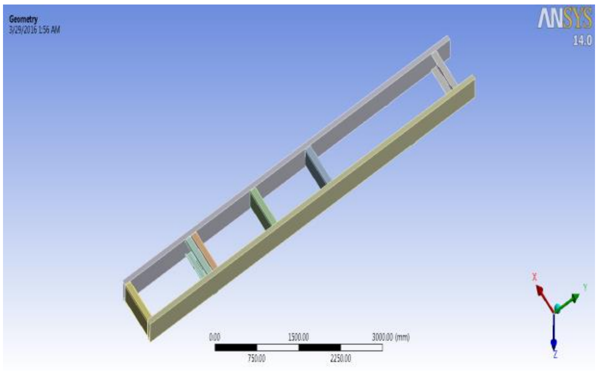

Figure 12 Solid Model

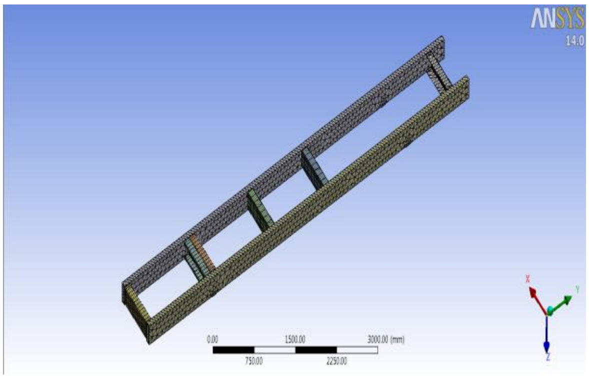

Figure 13 Meshed Model

5.3 Finite Element Analysis of Chassis

A. Existing "C" Section Chassis

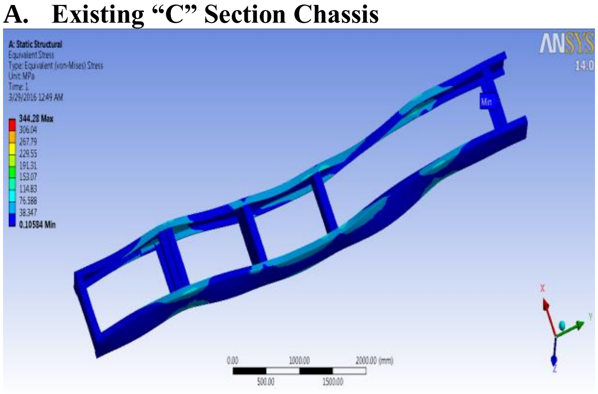

Figure 14 Equivalent (Von Mises) Stress

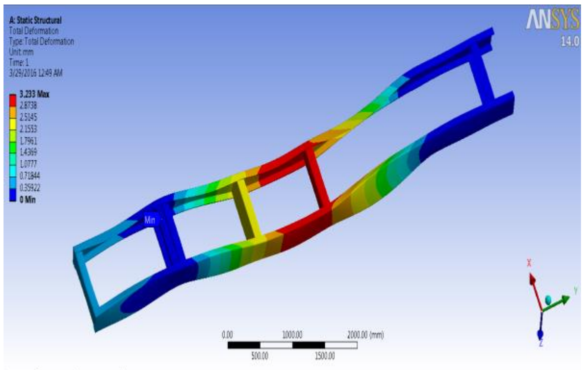

Figure 15 Total Deformation

B. Modified "I" Section Chassis

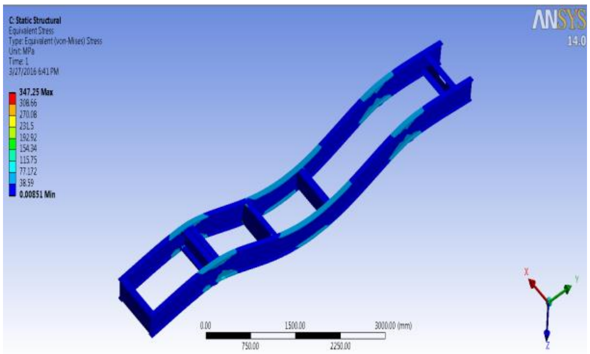

Figure 16 Equivalent (Von Mises) Stress

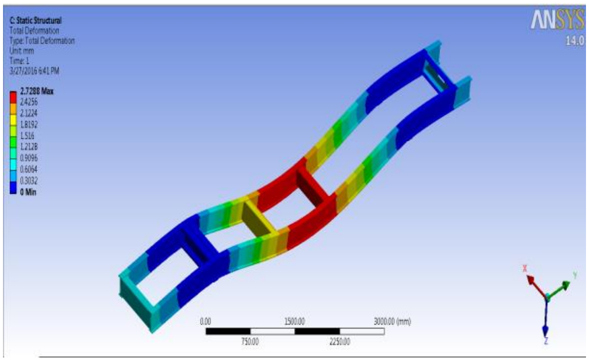

Figure 17 Total Deformation

C. Modified "Box" Section Chassis

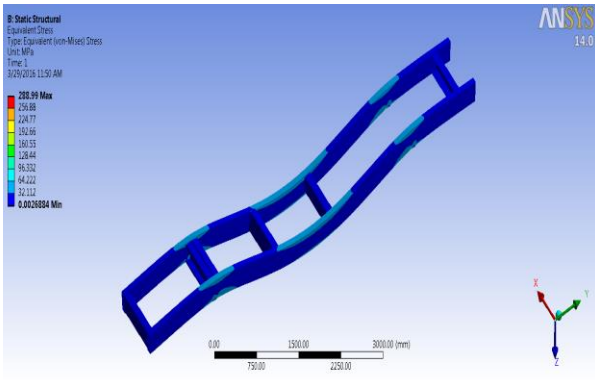

Figure 18 Equivalent (Von Mises) Stress

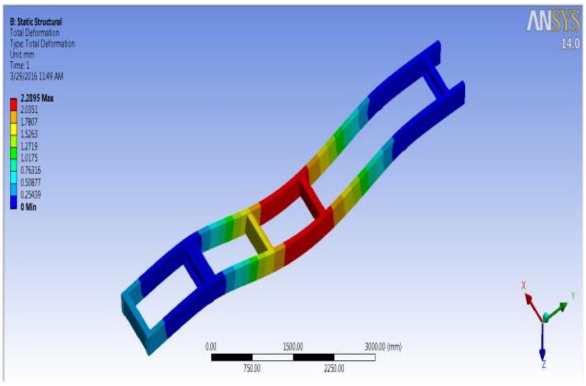

Figure 19 Total Deformation

VI. RESULT

After the calculation we have concluded that Rectangular Box section is safer under 25 tone load which is the Total weight of vehicle including gross vehicle weight. The displacement is good of Rectangular Box section in comparison to C and I section type chassis.

Table 3 Analytical and Analysis result comparison

Section	Analytical Result		Analysis Result	
	Von Mises Stress (N/mm^2)	Total Deformation (mm)	Von Mises Stress (N/mm^2)	Total Deformation (mm)
C	351.80	2.162	344.28	3.233
I	351.80	2.162	347.25	2.728
Box	347.13	1.901	288.99	2.289

VII. CONCLUSION

From the results, it is observed that the Rectangular Box section is more strength full than the C and I section design specifications. The Rectangular Box section is having least deflection i.e., 1.901 mm in all the three chassis of different cross section. By comparing all result we are suggested that Box section is better than the C and I section for designing of chassis. The results obtained are quite favorable which was expected.

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