Proceedings of 4th RIT Post Graduates Conference (RIT PG Con-18)
NOVATEUR PUBLICATIONS
JournalNX- A Multidisciplinary Peer Reviewed Journal (ISSN No:2581-4230)
April, 13th, 2018

DESIGN OF TRAILER STRUCTURE FOR 12 TON PAYLOAD USING ADVANCED LIGHTWEIGHT MATERIAL FOR WEIGHT REDUCTION

Vyom Bhushan
Department of Automobile Engg., R.I.T.
Islampur, India
bhushanvyom21@gmail.com

Sanjay D. Yadav
Department of Automobile Engg., R.I.T.
Islampur, India
sanjay.yadav@ritindia.edu

***Abstract*—Automotive structure is a vital component of every vehicle. It gives strength to the vehicle. Generally, all structures of truck-trailers which are commercial in nature have heavy weight because of that they have high fuel consumption and high emission which spoils the environment. In this research, an effort has been tried for selecting advanced lightweight material with high strength and low density for weight reduction. Finally, considerable weight reduction of 73.6% has been observed in the structure using advanced lightweight material. In addition, the fuel consumption and emissions of the vehicle decrease, which results to prevention of environment from pollution due to vehicles.**

Keywords—chassis structure; chassis design; metal matrix composite; weight reduction; structure deformation.

I. INTRODUCTION

All vehicles have a chassis structure on which many mechanical parts such as engine, assemblies of axles, brakes and tyres etc. are fastened. Vehicular chassis structures give good strength and better flexibility to the vehicle. Chassis structure is the structural element of each commercial automobile. It withstands all the loads and parts attached to it. In case of truck-trailers, all-terrain potential is needed for the movement of vehicle on several kinds of terrain at full load.

The chassis structure absorbs energy from impacts during frontal, side and rollover cases of collisions. In general, the chassis structure is focused to stress along with bending moment and vibrations due to the irregularities in the surface of road and the parts fitted to it.

II. LITERATURE REVIEW

Joel Galos *et al.* [1] designed a heavy duty trailer for transportation purpose mainly related to goods which was lightweight in nature and suggested composite solution for chassis structure for building a balance between cost, performance and reduction in weight.

Divyanshu Sharma and Y D Vora [2] predicted design of a trailer structure and found many different kinds of chassis. They also designed and analyzed trailer structure for a heavy duty trailer with the help of FEA software.

Divyanshu Sharma and Y D Vora [3] designed and analyzed a trailer structure, heavy duty in nature and capable to sustain high vibrations which they analyzed using modal analysis with FEA software.

Gajanan S. Datar *et al.* [4] analyzed a chassis structure for 40 tonne capacity regarding heavy duty application for static as well as dynamic conditions for finding out the performance of loads on the trailer structure.

Ahmad O. Moaaz and Nouby M. Ghazaly [5] explained analysis for fatigue in a chassis structure of a truck regarding heavy duty application by finding various methods of numerical analysis.

Hemant B. Patil *et al.* [6] carried out analysis of a truck chassis structure having ladder type low loader construction containing C-channels for structural analysis with an application of 7.5 ton using FEA software.

Anand Gosavi *et al.* [7] designed a chassis structure with six-axles and carried out structural analysis for the reduction in trailer structure weight. They observed up to 37% reduction in weight of the chassis structure.

O Kurdi *et al.* [8] carried out analysis of stress for a structure of a truck for heavy duty application through FEA for modifying the position of critical point having highest stress.

Akash Singh Patel and Jaideep Chitransh [9] designed and carried out an analysis for existing structure of a TATA 2518 TC vehicle which was heavy vehicle in nature by consideration of several different cross-sections.

III. PROBLEM STATEMENT

Most of the structures of commercial truck-trailers have heavy weight which causes high fuel consumption with an increase in emissions of the vehicle due to which the environment gets polluted.

IV. OBJECTIVE

The main objective of the present research is to select an appropriate advanced lightweight material for trailer structure for analyzing the structure of the chassis using that material for deformation and reduction in weight which may decrease the consumption of fuel and reduction in vehicular emissions for preventing the environment from pollution.

V. THEORETICAL DESIGN OF STEEL TRAILER STRUCTURE

A. *Properties of Structural Steel - AISI 1015 Steel*

- Modulus of Elasticity = 205 GPa
- Poisson's Ratio = 0.30
- Density = 7833.409 kg/m^3
- Coefficient of Thermal Expansion = 12×10^{-6}/^{o}K
- Critical Damping Ratio = 0.03
- Ultimate Tensile Strength = 385 MPa

- Yield Strength = 325 MPa

B. Design of Trailer Structure

The specifications of trailer structure have been shown in Table I below:

TABLE I. Specifications of Trailer Structure

S. No.	Parameter	Value
1	Total Length	7750 mm
2	Total Width	3000 mm
3	Wheelbase	3825 mm
4	Front Overhang	1600 mm
5	Rear Overhang	1600 mm
6	Ground Clearance	330 mm
7	Capacity (G.V.W.)	13.94 Ton
8	Kerb Weight	1.94 Ton
9	Payload	12 Ton

Trailer frame has been considered to be made from 'C'-channels of dimensions (ISMC 350 and ISMC 300) as per ISI standards.

1) Basic Calculations for Trailer Structure:

Capacity of Trailer = 13.94 Ton (Kerb Weight + Payload)

Capacity of Trailer = 136.704 kN

Factor of Safety = 1.5

Total Load Capacity on the Trailer = 205.02 kN

The design of chassis structure has been performed by the consideration of concentrated loads as per the detailed of centre of gravity. The chassis structure has two beams. So, half load of the total load will act on one beam load acting on the trailer.

Load acting on one beam = $\frac{205.02}{2}$ = 102.51 kN/Beam

2) Load Conditions for Trailer Structure:

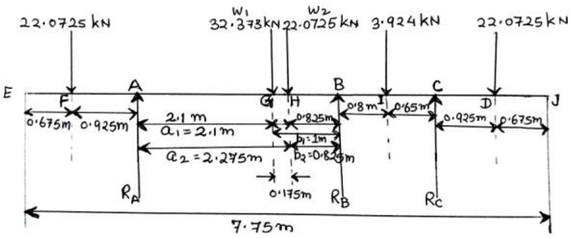

Fig. 1. Total load acting on the beam

3) Fixed End Moments:

Moment Distribution Method:

In Span AE,

M_{AE} = (22.07 x 0.925) = 20.41 kN m

M_{EA} = 0

In Span AB,

$$M_{AB} = \frac{W_1 a_1 b_1^2}{L^2} + \frac{W_2 a_2 b_2^2}{L^2}$$

$$= \frac{32.37 \times 2.1 \times (1)^2}{(3.1)^2} + \frac{22.07 \times 2.275 \times (0.8251)^2}{(3.1)^2}$$

M_{AB} = 10.63 kN m

$$M_{BA} = \frac{W_1 b_1 a_1^2}{L^2} + \frac{W_2 b_2 a_2^2}{L^2}$$

$$= \frac{32.37 \times 1 \times (2.1)^2}{(3.1)^2} + \frac{22.07 \times 0.8251 \times (2.275)^2}{(3.1)^2}$$

M_{BA} = 24.65 kN m

In Span BC,

$$M_{BC} = \frac{-WL}{8} = \frac{-3.924 \times 1.45}{8} = -0.711 \text{ kN m}$$

$$M_{CB} = \frac{WL}{8} = \frac{3.924 \times 1.45}{8} = 0.711 \text{ kN m}$$

In Span CJ (Cantilever)

M_{CJ} = 22.072 x 0.925 = 20.414 kN m

M_{JC} = 0

Stiffness Factor and Distribution Factor

For Joint B,

$$\left.\begin{aligned} k_{BA} &= \frac{3\,EI}{L_{BA}} = \frac{3\,EI}{3.1} = 0.967 \\ k_{BC} &= \frac{3\,EI}{L_{BC}} = \frac{3\,EI}{1.45} = 2.069 \end{aligned}\right\} 3.036$$

$$D.F._{(BA)} = \frac{k_{BA}}{k_{BA} + k_{BC}} = \frac{0.967}{3.036} = 0.319$$

$$D.F._{(BC)} = \frac{k_{BC}}{k_{BA} + k_{BC}} = \frac{2.069}{3.036} = 0.681$$

$D.F._{(CB)}$ and $D.F._{(AB)}$ = 1 (Cantilever)

TABLE II. Moment Distribution Table

Joint	E		A		B		C	J
Member	EA	AE	AB	BA	BC	CB	CJ	JC
D.F.		0	1	0.319	0.681	1	0	
F.E.M.	0	+20.41	–10.63	+24.65	–0.711	+0.711	–20.414	0
			–9.78			19.703	0	
				4.89	9.85			
		+20.41	–20.41	+19.76	+9.141	+20.41	–20.41	
				–9.225	–19.68			
		+20.41	–20.41	+10.535	–10.535	+20.41	–20.41	

4) Calculations for Free Bending Moment:

Span BC

$$\frac{Wab}{L} = \frac{3.924 \text{x} 0.800 \text{x} 0.650}{1.45} = 1.407 \text{ kN m}$$

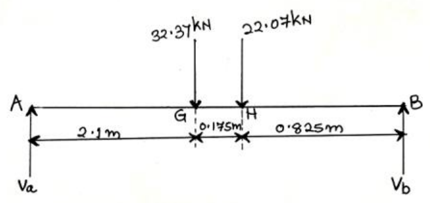

Fig. 2. Span AB

Span AB

$\Sigma Fy = 0$

$0 = V_a - 32.37 - 22.07 + V_b$

$V_a + V_b = 54.44$ kN . . . (1)

$\Sigma M_a = 0$

$0 = -(V_b \times 3.1) + (22.07 \times 2.275) + (32.37 \times 2.1)$

$V_b = 38.124$ kN

Putting value of V_b in equation (1),

$V_a + 38.124 = 54.44$

$V_a = 16.315$ kN

$M_G = (38.124 \times 1) - (22.07 \times 0.175)$

$M_G = 34.261$ kN m

$M_H = (38.124 \times 0.825)$

$M_H = 31.45$ kN m

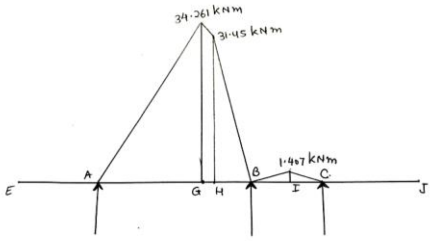

Fig. 3. Free Bending Moment Diagram

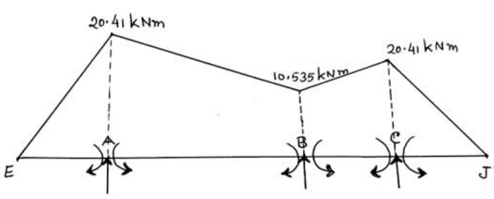

Fig.4. Support Moment Diagram

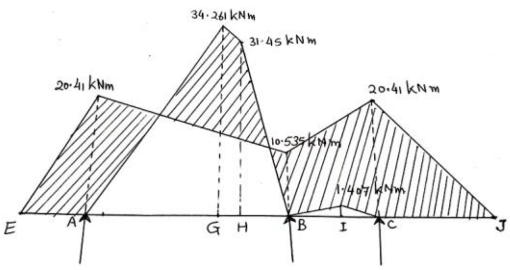

Fig.5. Net Bending Moment Diagram

5) *Calculations for Reactions:*

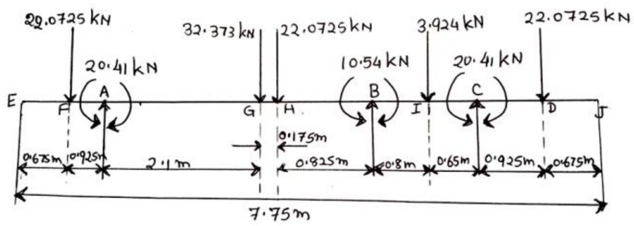

Fig.6. Loads and Moments acting on the beam

$\Sigma f y = 0$

$R_A + R_B + R_C = 22.0725 + 32.373 + 22.0725 + 3.924 + 22.0725$

$R_A + R_B + R_C = 102.51$ kN . . . (2)

Consider Span EAB,

Taking moment about point B (from left),

$M_B = 0$

$0 = -22.0725 \times 4.025 - 20.41 + 20.41 - 32.373 \times 1 - 22.0725 \times 0.825 + 10.54 + R_A \times 3.1$

$R_A = 41.57$ kN

Consider Span BCJ,

Taking moment about point B,

$M_B = 0$

$0 = 22.0725 \times 2.375 + 20.41 - 20.41 + 3.925 \times 0.80 - 10.54 - R_C \times 1.45$

$R_C = 31.05$ kN

Putting values of R_a and R_c in equation (2),

$41.57 + R_B + 31.05 = 102.51$

$R_B = 29.90$ kN

6) *Calculations for Shear Force:*

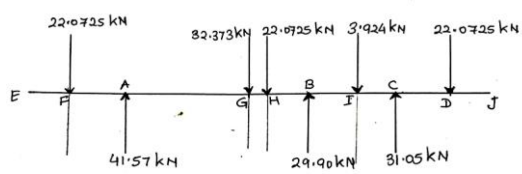

Fig.7. Loads acting on the beam

S.F. at J = 0

S.F. at $D_R = 0$

S.F. at $D_L = 22.072$ kN

S.F. at $C_R = 22.072$ kN

S.F. at $C_L = 22.072 - 31.05 = -8.98$ kN

S.F. at $I_R = 22.072 - 31.05 = -8.98$ kN

S.F. at $I_L = 22.072 - 31.05 + 3.924 = -5.054$ kN

S.F. at $B_R = 22.072 - 31.05 + 3.924 = -5.054$ kN

S.F. at $B_L = 22.072 - 31.05 + 3.924 - 29.90 = -34.954$ kN

S.F. at $H_R = 22.072 - 31.05 + 3.924 - 29.90 = -34.954$ kN

S.F. at H_L = 22.072 – 31.05 + 3.924 – 29.90 + 22.072

= – 12.882 kN

S.F. at G_R = 22.072 – 31.05 + 3.924 – 29.90 + 22.072

= – 12.882 kN

S.F. at G_L = 22.072 – 31.05 + 3.924 – 29.90 + 22.072 + 32.373 = 19.491 kN

S.F. at A_R = 22.072 – 31.05 + 3.924 – 29.90 + 22.072 + 32.373 = 19.491 kN

S.F. at A_L = 22.072 – 31.05 + 3.824 – 29.90 + 22.072 + 32.373 – 41.57 = – 22.072 kN

S.F. at F_R = 22.072 – 31.05 + 3.924 – 29.90 + 22.072 + 32.373 – 41.57 = – 22.072 kN

S.F. at F_L = 22.071 – 31.05 + 3.924 – 29.90 + 22.072 + 32.373 – 41.57 + 22.072 = 0 kN

S.F. at E = 0 kN

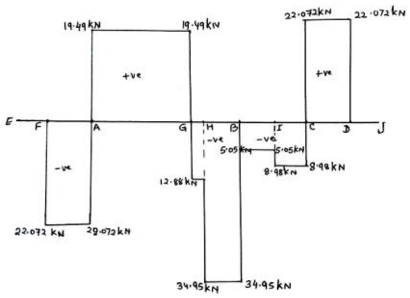

Fig.8. Shear Force Diagram

7) Calculations for Maximum Deflection:

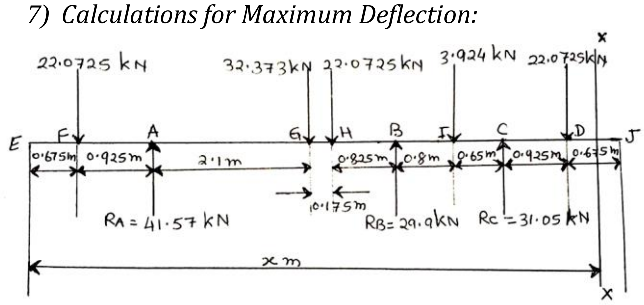

Fig.9. Reactions acting on the beam

We consider a section X-X in DJ span at a distance x metre from E,

Taking moment of all forces about X–X section,

M_{XX} = – 22.0725 [x – 0.675] + R_A [x – 1.6] – 32.373 [x – 3.7] – 22.0725 [x – 3.875] + R_B [x – 4.7] – 3.924 [x – 5.5] + R_C [x – 6.15] – 22.0725 [x – 7.075]

According to Macaulay's theorem,

M_{xx} = EI d^2y/dx^2 = – 22.0725 [x – 0.675] + R_A [x – 1.6] – 32.373 [x – 3.7] – 22.0725 [x –3.875] + R_B [x – 4.7] – 3.924 [x – 5.5] + R_C [x – 6.15] – 22.0725 [x – 7.075]

Integrating with respect to x, we get

EI dy/dx = – 22.0725 [x – 0.675]^2/2 + R_A [x – 1.6]^2/2 – 32.373 [x – 3.7]^2/2 – 22.0725 [x –3.875]^2/2 + R_B [x–4.7]^2/2 – 3.924 [x – 5.5]^2/2 + R_C [x – 6.15]^2/2 – 22.0725 [x – 7.075]^2/2 + C_1

Again integrating with respect to x, we get

EI y = – 22.0725 [x – 0.675]^3/6 + 41.57 [x – 1.6]^3/6 – 32.373 [x – 3.7]^3/6 – 22.0725 [x –3.875]^3/6 + 29.90 [x – 4.7]^3/6 – 3.924 [x – 5.5]^3/6 + 31.05 [x – 6.15]^3/6 – 22.0725 [x –7.075]^3/6 + C_1x + C_2 . . . (3)

Applying boundary conditions,

At A, i.e. at x = 1.6 m, y = 0

0 = – 22.0725 (1.6 – 0.675)^3/6 + 1.6 C_1 + C_2

1.6 C_1+ C_2 = 2.9116 . . . (4)

At C, i.e. at x = 6.15 m, y = 0

0 = – 22.0725 (6.15 – 0.675)^3/6 + 41.57 (6.15 – 1.6)^3/6 – 32.373 (6.15 – 3.7)^3/6 – 22.0725 (6.15 – 3.875)^3/6 + 29.9 (6.15 – 4.7)^3/6 – 3.924 (6.15 – 5.5)^3/6 + 6.15 C_1+ C_2

6.15 C_1 + C_2 = 58.7697 . . . (5)

From equations (4) and (5), we get,

C_1 = 12.2765

C_2= – 16.7308

Putting values of C_1 and C_2 in equation (3), we get

y = [– 22.0725 [x – 0.675]^3/6 + 41.57 [x – 1.6]^3/6 – 32.373 [x – 3.7]^3/6 – 22.0725 [x – 3.875]^3/6 + 299 [x – 4.7]^3/6 – 3.924 [x – 5.5]^3/6 + 31.05 [x – 6.15]^3/6 – 22.0725 [x – 7.075]^3/6 + 12.2765 x – 16.7308] / EI . . . (6)

Above equation is the general equation of Deflection.

Deflection at E, i.e. at x = 0,

y_E = – 16.7308 kN m^3/(EI) = – 16.7308 × 10^9 kN mm^3/(EI)

Deflection at F, i.e. at x = 0.675 m

y_F = (12.2765 × 0.675 – 16.7308)/(EI) = – 8.444 kN m^3/(EI)

= – 8.4444 × 10^9 kN mm^3/(EI)

Deflection at G, i.e. at x = 3.7 m

y_G = – 8.975 kN m^3/(EI) = – 8.97510^9 kN mm^3/(EI)

Deflection at H, i.e. at x = 3.875 m

y_H = – 8.156 kN m^3/(EI) = – 8.156 × 10^9 kN mm^3/(EI)

Deflection at I, i.e. at x = 5.5 m

y_I = 3.8407 kN m^3/(EI) = 3.8407×10^9 kN mm^3/(EI)

Deflection at D, i.e. at x = 7.075 m

y_D = – 16.8493 kN m^3/(EI) = – 16.8493 × 10^9 kN mm^3/(EI)

Deflection at J, i.e. x = 7.750 m

y_J = – 31.2728 kN m^3/(EI) = – 31.2728 ×10^9 kN mm/(EI)

Maximum Deflection occurs at J,

y_{Max} = y_J = – 31.2728 ×10^9 kN mm/(EI)

For 'C' Channel (According to ISMC 350)[14],

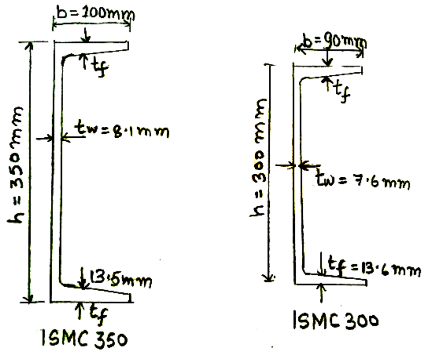

Fig.10. 'C'-Channels[14]

h = 350 mm, b = 100 mm,

thickness of flange (t_f) = 13.5 mm, thickness of web (t_w) = 8.1 mm

I_{XX} = 10008.0 cm^4 = 100080000 mm^4

Z_{XX} (Section Modulus) = 571.9 cm^3 = 571900 mm^3

According to general bending equation,

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

Maximum bending moment acting on the beam,

M_{Max} = 34.261×10^6 N mm

Z_{XX} = 571.9 cm^3 = 571900 mm^3

Stress induced in the beam,

$\sigma = M_{Max} / Z_{XX}$ = 34.261×10^6 / 571900 = 59.9073 N/mm^2

Maximum deflection produced on the beam,

E = 205 GPa = 205 kN/mm^2

I_{XX} = 10008.0 cm^4 =100080000 mm^4

y_{Max} = − (31.2728 × 10^9) / (205 × 100080000) = 1.524 mm downward

According to IS 800:2007[16],

Maximum Allowable Deflection = Span/300 mm = 7750/300 mm = 25.8333 mm

Since, 1.524 mm < 25.833 mm

Hence, Design is safe.

The proposed trailer structure has two longitudinal members ('C' Channels of ISMC 350) and seven cross members ('C' Channels of ISMC 300).[14]

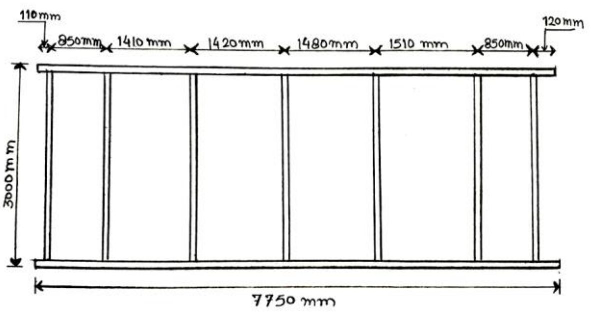

Fig.11. Proposed Trailer Structure

VI. Selection of Advanced Lightweight Material for Trailer Structure

The metal matrix composite of Aluminum-Beryllium, i.e. AlBeMet AM162 Extruded Bar has high modulus of elasticity with low-density and has 62 wt% commercially pure beryllium and 38 wt% commercially pure aluminum.

A. Properties of AlBeMet AM 162 Extruded Bar

- Modulus of Elasticity = 202 GPa
- Poisson's Ratio = 0.17
- Density = 2071 kg/m^3
- Coeff. of Thermal Expansion = 13.91×10^{-6}/^{o}K
- Critical Damping Ratio = 1.5×10^{-3}
- Ultimate Tensile Strength = 400 MPa
- Yield Strength = 276 MPa

VII. Theoretical Design of Advanced Lightweight Material Trailer Structure

Maximum deflection produced on the beam with Advanced Lightweight Material, AlBeMet AM 162 Extruded Bar,
E = 202 GPa = 202 kN/mm^2
I_{XX} = 100080000 mm^4

$y_{Max} = -\frac{31.2728 \times 10^9}{EI} = -\frac{31.2728 \times 10^9}{202 \times 100080000}$ = 1.547 mm Downward

According to IS 800:2007 [16],
Maximum allowable deflection = $\frac{Span}{300} = \frac{7750}{300}$ mm
∴ Maximum allowable deflection in beam = 25.833 mm
Since, 1.547 mm is less than the maximum allowable deflection 25.833 mm.
Hence, Design is safe.

VIII. Results

The results have been compared and shown in Table III below:

TABLE III. Results

Material	Theoretical Deflection	Weight
Structural Steel AISI 1015	1.524 mm	1404.35 kg
AlBeMet AM 162 Extruded Bar	1.547 mm	370.744 kg
Reduction in Weight	–	73.6%

IX. Conclusion

The trailer structure has been designed for 12 ton payload for maintaining the strength using advanced lightweight material.

From the results, it has been found that the chassis structure with advanced lightweight material, i.e. AlBeMet AM 162 Extruded Bar has sufficient strength and withstands all the loads with a theoretical deflection of 1.547 mm which is less than that of maximum allowable deflection as per the standard, IS 800:2007.

Finally, a noticeable reduction in weight of 73.6% has been found in the chassis structure using advanced lightweight material which may lead to the decrease in consumption of fuel and emissions of the vehicle which results to the protection of the environment from pollution.

X. FUTURE SCOPE

The finite element analysis of the trailer structure can be performed further for the validation and determination of displacements, stresses, strains and forces in structure and its components caused by the loads.

REFERENCES

[1] J. Galos, Dr M. Sutcliffe and Prof D. Cebon, "Design of a Lightweight Heavy Goods Vehicle Trailer", *European Transport Conference*, Association for European Transport, pp. 1–17, 2014.

[2] D. Sharma and Y. D. Vora, "Design and Analysis of Heavy Duty Vehicle (Trailer) Chassis through FEM Software", *International Journal of Engineering Technology, Management and Applied Sciences*, Vol. 5, Issue 4, pp. 574-580, April 2017.

[3] D. Sharma and Y. D. Vora, "Design and Vibration Analysis of Heavy Duty Vehicle (Trailer) Chassis Through FEM Software", *International Journal of Engineering Science Invention Research & Development*, Vol. 3, Issue 11, pp. 707-712, May 2017.

[4] G. S. Datar, R. S. Bindu and D. V. Dandekar, "Design and Analysis of 40 Tonne Trailer Used in Heavy Commercial Vehicles", *International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME)*, Vol.1, Issue 2, pp. 14-21, 2012.

[5] A. O. Moaaz and N. M. Ghazaly, "A Review of the Fatigue Analysis of Heavy Duty Truck Frames", *American Journal of Engineering Research (AJER)*, Vol. 3, Issue 10, pp 01-06, 2014.

[6] H. B. Patil, S. D. Kachave and E. R. Deore, "Stress Analysis of Automotive Chassis with Various Thicknesses", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Vol. 6, Issue 1, pp. 44-49, March - April 2013.

[7] A. Gosavi, A. K. Shrivastava and A. K. Sinha, "Structural Analysis of Six Axle Trailer Frame Design and Modification for Weight Reduction", *International Journal of Emerging Technology and Advanced Engineering*, Volume 4, Issue 1, pp 523-531, January 2014.

[8] O. Kurdi, R. A. Rahman, M. N. Tamin, "Stress Analysis of Heavy Duty Truck Chassis using Finite Element Method", *ResearchGate*, pp 1-7, 2015.

[9] A. S. Patel and J. Chitransh, "Design and Analysis of Tata 2518TC Truck Chassis Frame with Various Cross Sections using CAE Tools", *International Journal of Engineering Sciences & Research Technology (IJESRT)*, Vol. 5, No. 9, pp. 692-714, 2016.

[10] J. Reimpell, H. Stoll, W. Jürgen, *The Automotive Chassis: Engineering Principles*, Great Britain, Butterworth Heinemann, Second Edition, , 2001.

[11] S. Ramamrutham and R. Narayanan, *Strength of Materials*, New Delhi, Danpat Rai Publishing Company, Nineteenth Edition, 2017.

[12] G. H. Ryder, *Strength of Materials*, Macmillan Publishers India Ltd., Third Edition, 2011.

[13] J. Pawlowski and Guy Tidbury, *Vehicle Body Engineering*, London, Business Books Ltd., 1969.

[14] BIS, Handbook for Structural Engineers - Structural Steel Sections, SP:6 (1), 1964.

[15] Code of Practice for Construction and Approval of Truck Cabs & Truck Bodies, (Revision 1)/F, AIS-093, 2014.

[16] BIS, Indian Standard-General Construction in Steel-Code of Practice (Third Revision), IS 800, 2007.