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Design and analysis of truck body for increasing the payload capacity

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Abstract: Truck industry is a major source of transportation in India. With an average truck travelling about 300 kilometers per day [1], every kilogram of truck weight is of concern to the industry in order to get the best out of the truck. The main objective of this project is to increase the payload capacity of automotive truck body. Every kilogram of increased vehicle weight will decrease the vehicle payload capacity in turn increasing the manufacturing cost and reducing the fuel economy by increase the fuel consumption. With the intension of weight reduction, standard truck body has been designed and analyzed in ANSYS software. C-cross section beams were used instead of conventional rectangular box sections to reduce the weight of the body. Light-weight Aluminum alloy Al 6061 T6 is used to increase the payload capacity. The strength of the Truck platform is monitored in terms of deformation and stress concentration. These parameters will be obtained in structural analysis test condition environment. For reducing the stress concentration the concept of beams of uniform strength is used. Accordingly necessary modifications are done so that the optimized model has a better stress distribution and much lesser weight compared to the conventional model. The results obtained by analyzing the modified model are compared with the standard model.

1. Introduction

Transport industry plays a crucial role in development of modern industrialized countries economy. The total weight of the load carried on the truck has been increasing drastically. Today's difficult challenge of transport vehicle is to meet the increasing demand for better performance, less weight and more reliability. All this criteria has to achieve in short duration of time. There is a considerable focus on design of the truck body, for increasing payload capacity. Replacement of rectangular cross section beams with C-cross section beams, use of Aluminum alloys instead of structural steel will be the feasible solutions for increasing payload capacity of the truck. With the use of aluminum the strength of the truck reduces, which can be augmented by using the concept of beams of uniform strength.

2. Objective

The main objective of this study is to increase the payload capacity of the automotive truck. Reduce the stress concentration by using the concept of beams of uniform strength. For this Models 1A, 1B, 2A, 2B, 3, 4 [10] has designed with the different modifications to analyzed in ANSYS.

3. Design Parameter Details

The Standard truck Ashok Leyland 1616 having a payload capacity of 10 tons has been considered, which has the following dimensions for the load body.

Table 1: Design parameters of truck body

Load capacity of the truck	10 tons
Length of the truck body	3505.2mm
Width of the truck body	2438.4mm
Height of truck body	1295.4mm
Bottom Floor thickness	4mm
Side guard thickness	4mm
Head board thickness	4mm
Rectangular cross section	152.4mm*76.2mm*5mm
Material of the truck body	Structural steel

4. Modelling and analysis of truck body

4.1 Geometric model of standard Truck body

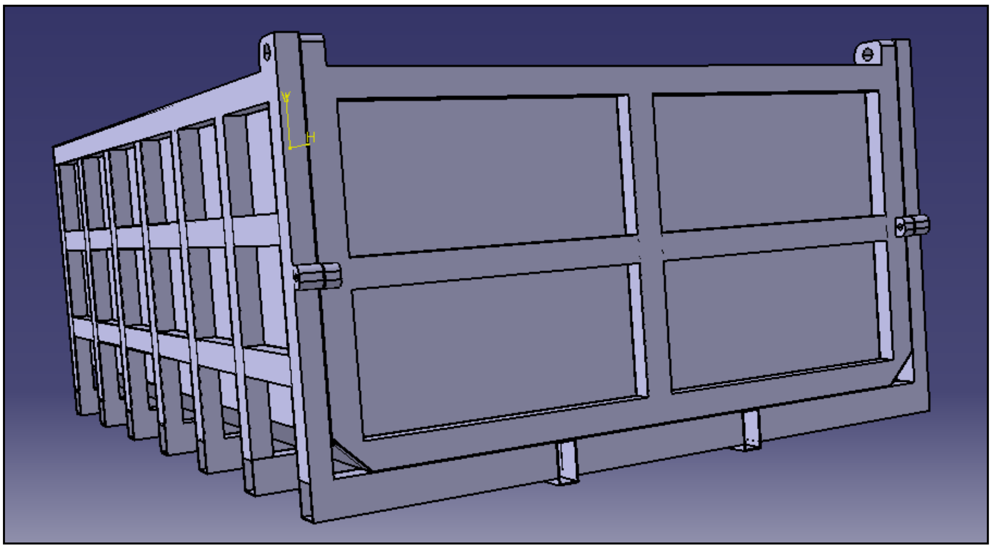

Figure 4.1.1 Geometric model of standard truck body

The geometric model of the standard truck body shown in Figure 4.1.1is modeled in CATIA-V5 modeling software. The dimensions of the Truck body are 3505.2 x 2438 x 1295.4 mm. The Material used for standard truck body is Structural steel having the yield strength of 250 MPa and Ultimate tensile strength of 460 MPa.

Table 2: Properties of structural steel

Modulus of Elasticity (GPa)	200
Yield Strength (MPa)	250
Ultimate Tensile Strength (MPa)	460
Poisson's ratio	0.3
Density (kg/m^3)	7850

4.2 Meshing of the model

The designed truck body is exported to the ANSYS Work bench. The model is meshed using fine mesh for obtaining better results. The number of nodes and elements [9] generated while meshing is as follows.

Table 3: Meshing details

No. of Nodes	264928
No. of Elements	128537

4.3 Boundary conditions

The boundary applied to the model such that the fixed supports had given to the longitudinal bars at the bottom of the truck body, as shown in the figure. Since the longitudinal bars are placed on the chassis frame, so the Ux, Uy, Uz are taken as zero displacement [2].

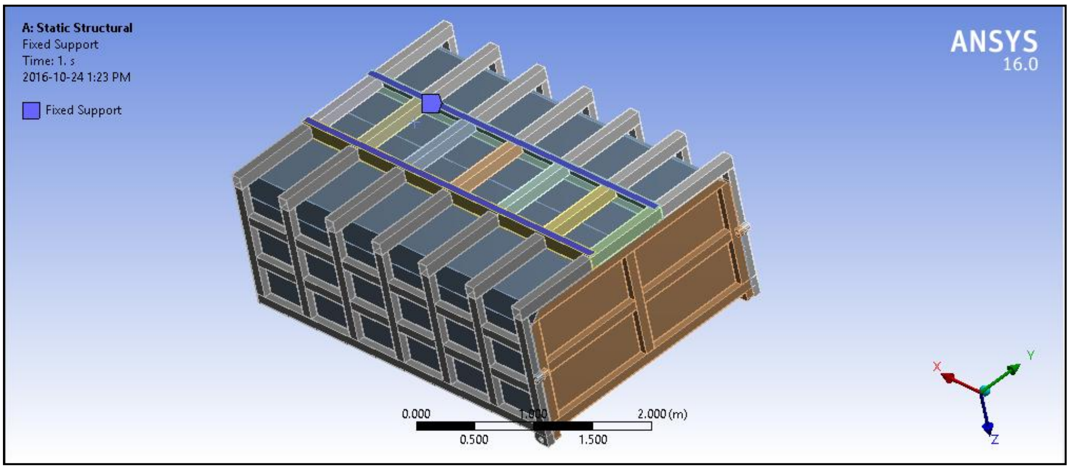

Figure 4.1.2: Model with Fixed Supports

4.4 Structural Analysis

To study and predict the behavior of the automotive truck body [6], we need to know the structural analysis, which comprises a set of physical conditions and mathematical equations. The structural analysis is the judgment of ability of a structure to withstand a load. From theoretical perspective the main use of the structural analysis is to calculation of deformation, internal resisting forces, and stresses. In usual practice, the structural analysis can be used to find the ability of the truck body.

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4.5 Loading methodology

The modeled Truck body is loaded by transferring the forces from material it carries. The main load bearing elements of the truck body are floor, head board, and side guard. The side guard and head board are designed in such a way that, it will carry the part load when the braking, turning, travel on the slopes [3, 9].

- **Floor** : 100% of Load carried
- **Side wall** : 15% of Load carried
- **Head board**: 15% of Load carried
-

5. Solution

5.1Model-1A:

The standard truck model with structural steel as a material is loaded for different loads such as 10, 15, 20, 25 tons.

Load case-1: Design load (10 tons)
The Maximum equivalent stress occurred at the bottom floor is shown below.

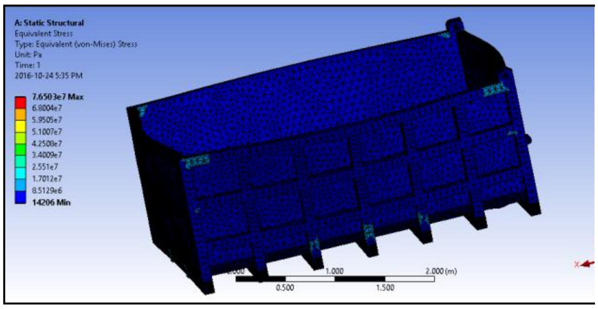

Figure 5.1.1: Equivalent stress

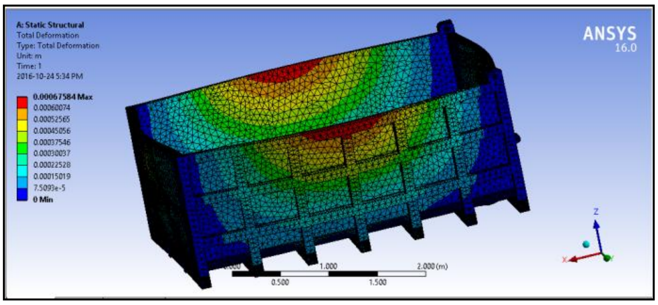

Figure 5.1.2: Total Deformation

Load case-2: Design Load (15 tons)

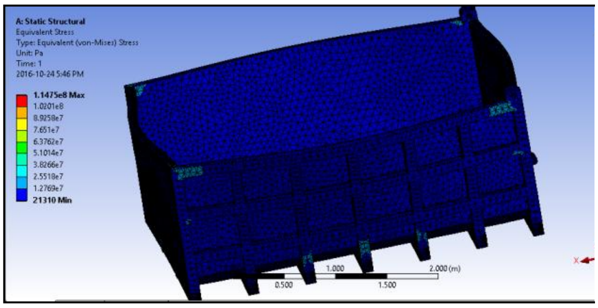

Figure 5.1.3: Equivalent stress

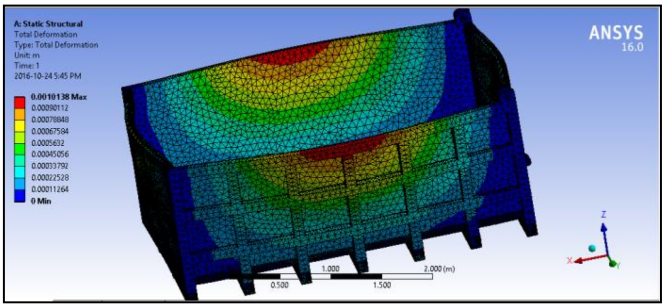

Figure 5.1.4: Total deformation

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Load case-3: Design Load (20 tons)

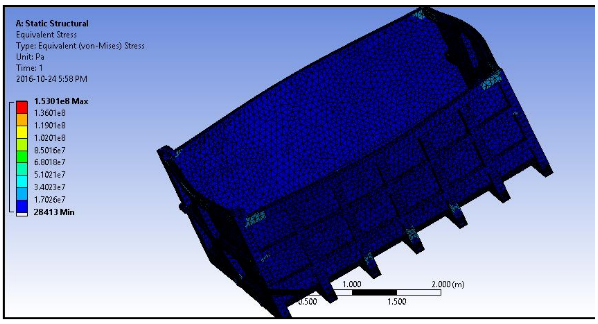

Figure 5.1.5: Equivalent stress

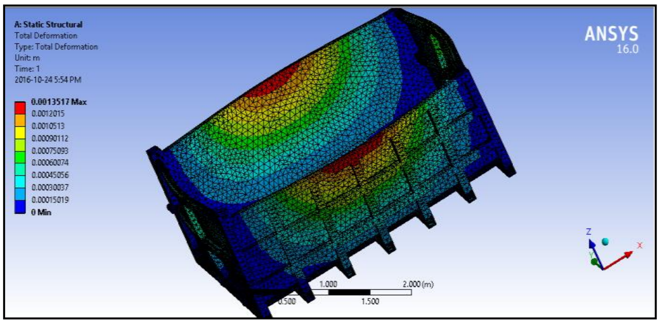

Figure 5.1.6: Total deformation

5.2 Model-1B

To increase the payload capacity the light weight material in automotive applications such as aluminum can be used.

Material selection criteria:
The selection of material as a substitute to Structural steel for increasing payload capacity has the following requirements [6]

- The density should be less than structural steel.
- The material should possess the cold forming properties for easy manufacturing.
- The strength requirements of the material have to meet the standard structural steel.
- The properties should be resistant to corrosion.
- The Material should have the high abrasion resistance.
- In the same time it should be cost effective.

By considering the all parameters mentioned above the aluminum 6061 T6 is considered as the substitute for structural steel, because of its high yield strength. The following table describes the properties of aluminum 6061 T6.

Table 4: Properties of aluminum 6061 T6

Modules of Elasticity (GPa)	68.9
Yield Strength (MPa)	276
Ultimate tensile strength (MPa)	310
Fatigue strength (MPa)	96.5
Poisson’s ratio	0.33
Density (kg/m^3)	2700

The standard model with aluminum alloy as a material is tested for different loads such as 10, 15, 20, 25 tons.

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Load case-1: Design load (10 tons)

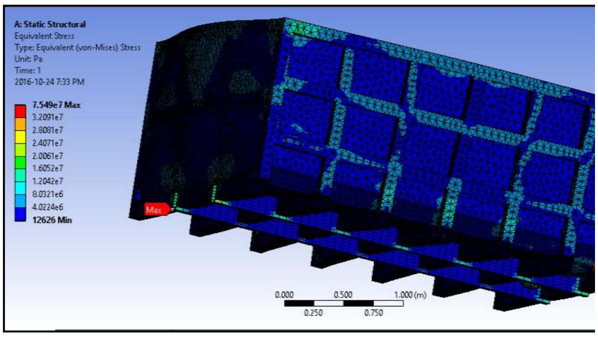

Figure 5.2.1: Equivalent stress

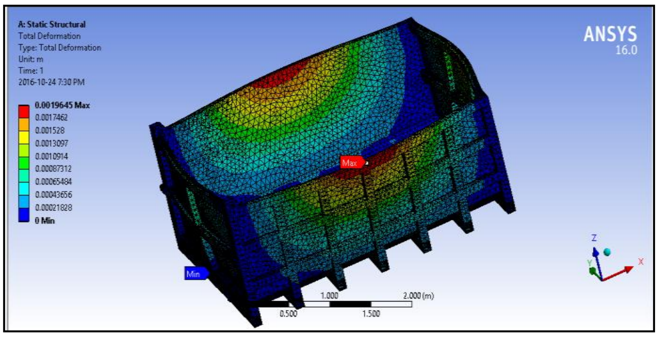

Figure 5.2.2: Total deformation

Load case-2: Design load (15 tons)

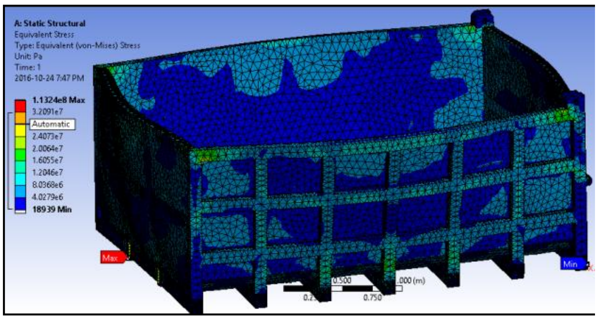

Figure 5.2.3: Equivalent stress

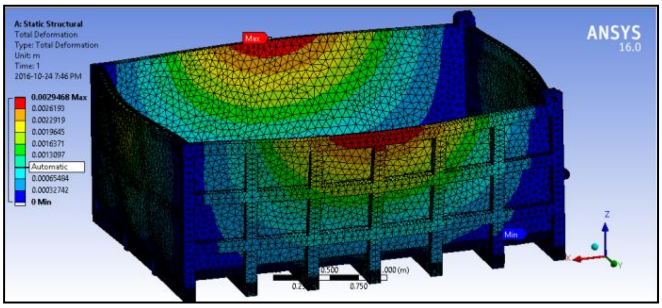

Figure 5.2.4: Total deformation

Load case-3: Design load (20 tons)

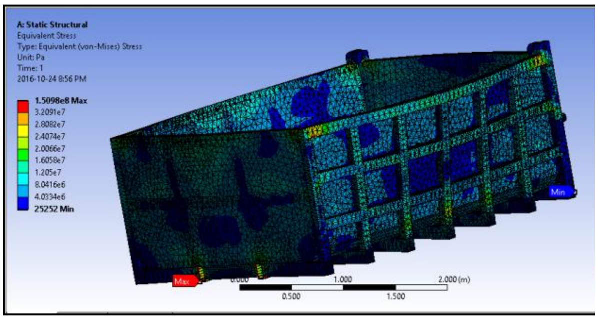

Figure 5.2.5: Equivalent stress

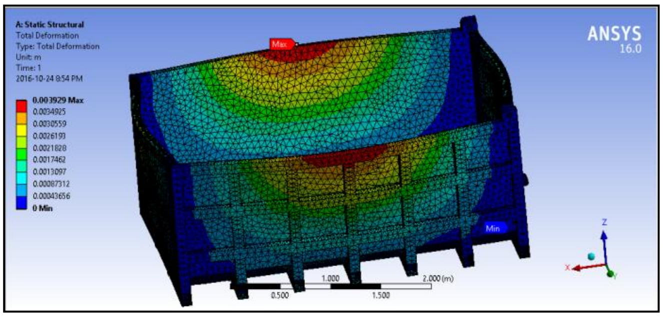

Figure 5.2.6: Total deformation

5.3 Model-2:

The standard model consists of rectangular cross section longitudinal beams at the bottom. Here the rectangular cross section beams are replaced by C-cross section beams. The weight of the truck will be reduced to some extent, which leads to increase in payload capacity. The following figure shows the modified truck model having C-cross section longitudinal beams.

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5.4 Model-2A:

Model-2A represents the modified model having the C-Cross section longitudinal beams with structural steel as a material. The model is tested under the different loads as 10, 15, 20, 25 tons.

Load case-1: Design load (10 tons)

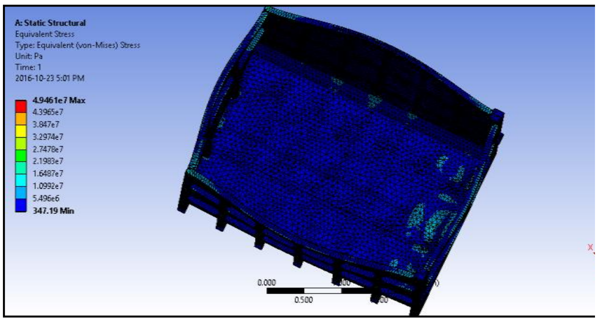

Figure 5.4.1: Equivalent stress

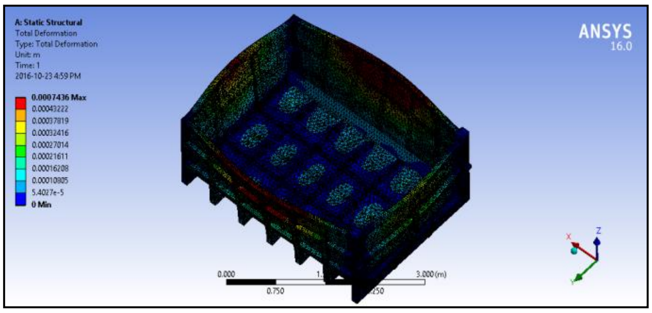

Figure 5.4.2: Total deformation

Load case-2: Design load (15 tons)

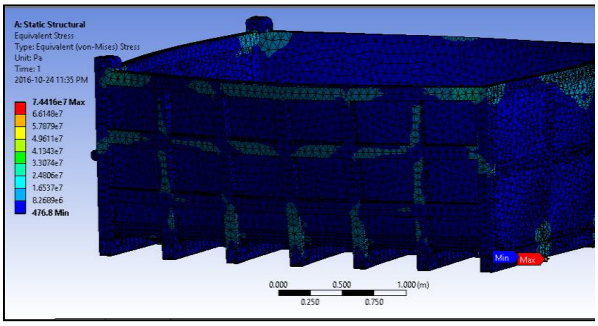

Figure 5.4.3: Equivalent stress

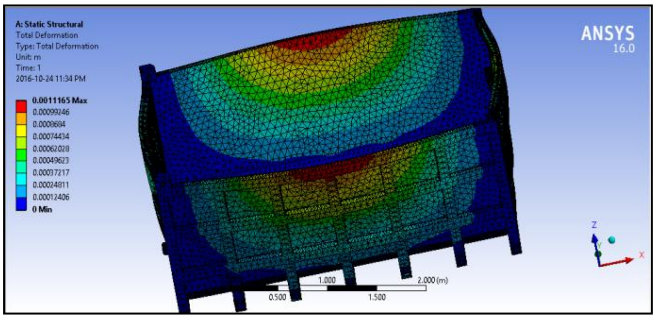

Figure 5.4.4: Total deformation

Load case-3: Design load (20 tons)

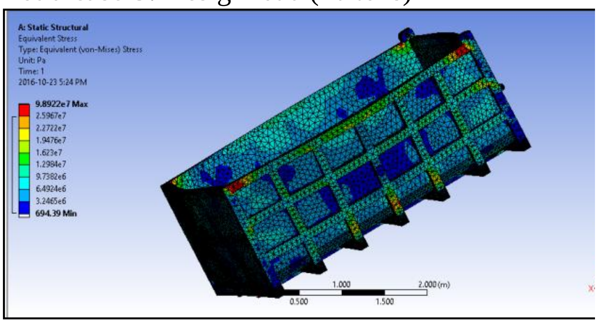

Figure 5.4.5: Equivalent stress

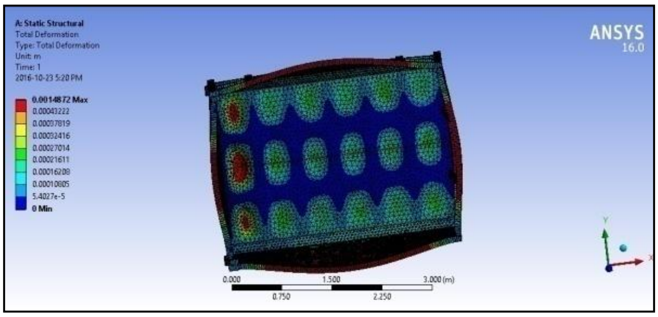

Figure 5.4.6: Total deformation

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Load case-4: Design load (25 tons)

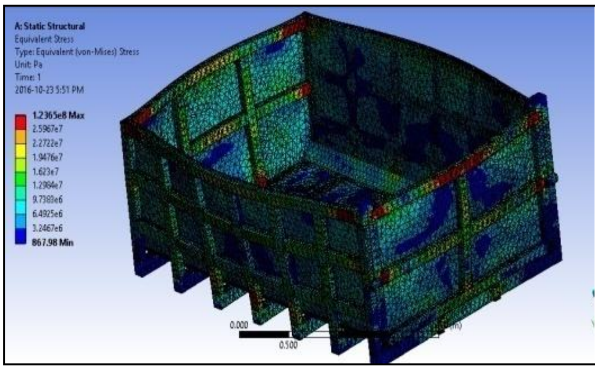

Figure 5.4.7: Equivalent stress

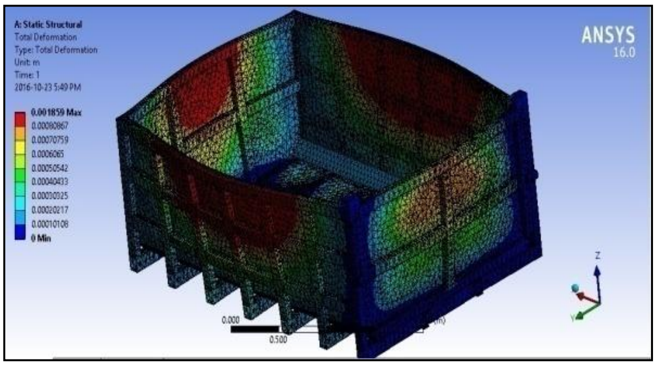

Figure 5.4.8:Total deformation

5.5 Model-2B:

Model-2B represents the modified model having the C-cross section longitudinal beams with aluminum alloy as a material. The model is tested with load conditions of 10, 15, 20, 25 tons.

Load case-1: Design load (10 tons)

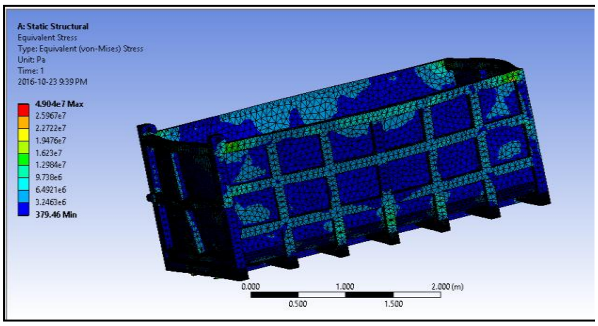

Figure 5.5.1: Equivalent stress

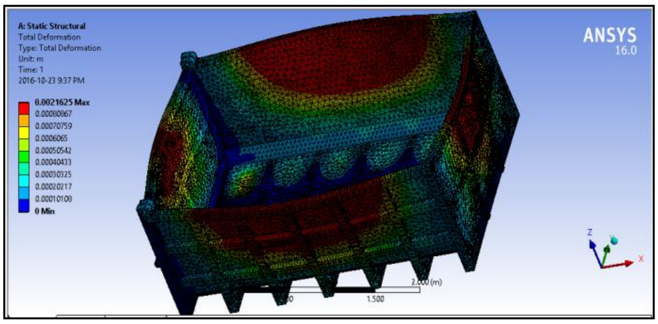

Figure 5.5.2: Total deformation

Load case-2: Design load (15 tons)

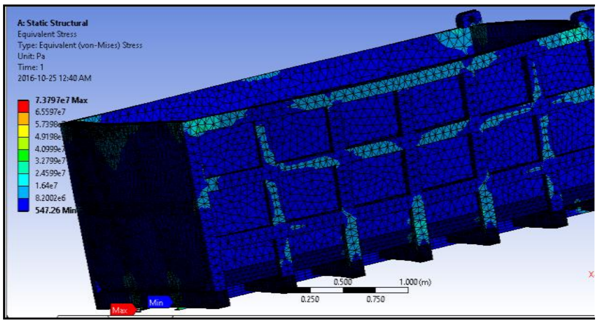

Figure 5.5.3: Equivalent stress

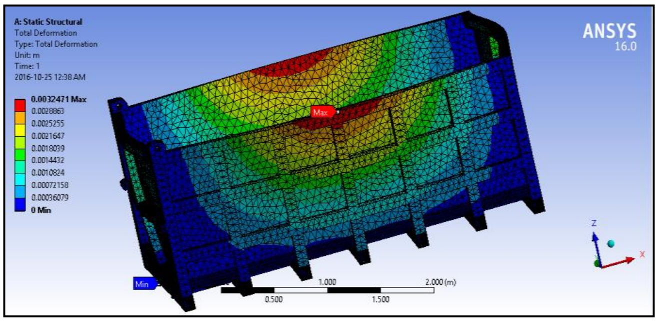

Figure 5.5.4: Total deformation

Load case-3: Design load (20 tons)

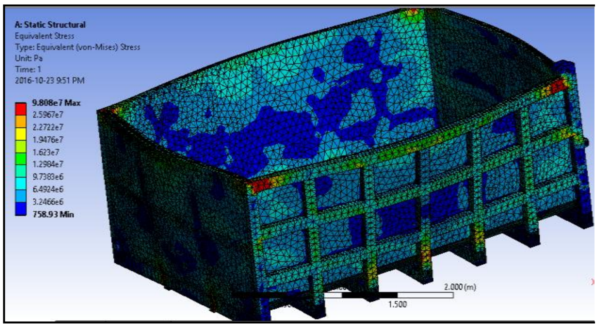

Figure 5.5.5: Equivalent stress

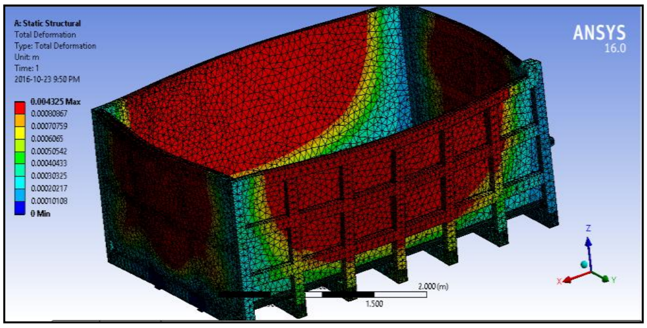

Figure 5.5.6: Total deformation

Load case-4: Design load (25 tons)

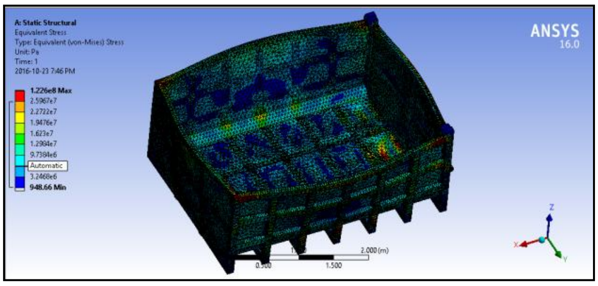

Figure 5.5.7: Equivalent stress

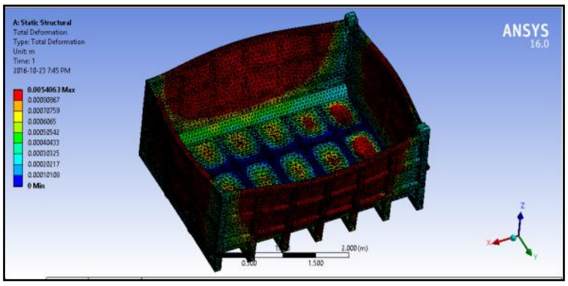

Figure 5.5.8: Total deformation

5.6 Model-3:

After analyzing the C-cross section beam of aluminum truck body at different loads, more deformation is observed at the side wall. To reduce the deformation the model is modified by increasing the thickness from 4mm to 6mm, which shows the better result. The deformation is reduced to some extent. The model is analyzed under different loads as shown below.

Load case-1: Design load (10 tons)

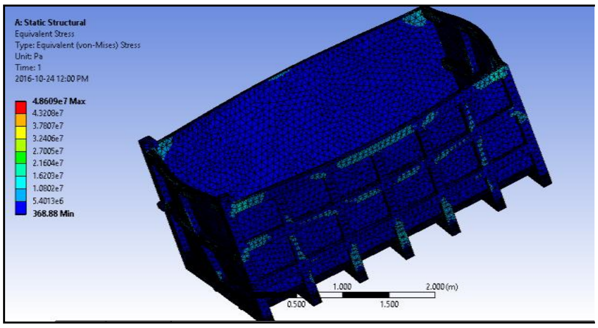

Figure 5.6.1: Equivalent stress

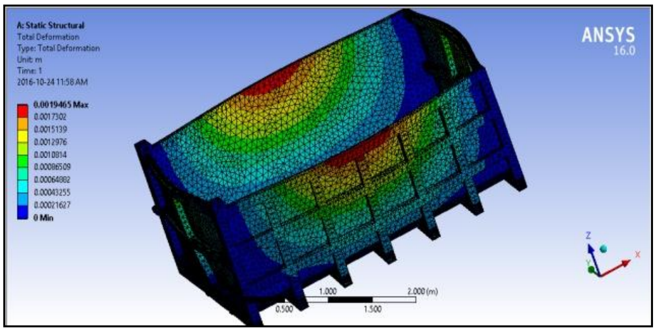

Figure 5.6.2: Total deformation

Load case-2: Design load (15 tons)

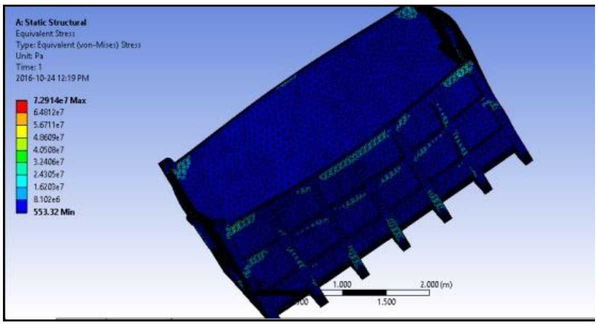

Figure 5.6.3: Equivalent stress

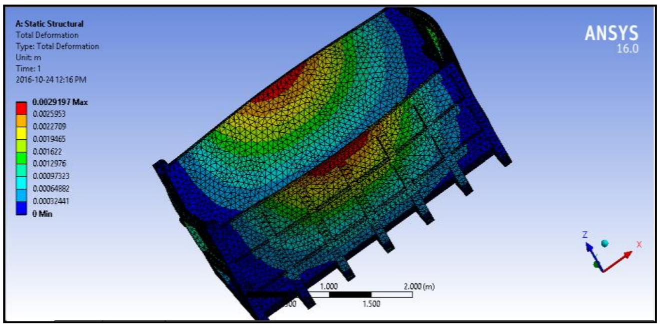

Figure 5.6.4: Total deformation

Load case-3: Design load (20 tons)

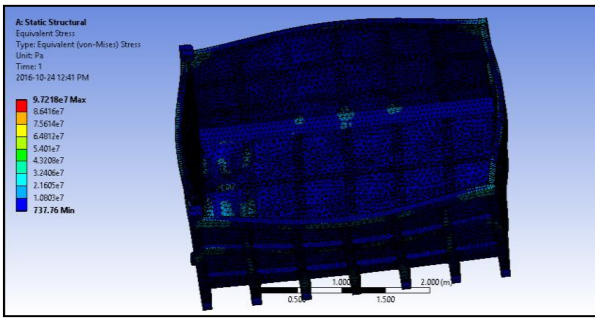

Figure 5.6.5: Equivalent stress

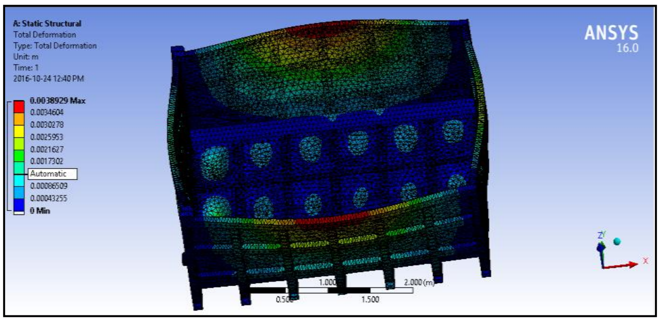

Figure 5.6.6: Total deformation

Load case-4: Design load (25 tons)

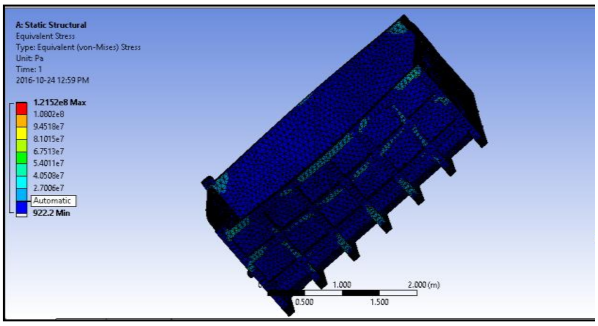

Figure 5.6.7: Equivalent stress

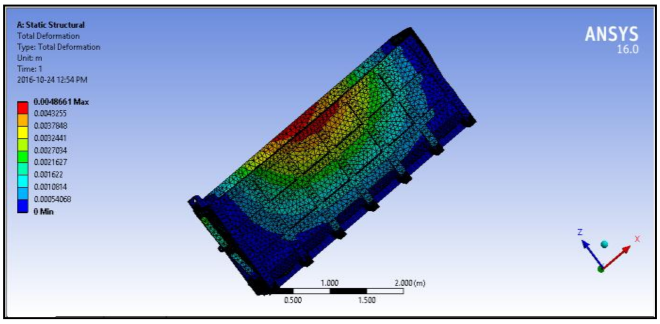

Figure 5.6.8: Total deformation

5.7 Model-4:

From the literature, to reduce the stress concentration of the aluminum truck the concept of beams of uniform strength is used [4]. The strength of the beam is dependent on the cross section of the beam. The concept of beams of uniform strength is the varying cross section, which reduces the stress concentration by maintaining the constant bending moment.

6 Analytical Calculation:

The Shear force, and bending moment for the Rectangular cross beam is calculated to find out the maximum bending moment in the cross beam [8].

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Payload capacity of the Truck =10 tons
Number of cross beams under the floor = 7
Load on each beam = (10000*9.81)/7

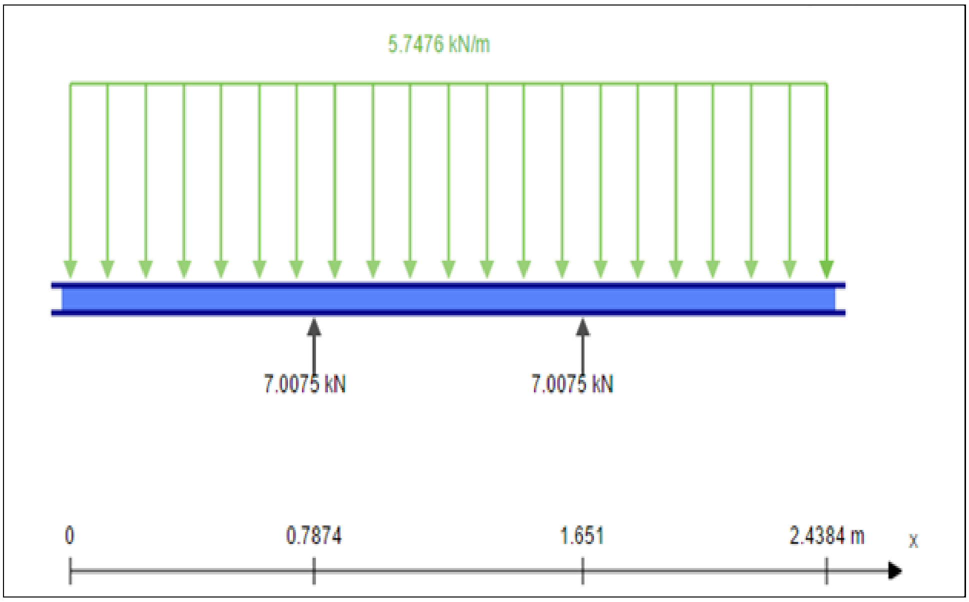

Figure 6.1: Free body diagram of cross beam

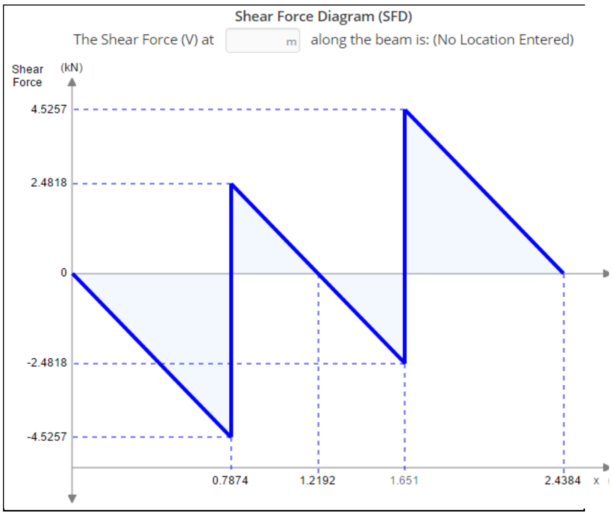

Figure 6.2: Shear force diagram (SFD)

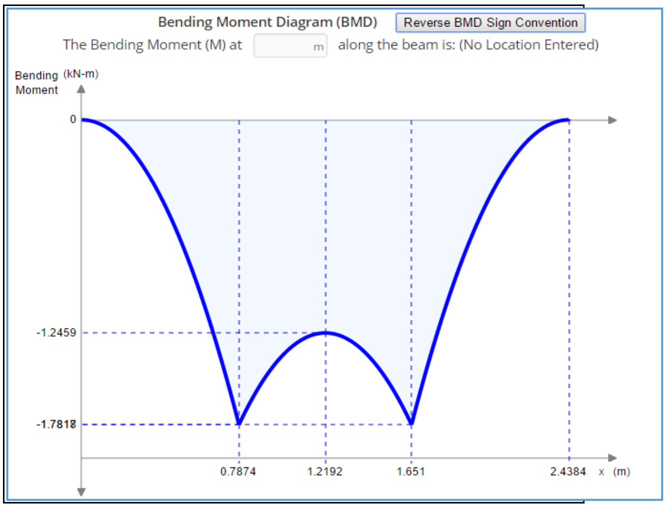

Figure 6.3: Bending Moment diagram

6.1 Calculation of bending stress:

Maximum Bending stress

$$\sigma_b = \frac{M}{I} * Y = 18.897 \text{ MPa}$$

$$\text{Allowable stress} = \frac{\sigma y}{FOS} = 138 \text{ MPa}$$

6.2 Calculation for Beam of Uniform strength:

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The moment of inertia of the rectangular shape is I = 5987109.4 mm^4
Keeping the width of the rectangular as constant, and the height of the rectangular beam is varied to obtain the beam of uniform strength. Here the height of the rectangular beam is variable, the equation for height of the rectangular beam is

$$Y=18.897*5987109.4/(2.873X^2-2481.4798X+1781752.436) \quad \ldots\ldots\ldots (1)$$

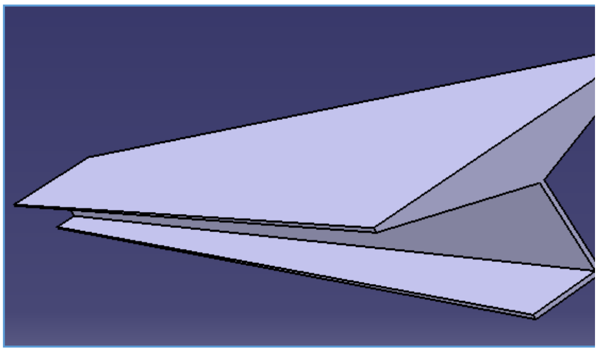

Figure 6.2.1: Beam of constant strength of modified model

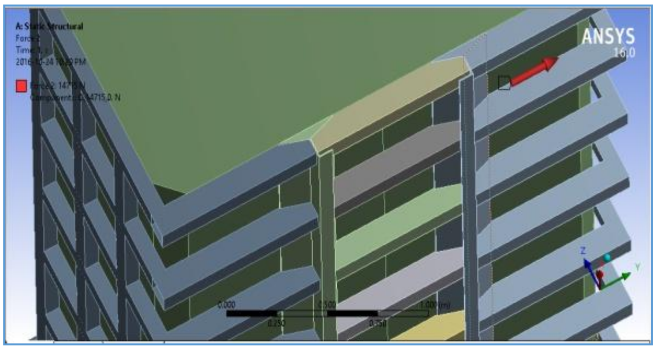

Figure 6.2.2: Floor bed of modified model

The modified beam of uniform strength model is tested under the different load conditions of 10, 15, 20, 25 tons.

Load case-1: Design load (10 tons)

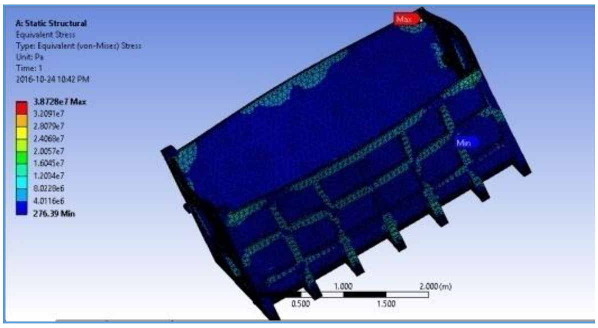

Figure 6.2.3: Equivalent stress

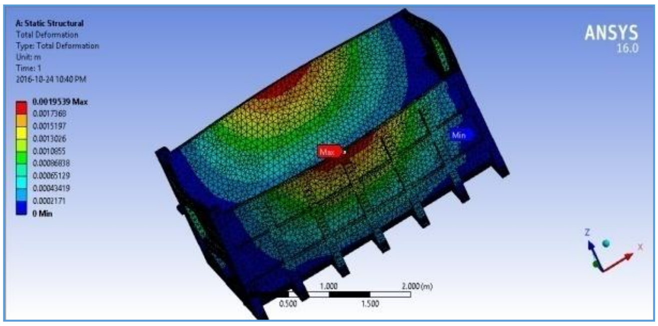

Figure 6.2.4: Total deformation

Load case-2: Design load (15 tons)

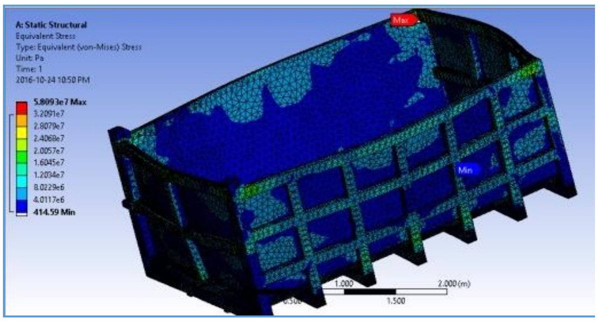

Figure 6.2.5: Equivalent stress

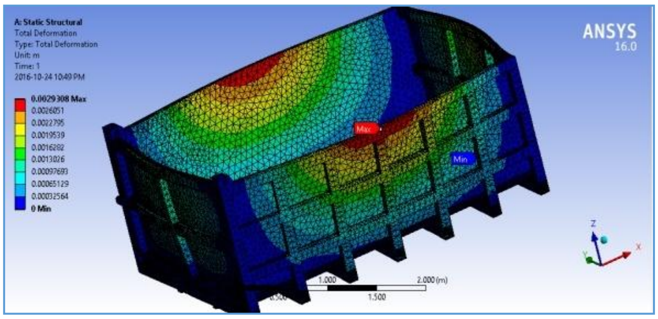

Figure 6.2.6: Total deformation

Load case-3: Design load (20 tons)

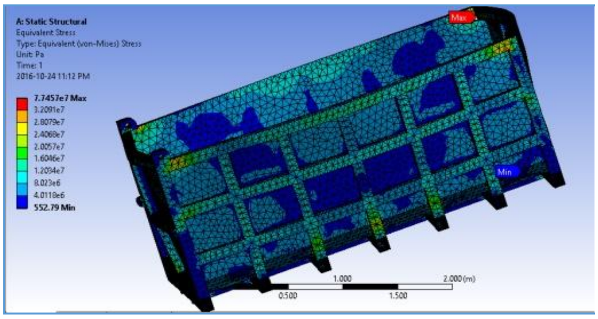

Figure 6.2.7: Equivalent stress

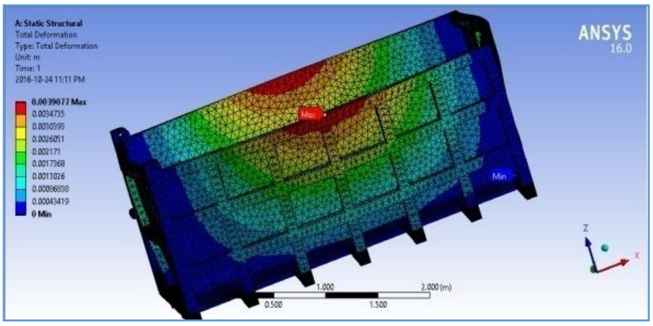

Figure 6.2.8: Total deformation

Load case-4: Design load (25 tons)

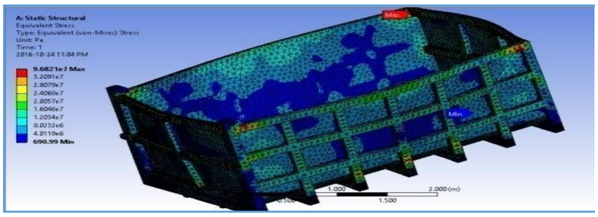

Figure 6.2.9: Equivalent stress

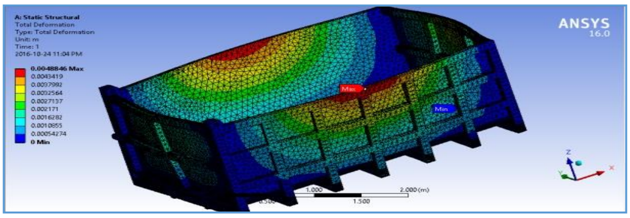

Figure 6.2.10: Total deformation

7. Observations

a. Weight of the truck body:

The following table shows the weight of the different models

Table 5: Weight of the models

Model-1A	1702.1 kg
Model-1B	585.45 kg
Model-2A	1661.5 kg
Model-2B	572.1 kg
Model-3	583.81 kg
Model-4	729.76 kg

b. Results for 10 tons load:

Table 6: Results from 10 tons load condition

Model	**Equivalent stress (MPa)**	**Total Deformation (mm)**
Model-1A	76.5	0.676
Model-1B	75.5	1.964
Model-2A	49.46	0.743
Model-2B	49.04	2.163
Model-3	48.61	1.946
Model-4	38.73	1.954

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c. *Results for 15 tons load:*

Table 7: Results from 15 tons load condition

Model	Equivalent stress (MPa)	Total Deformation (mm)
Model-1A	114.75	1.013
Model-1B	113.2	2.947
Model-2A	74.416	1.11
Model-2B	73.797	3.247
Model-3	72.914	2.919
Model-4	58.1	2.93

d. *Results for 20 tons load:*

Table 8: Results from 20 tons loading condition

Model	Equivalent stress (MPa)	Total Deformation (mm)
Model-1A	153.01	1.325
Model-1B	151	3.93
Model-2A	98.92	1.487
Model-2B	98.08	4.325
Model-3	97.22	3.893
Model-4	77.46	3.91

e. *Results for 25 tons load:*

Table 9: Results from 25 tons loading condition

Model	Equivalent stress (MPa)	Total Deformation (mm)
Model-1A	172.1	1.69
Model-1B	168.52	4.81
Model-2A	123.65	1.859
Model-2B	122.6	5.406
Model-3	121.52	4.866
Model-4	96.22	4.885

f. *Payload capacity:*

Table 10: Payload capacity of different models

Model	Increase in payload capacity (tons)	% increase in payload capacity
Model-1A	-	-
Model-1B	1.11665	11.16
Model-2A	0.0406	0.406
Model-2B	1.13	11.3
Model-3	1.11829	11.18
Model-4	0.97234	9.72

8. Results and Discussions

- The Model-1A is the standard truck having the original dimensions and structural steel as a material, considering the factor of safety (FOS=2) having the allowable yield strength 125MPa, has failed at 20 tons. This is because of at 20 tons load the equivalent stress is more than the allowable yield strength. The deformation is 1.325 mm and the weight of the truck is 1.7021 tons.
- The Model-1B also tested under the same loads, it also failed at 20 tons because of the Equivalent stress 151MPa is more than the allowable yield strength 138MPa. The deformation is more than the Model-1A but the payload capacity is increases by 1.11665 tons.
- Model-2A is tested under the loads of 10, 15, 20, 25 tons load. The model is safe even at 25 tons, but the deformation is quite higher than the Model-1A at 20 tons. Here the increased payload capacity is 0.0406 tons.
- Model-2B has increase in payload capacity of 1.13 tons, which is more than the previous models. The model is having the load carrying capacity of 25 tons keeping the minimum factor of safety (FOS=2) [7], because the equivalent stress 122.6MPa is less than the allowable yield strength 138MPa of the aluminium alloy.
- Model-2B having the more deformation at the side wall, which is undesirable. To minimize the deformation the thickness of the beam has increased to 6 mm, which is a Model-3, which shows that the deformation has reduced around 0.5 mm. The equivalent stresses also reduced 1MPa. This is the best result compare to above all three models. The Increase in payload capacity is less than the Model-2B, but which is more than the Model-1A.
- The Model-4 has the increase in payload capacity of 0.97234tons. The equivalent stress is less than all models at the respective loading conditions, which is desirable one. The deformation also less than the Model-2B. Comparing all the models of truck body the model-4 has the best result in terms of equivalent stress and total deformation.

9. Cost analysis

Cost per kilogram of Structural Steel = Rs. 25
Cost per kilogram of Aluminum 6061 = Rs. 300
Model-1A
Weight of a Structural Steel Body = 1700 kg
Material Cost for building a Structural Steel Body = 1700*25 = Rs. 42500
Model-1B
Weight of the Body = 586 kg
Material Cost = 586*300 = Rs. 175800
Model-2A
Weight of the Body = 1662 kg
Material Cost = 1662*25 = Rs. 41550
Model-2B
Weight of the Body = 572 kg
Material Cost = 572*300 = Rs. 171600
Model-3
Weight of the Body = 584 kg
Material Cost = 584*300 = 175200

Model-4
Weight of Optimized Body = 730 kg
Material cost = 730*300 = Rs. 219000

Cost difference for building a Baseline model and optimized model (Model-4) of body = Rs.176500. According to NR Can [1] for every 100 kg reduction in weight of a truck, the fuel efficiency increases by 0.5L per every 100 km. By considering the model-4, a total of about 970 kg of weight reduction is obtained, so the reduction of fuel consumption is 9.7*0.5 Liters per 100 km i.e., 4.85 Liters per 100 km. Overall cost reduction when the truck fitted with optimized Body runs for 100 km = 4.85*55 = Rs. 266.75. Number of kilometers the truck has to run to compensate the increased price = (176500/266.75)*100= 66167 km.

On an average in India, a truck travels about 300 kilometers per day [5], taking this into account, the number of days required to recover the extra money invested in aluminum body = 66167/300 = 221 days which is approximately equal to 7 and half months. After this period, for every 100 km run of the truck the owner gets an advantage of Rs. 266.75

10. Conclusion

After analyzing different models at 10, 15, 20, 25 ton loads the following conclusions were made

- The Aluminium alloy truck body with rectangular tube stiffener of 6mm thickness for side wall (Model-3) has improved payload capacity by 1.1 ton, and the equivalent stress 121.52MPa for 25 ton capacity compared to standard model.
- The Aluminium alloy truck body with uniform strength beams (Model-4) has the increasing payload capacity of 0.97234 tons, and the equivalent stress 96.22MPa at 25 tons loading condition.
- Out of these two models Model-4 has the better results in terms of equivalent stress and total deformation.
- The cost of aluminium alloy body is quite high. Cost analysis has done to explain the Break-even point, that is after seven and half month the advantage of the aluminium body can be achieved.

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