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Design & Analysis of Rigid Tow Bar for Recovery of Damaged Underground Mining Truck

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Abstract: **Earlier underground mining trucks weighed about 30-40 tons. As the time passed by weight of the underground mining trucks increased due to increase in operational capacity. Therefore the increased weight (50-60 tons) of today's underground mining trucks has introduced a tow bar failure problem encountered during field recovery operations. This problem is due to insufficient strength of the tow bar system currently used in the mining field. In this work design and analysis of a tow bar for recovering the disabled underground mining truck by a recovery vehicle from the mine field to the workshop or garage is carried out using commercially available software packages such as CATIA (V5R19), HYPERMESH (13), and NASTRAN (R9). The obtained software results are compared with the analytical results to validate the design. This newly designed tow bar system is capable of towing the new heavy underground mining trucks.**

Keywords: **Operational capacity, Tow Bar CATIA, HYPERMESH, NASTRAN.**

I. INTRODUCTION

Towing is the process of coupling one object to another, so that one can be pulled along behind the other. The towing source (lead object) is usually a truck or other motorized land vehicle, but anything from water-borne vessels to tractors to animals to people can tow cargo. The coupling may consist of a chain, rope, bar, integrated platform, or some other means of keeping the two objects together while in motion. A tow hitch or tow bar or recovery point is a device attached to the chassis of a vehicle for towing. The tow bar can be a simple rod type structure or a rigid A-frame type. These are the two most widely used tow bar in the industry, with both having their advantages and disadvantages. The A frame tow bar is solid & bulky. The overall cost is more as more material is needed. The single frame tow bars are used for light and medium weight units. The main advantage of this frame is its low price and weight. The cross section of tow bar can be circular, square or rectangular. Square and rectangular sections make the structure more robust; however, it increases the stress concentration at edges and is likely to fail after a certain number of stress cycles. Circular section gives uniform stress concentration throughout; however, it has lesser load pulling capacity as compared to the other sections.

II. LITERATURE REVIEW

The tow bar does a lot of work while towing. Every little bump in the road and every turn you make transfers stress through the tow bar and compresses, twists and stretches the tow bar material constantly. Tow bars are subjected to both constant fatigue loading and heavy application specific loads, with each putting different demands on the structure and steel used in the tow bar construction. It is vital that the correct steel grade and section type is used to ensure that each part will be able to endure the load it will experience.

Pankaj Khannade et al., (1) have done design and analysis of a tow bar for a portable compressor unit. The design is limited to medium sized portable compressors.

Abhishek Adnoor et al., (2) have used the concept of universal type of tow bar. Here they have conducted a non-linear analysis of a tow bar and found out the equivalent stress and deformation. Static analysis and modal analysis were carried out to find the natural frequency, finally buckling analysis was also carried out.

Christopher Cavallaro et al., (3) have developed a new lightweight composite tow bar for MIAl and MIA2 Main Battle Tanks.This effort resulted in a new tow bar design which was lighter, stronger, and offered interchangeability of identical legs at a reasonable cost.

Fadzli Ibrahim et al., (4) in this investigation, the structural integrity of a towing bar using finite element analysis (FEA) was studied. The simulation analysis was done for four different cases, where force was applied at four different angles; 0, 30, 45 and 60˚. The results of the FEA simulations showed that the maximum force that can be applied to the towing bar reduced drastically when the load was applied at increasing angles.

III. MODELLING METHODOLOGY

This work deals with conventional stress and finite element analysis of rigid tow bar for recovery of damaged underground mining truck. In the present work the focus is given on design modification & optimization of the existing design of the tow bar, design modification of the existing bracket to withstand higher load. Load distribution calculations are carried out by considering following two situations:

a) Tensile force acts on the tow bar when the recovery vehicle begins to pull the disabled truck.

b) Compressive forces acts on the tow bar during braking by the recovery vehicle to bring the disabled truck to rest condition Design & Analysis of the tow bar is carried out using the following software packages:

- CATIA V5 R19: For Solid modelling of the tow bar components.
- HYPERMESH 9.0: For discretization and applying the Boundary conditions.
- NASTRAN 2008 r1: For Finite Element Analysis of the tow bar components.

Table 1: Material Properties: IS 8500 (1991) Structural Steel – Micro alloyed

Young’s Modulus, E	210000 N/mm^2
Yield strength	380 N/mm^2
Tensile strength	540 N/mm^2
Density ρ	7.8×10^{-6} kg/mm^3

IV. DESIGN CALCULATIONS

The following conditions were considered while carrying out the calculations

1. Coefficient of friction $\mu = 0.7$.

2. Recovery vehicle moving velocity u =15km/hr.

3. Deceleration $a_d = 6\ m/s^2$

4. Factor of Safety = 2.5

5. Mass of the mining truck m = 60000 kg = 588,600 N.

4.1 Design of Bar:

Case 1: Tensile loading

a) Force required to pull the damaged truck $F = m \times \mu = 412{,}020$ N.

b) Component of force acting on single bar P $=\theta = \frac{\text{adj}}{\text{hyp}} = \frac{F/2}{\text{hyp}} \Longrightarrow \text{hyp} = \frac{F/2}{\cos\theta_o} = \frac{412020/2}{\cos(24.23)}$ = 225,912 N, where θ_o = Half the angle between the two bars =

24.23°.

c) Design yield strength σ_{dy} = Yield strength / FOS = 152 MPa.

d) Diameter of the rod d = $\sqrt{\frac{P}{\sigma\frac{\pi}{4}}}$ = 44 mm.

Case 2: Compressive loading

a) Compressive force acting on bars during braking $F = m \times a_d = 360000$ N

Compressive force acting on single bar = 197,389 N. (P_{des})

b) Critical buckling load $P_{cr} = \frac{\pi^2}{L^2} \times E \times I$

FOS = $\frac{P_{cr}}{P_{des}} \Rightarrow P_{cr} = FOS \times P_{des}$

Mass moment of inertia I = $\frac{P_{des} \text{ X } FOS \text{ X } L^2}{E \times \pi^2}$ = $1.15236 \text{ x } 10^6 \text{ mm}^4$

$$\frac{\pi \times d^4}{64}$$

But Mass moment of inertia I, also =

Calculating d from above equation, Diameter of the rod d = 70 mm.

c) Mass = Density × Volume

Volume = $\frac{\pi}{4} \text{ x } d^2 \text{ x } L$ where L = length of the bar = 2194 mm

∴ Mass of the one rod = 66 kg.

d) Stress $\sigma = \frac{P_{des}}{A}$ = 51.3 MPa.

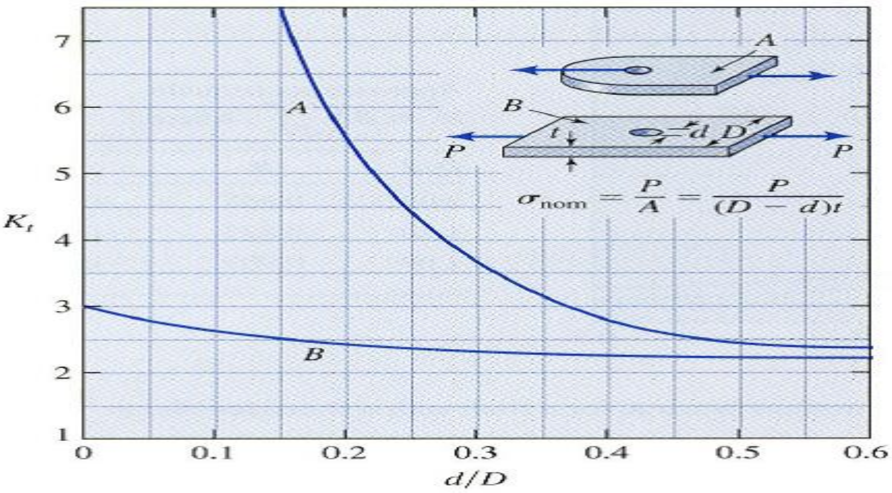
***4.2 Design of Bracket*:**

1. Hole diameter = 50 mm
2. Distance between outer edge of hole and curved edge of the bracket L= 40mm
3. Width of the bracket W = 115 mm
4. Thickness of the bracket T = 30 mm

Force acting on one arm of bracket = 112955.8 N.

Tensile stress:- $\sigma_t = P/A = \frac{112955.8}{(115-50) \text{ x } 30}$ = 57.92 MPa.

d/w = 50/115 = 0.43



Graph showing stress concentration factor for a thick plate with a hole

From the graph (considering the "A" curve) => $K_t = 2.6$

=> Maximum stress $\sigma_{max} = K_t \times \sigma_{nom}$ => 2.6 × 57.92 => 150.592 MPa

Checking for safe design**:**

$\sigma_{working}/\sigma_{design}$ = 380/150.592 = 2.5

FOS = 2.5, Hence design is satisfied

Mass of the whole bracket = 13.2 kg.

Mass of the whole tow bar = 230 kg.

V. FINITE ELEMENT ANALYSIS

The material properties are shown in table 1. In present analysis conventional bar and bracket were modelled in HYPERMESH with tetra elements. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. For static analysis, the tow bar components are fixed at one end and the force is applied at the free end. The displacements and stress distributions are shown in figure 5.1 to 5.12.

5.1 Displacement Plot of Bar (Compression):

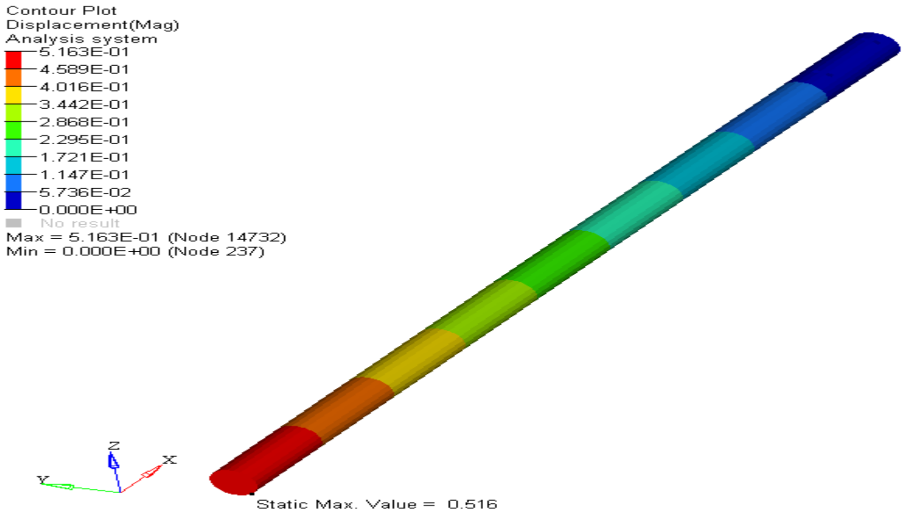


Fig: 5.1 Displacement of bar for compressive loading

The above figure shows the maximum and minimum deformation of the bar. Red region indicates the maximum deflection and blue region indicates minimum deflection. The maximum deflection of the bar is 0.516mm for the applied load of 197.389 kN.

5.2 Stress Plot of the Bar (Compression):

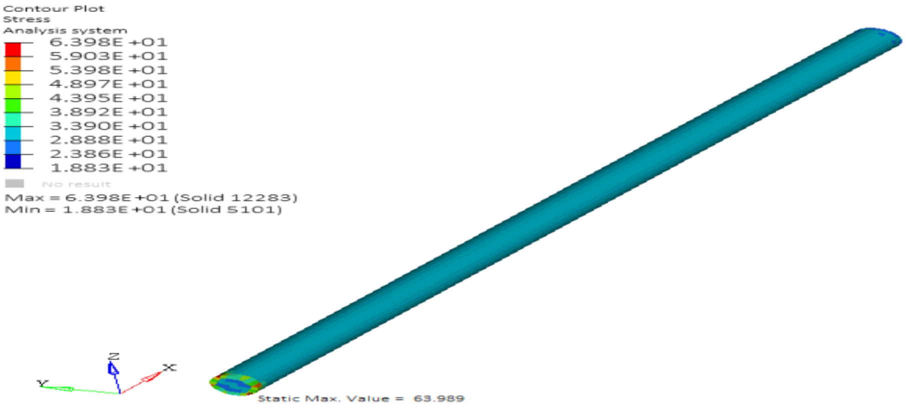


Fig 5.2 Stress distribution in bar for compressive loading

The figure 5.2 shows the maximum and minimum stress in the bar. Red region indicates the maximum stress and blue region indicates minimum stress. The maximum stress in the bar is 63.99Mpa.

5.3 Displacement plot of Single Bracket:

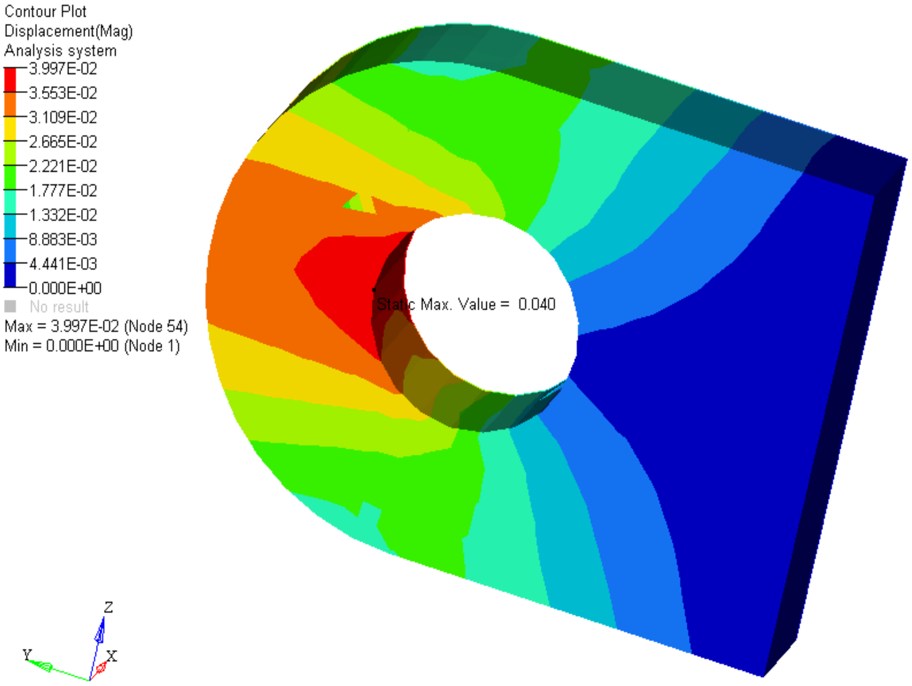


Fig: 5.3 Displacement of single bracket

The above figure shows the maximum and minimum deformation of the single bracket. Red region indicates the maximum deflection and blue region indicates minimum deflection. The maximum deflection of single bracket is 0.040mm for the applied load of 112.95 kN.

5.4 Stress plot of Single Bracket:

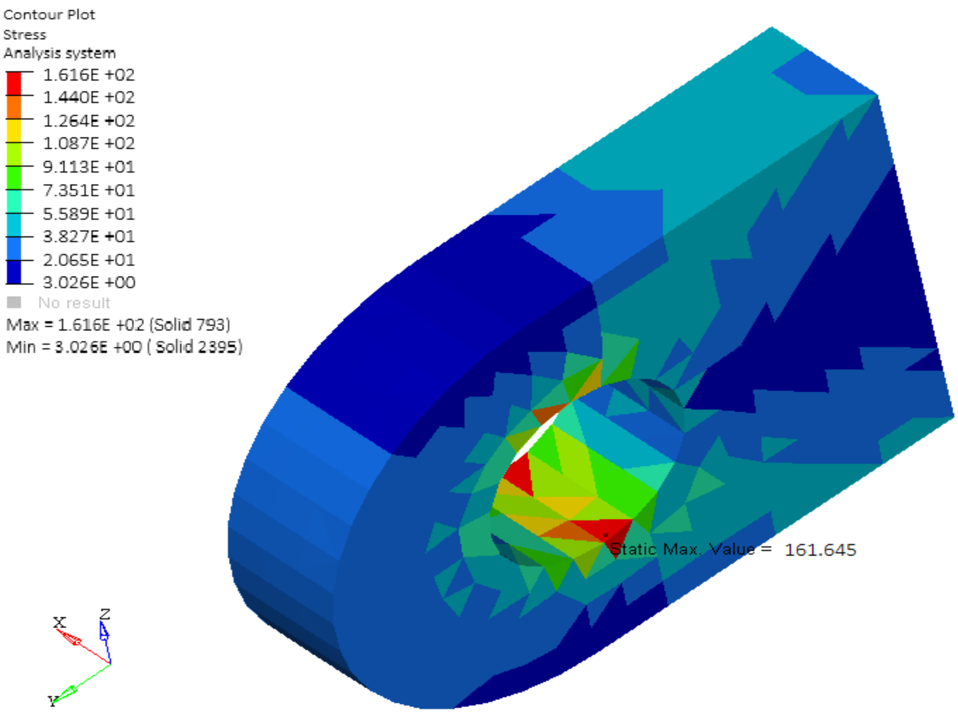


Fig: 5.4 Stress distributions in single bracket

The figure 5.4 shows the maximum and minimum stress in the single bracket. Red region indicates the maximum stress and blue region indicates minimum stress. The maximum stress in the single bracket is 161.645Mpa.

5.5 Displacement plot of Double bracket:

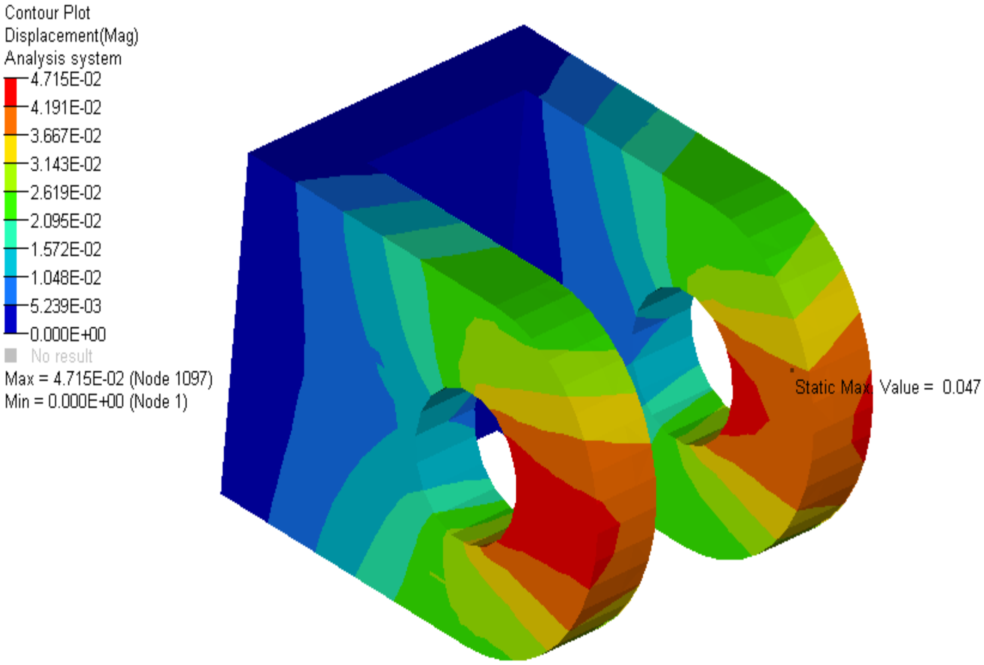


Fig: 5.5 Displacement of double bracket

The above figure shows the maximum and minimum deformation of the double bracket. Red region indicates the maximum deflection and blue region indicates minimum deflection. The maximum deflection of the double bracket is 0.047mm for the applied load of 225.91 kN.

5.6 Stress plot of Double Bracket:

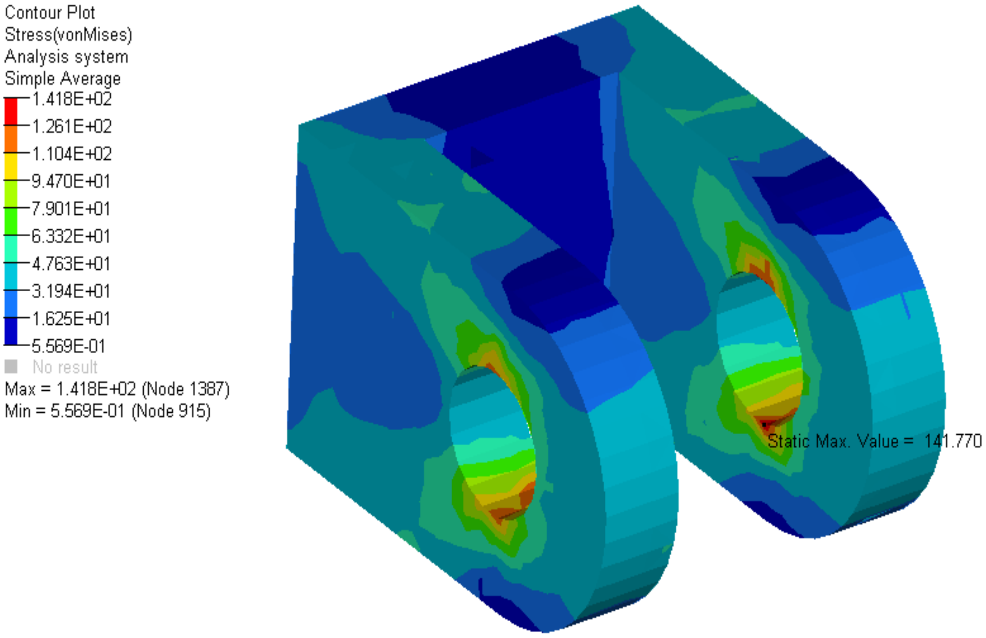


Fig: 5.6 Stress distribution in double bracket

The figure 5.6 shows the maximum and minimum stress in the double bracket. Red region indicates the maximum stress and blue region indicates minimum stress. The maximum stress in the double bracket is 141.770 MPa.

5.7 Displacement plot of Tow Bar Assembly (Compression):

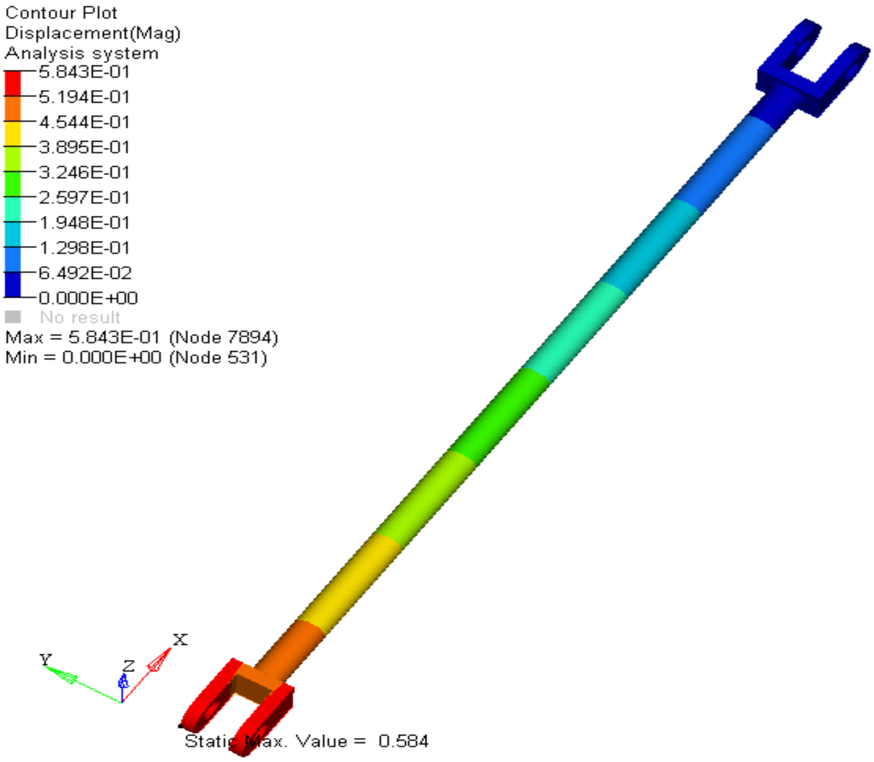


Fig: 5.7 Displacement of tow bar assembly for compressive loading

The above figure shows the maximum and minimum deformation of the tow bar assembly. Red region indicates the maximum deflection and blue region indicates minimum deflection. The maximum deflection of the tow bar assembly is 0.584mm for the applied load of 197.39 kN.

5.8 Stress plot of Tow Bar Assembly (Compression):

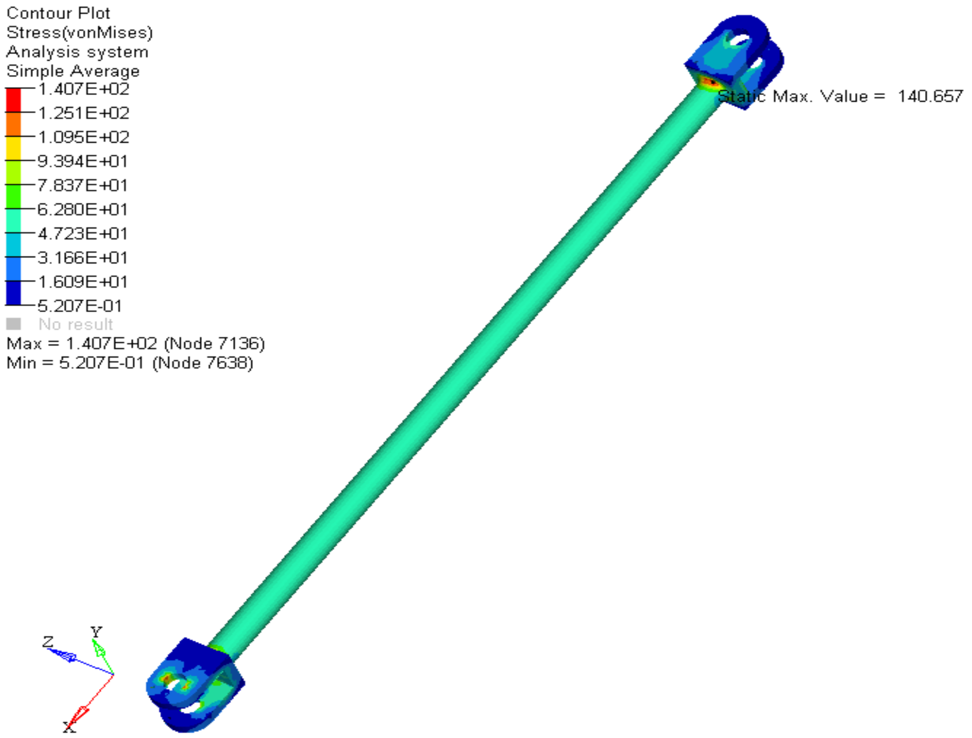


Fig: 5.8 Stress distributions in tow bar assembly for compressive loading

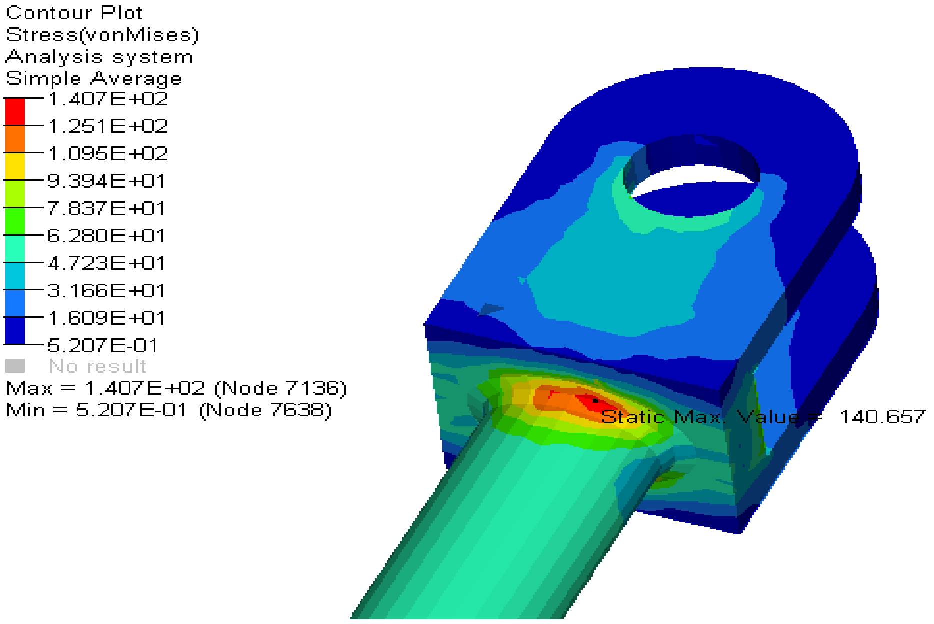


Fig: 5.9 Enlarged view showing maximum stress of tow bar assembly for compressive loading

The above figure shows the maximum and minimum stress in the tow bar assembly. Red region indicates the maximum stress and blue region indicates minimum stress. The maximum stress in the tow bar assembly is 140.657 Mpa.

5.9 Displacement plot of Tow Bar Assembly (Tension):

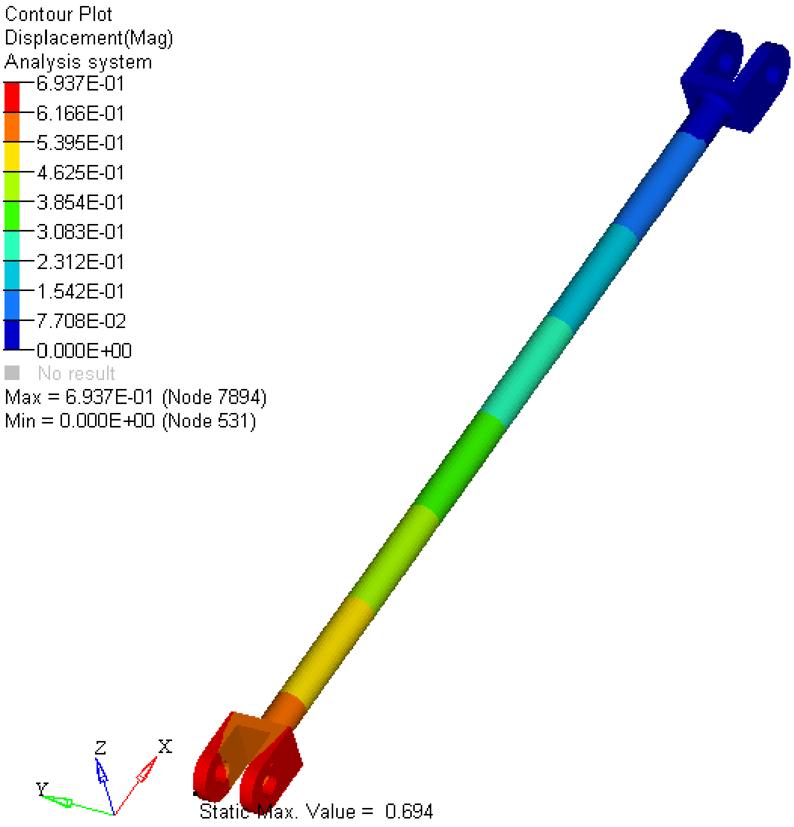


Fig: 5.10 Displacement of tow bar assembly for tensile loading

The figure 5.10 shows the maximum and minimum deformation of the tow bar assembly. Red region indicates the maximum deflection and blue region indicates minimum deflection. The maximum deflection of the tow bar assembly is 0.694mm for the applied load of 225.91 kN.

5.10 Stress plot of Tow Bar Assembly (Tensile):

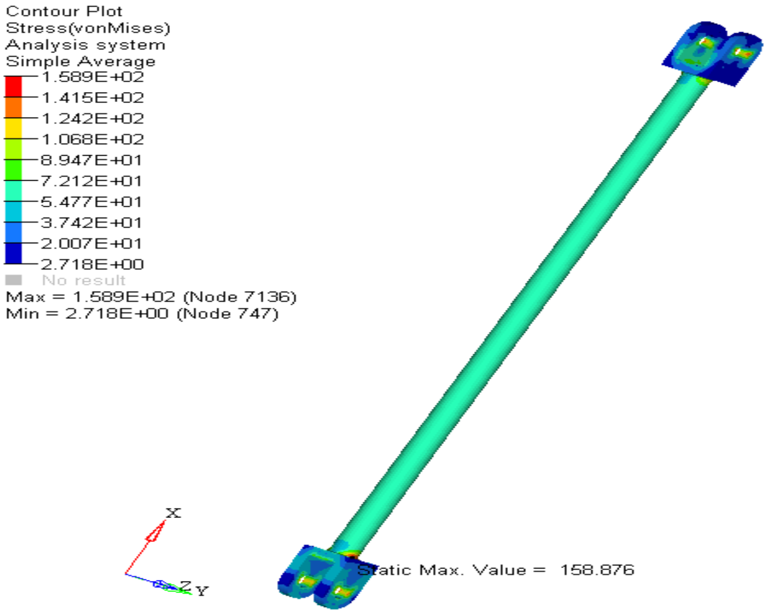


Fig: 5.11 Stress distribution in tow bar assembly for tensile loading

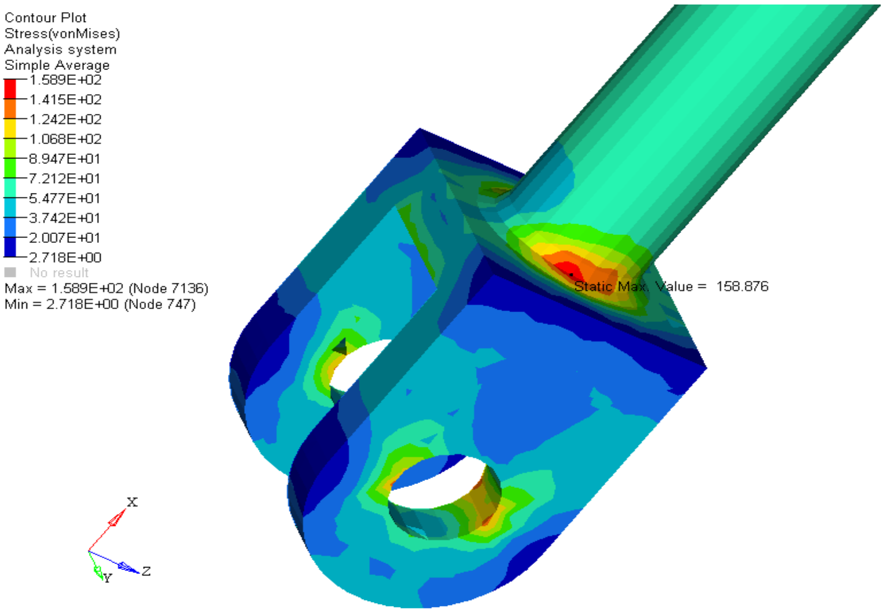


Fig: 5.12 Enlarged view of stress distribution in tow bar assembly for tensile loading

The above figure shows the maximum and minimum stress in the tow bar assembly. Red region indicates the maximum stress and blue region indicates minimum stress. The maximum stress in the tow bar assembly is 158.876 MPa.

VI. CONCLUSIONS

1. Analytical calculation for each component of tow bar assembly has been carried out with minimum Factor of Safety of 2.5

2. Finite Element analysis for each component of tow bar assembly is carried out.

a) Tow bar - Maximum stress obtained for the tensile load of 23 tons is 64 MPa which is well within the yield strength of Material.

b) Bracket - Maximum stress obtained for the tensile load of 11.541 tons is 161.645 MPa which is well within the yield strength of material.

c) Tow bar Assembly - Maximum stress obtained for the tensile load of 23 tons is 158.876 MPa which is well within the yield strength of material.

3. The newly designed tow bar system is capable of towing the heavy mining truck.

VII. SUMMARY

COMPONENT	THEORITICAL RESULTS	FEA RESULTS
Bar (Tensile loading)	58.7 MPa	63.989 MPa
Bar (Compression loading)	51.3 MPa	55.99 MPa
Single Bracket	150.59 MPa	161.645 MPa
Double Bracket	-	141.77 MPa
Tow Bar assembly (Tensile loading)	-	158.876 MPa
Tow Bar Assembly (Compression loading)	-	140.657 MPa

REFERENCES

[1] "Design & stress analysis of tow bar for medium sized portable compressor", International journal of research in engineering & advance technology.

[2] Abhishek Adnoor, H. L. Guruprasad and B. H. Maurthi "Nonlinear Buckling Analysis of a Tow bar", Indian J.Sci.Res. 9 (1): 088-095, 2014.

[3] Fadzli Ibrahim & Mohammad Shafiq Toha, "Finite Element Analysis (FEA) of a C130 Towing bar ", International journal of research in engineering & advance technology.

[4] Pankaj Khannade, Akash Chitnis, Gangadhar Jagdale, "Design and Stress Analysis of Tow Bar for Medium Sized Portable Compressors", IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 2, Issue 3, June-July, 2014, ISSN: 2320 – 8791.

[5] National Code of Practice, Section P, "Heavy Vehicle Modifications, (Tow Coupling/Fifth Wheels)" 2010.

[6] Dr. K. Lingaiah, "Machine Design Data Handbook – Volume-1" Suma Publishers, March 2004.

[7] Robert Nortan, "Elements of Machine design" TATA McGraw Hill, October 2010.

[8] Indian Standard, "Structural Steel-Micro Alloyed (Medium and High Strength Qualities)", First Revision, IS 8500