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Design and Finite Element Analysis of All-Terrain Vehicle Roll Cage

[1]Prashant D Chaudhari, [2]Gaurav S Gajare

[1,2]Department of Mechanical Engineering, Dr. Vithhalrao Vikhe Patil College of Engineering, Ahmednagar, Maharashtra, India

[1]prashantchaudhari4296@gmail.com, [2]gauravgajare84@gmail.com

Abstract – **The paper emphasizes on designing a high performance All-Terrain Vehicle (ATV). We started the designing of 3D model of vehicle using CATIA V5 software. With considering, the critical parameters such as overall weight, safety, high strength, and ergonomics, the roll cage of all-terrain vehicle is designed and then its static analysis is carried out. The Roll cage plays a major role which provides safety to the driver and also it is a main building block of ATV. In this research paper, the roll cage is designed by considering all the constraints provided by SAE (Society of Automotive Engineers). The finite element analysis was done using ANSYS 15.0. Various impacts that the roll cage can undergo are studied. From the optimum design with considering the factor of safety in the account, the roll cage was designed with superior weight to strength ratio. The results obtained after the analysis stated the designed to be safe and sound.**

Keywords* — *All Terrain Vehicle, Ergonomics, FEA, Roll Cage, SAE, Safety.

I. INTRODUCTION

The roll cage is a basic building block of an ATV. It protects the driver and safeguards all the other systems inside. It also supports all the systems such as the steering system, suspension system, transmission system, etc. The objective of this paper is to design a lightweight and high strength roll cage. The cockpit dimensions are assumed according to average driver size. And Engine compartment dimensions are taken according to engine and transmission dimensions. Using this assumption no. of designs were made in CATIA V5 so that optimum strength to weight ratio can be obtained. Final selection of design was done by using ANSYS 15.0 Software. It is important to consider all the possible circumstances which will lead to failure. The aim of this paper is to calculate and study the stress-strain behavior of Roll cage at every possible static loading condition. The performance of the vehicle during the race depends upon the design of safe and lightweight roll cage. Driver spends maximum time during the into the cockpit hence it becomes more important to make the cockpit more friendly and comfortable for the driver handling.

1.1. Design Specifications

The roll cage is designed considering all the rules in SAE BAJA rule book 2018 [1]. Clearance of 3 inches is to be maintained between driver and roll cage members. The circular tube is used for roll cage having 1 inch OD & 2 mm thickness. The material used for the tube is AISI 4130 its selection is discussed in the following topic.

1.2. Material Selection

One of the important design consideration that increases the safety, reliability and performance in any automobile design is the material selection. As per the rule book constraint, there should be at least 0.18% of carbon content in metal according to BAJA SAE INDIA rulebook [1]. Considering strength to weight ratio of material we selected AISI 4130 (Chromoly) material for our design. One more property of AISI 4130 while selecting material was its corrosion resistance. Chromoly is an alloy steel of chromium and molybdenum. Molybdenum helps in increasing the strength of the material. Following is the comparison of AISI 1080 & AISI 4130 material considered.

Material	AISI 1080	AISI 4130
Density (kg/m^3)	7870	7850
Yield Strength (MPa)	370	460
Tensile Strength (MPa)	440	731

Table 1: Material Comparison

II. METHODOLOGY

Designing of ATV Roll cage is a creative work. Where we have to follow all the constraints given in BAJA SAE INDIA rulebook. Following those constraints we first made a rough sketch on paper and dimensions were taken according to the average size of a human being. Then for

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modelling, we used CATIA V5 software. While modelling weight of Roll cage was considered as it plays a major role in the performance of an ATV. For minimizing the weight of a roll cage thickness of pipe was optimized to 2 mm as it is provided to be greater than 1.6 mm according to SAE Rulebook [1]. Even though we used the thickness of 2 mm, the strength of a roll cage was not compromised as we used better strength to weight ratio material AISI 4130 (chrome-moly). Our model was further analyzed in ANSYS 15.0 software. By following all the above constraints we finally modelled our design which is shown in Fig. 1(a,b,c).

Attributes	Values
Length	1850 mm
Width	889 mm
Height	1194 mm
Weight	30 kg
Weight (with driver)	210 kg

Table 2. Basic dimensions of following Roll cage

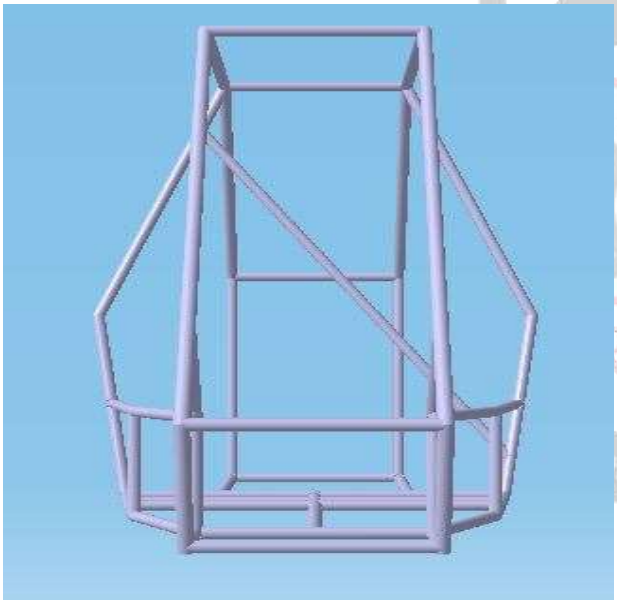

Figure 1(a): Front View of Roll Cage

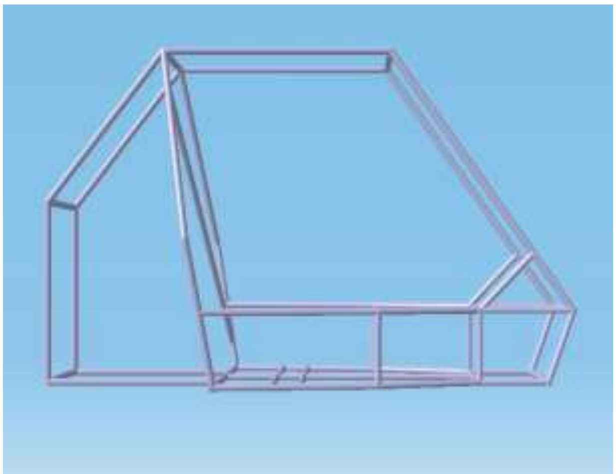

Figure 1(b): Side View of Roll Cage

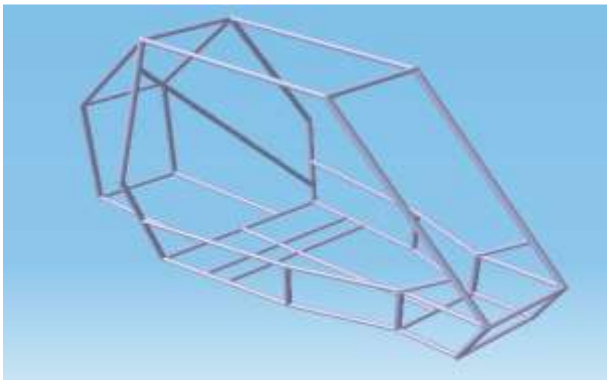

Figure 1(c): Isometric View of Roll Cage

III. FINITE ELEMENT ANALYSIS (FEA)

Analysis of a roll cage can be performed on different software. Out of which more favorable and user-friendly is ANSYS. We have used ANSYS 15.0 for our roll cage analysis. While performing FEA weight of ATV with the driver was considered to be 210 kg. And other following assumptions were made.

1. Cross section of a roll cage is uniform.
2. The roll cage is stationary
3. Time of impact is considered to be 0.2 seconds.
4. The material is Homogeneous.
5. Boundary conditions were applied to suspension mounting points (constrained).
6. Meshing:
   A. Mesh Size - 3.5 mm
   B. Element Type - Triangles & Quadrilaterals

3.1 Front Impact Analysis

A. Impact force calculation

During front impact analysis roll cage is considered to be stationary. And forces are applied on the front face of the roll cage.

Force applied is calculated as follows:

Mass = 210 kg
Max. Velocity (Initial velocity) = 60 km/hr
= 16.67 m/sec

Time of Impact = 0.2 sec
Final Velocity = 0 m/sec.
Force = mass x (initial velocity - final velocity)/Time of impact
F = 210 x (16.67 - 0) / 0.2
F = 17503.5 N

B. Front impact Ansys 15.0 images

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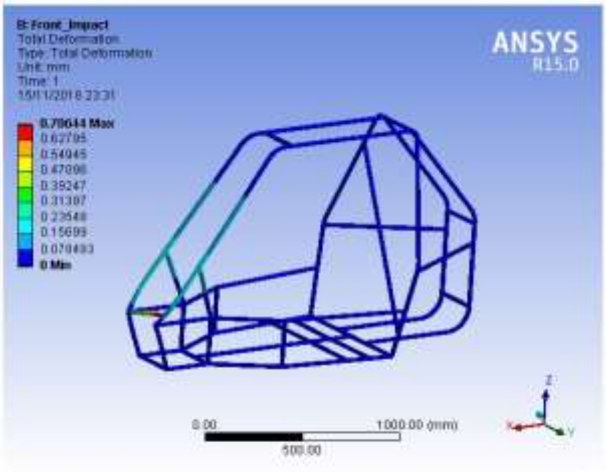

Figure 2: Total Deformation in Front Impact

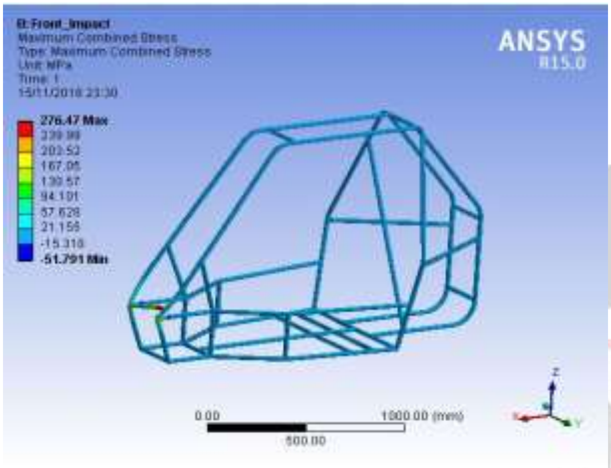

Figure 3: Max. Stress in Front Impact

C. The factor of Safety (FOS)

The factor of the safety of roll cage should be greater than 1.5. From front impact analysis maximum stress obtained is 276.47 MPa. So FOS can be calculated as follows.

FOS = Maximum stress/ Allowable stress

= 460 / 276.47

= 1.66

Here FOS obtained for front impact is 1.66 which is greater than 1.5. So we can conclude that our design is safe in front impact analysis.

3.2 Rear Impact Analysis

A. Impact force calculation

The similar to front impact analysis roll cage is considered to be stationary. And forces are applied on a rear part of the roll cage.

Force applied is calculated as follows:

Mass = 210 kg

Max. Velocity (Initial velocity) = 60 km/hr

= 16.67 m/sec

Time of Impact = 0.2 sec

Final Velocity = 0 m/sec.

Force = mass x (initial velocity - final velocity)/Time of impact

F = 210 x (16.67 - 0) / 0.2

F = 17503.5 N

B. Rear impact Ansys 15.0 images

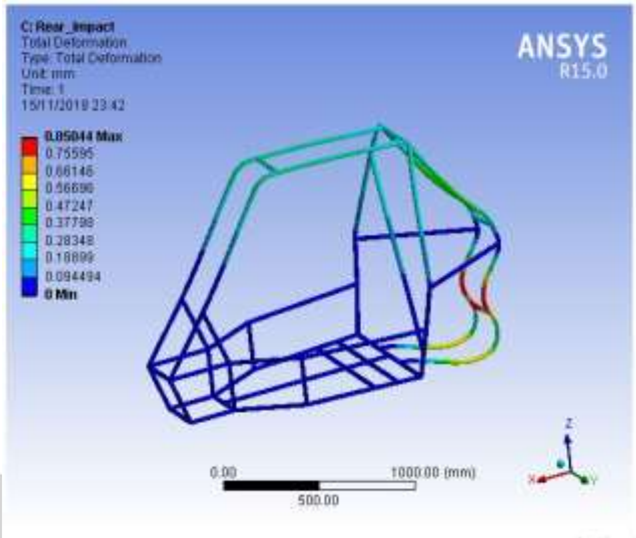

Figure 4: Total Deformation in Rear Impact

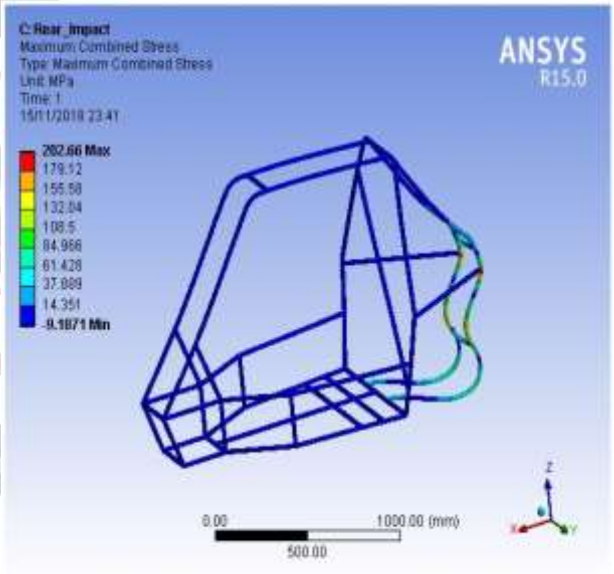

Figure 5: Max. Stress in Rear Impact

C. The factor of Safety (FOS)

The factor of the safety of roll cage should be greater than 1.5. From rear impact analysis maximum stress obtained is 202.66 MPa. So FOS can be calculated as follows.

FOS = Maximum stress/ Allowable stress

= 460 / 202.66

= 2.26

Here FOS obtained for rear impact is 2.26 which is greater than 1.5. So we can conclude that our design is safe in rear impact analysis.

3.3 Side Impact Analysis

A. Impact force calculation

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In Side Impact Analysis side forces are considered to be g-force. Forces are applied on the side impact members and suspension mountings are constrained while analysis.

G-force is calculated as follows

Mass = 210 kg

Gravitational force = 10 m/s^2

Side Impact Forces = 3 x gravitational force x mass

= 3 x 10 x 210

= 6300 N

B. Rear impact Ansys 15.0 images

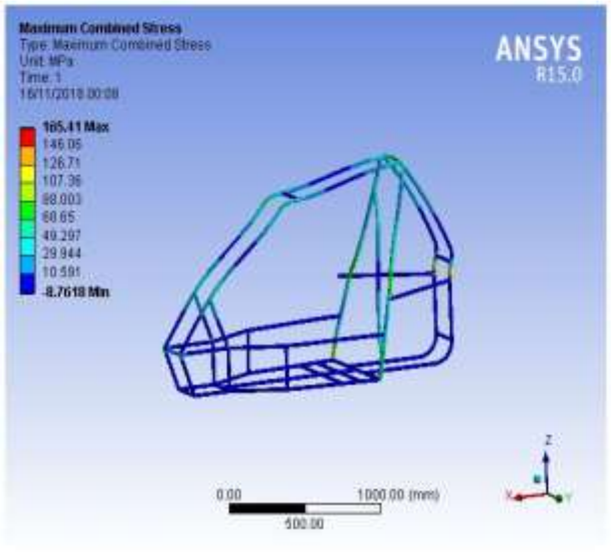

Figure 6: Total deformation in side impact

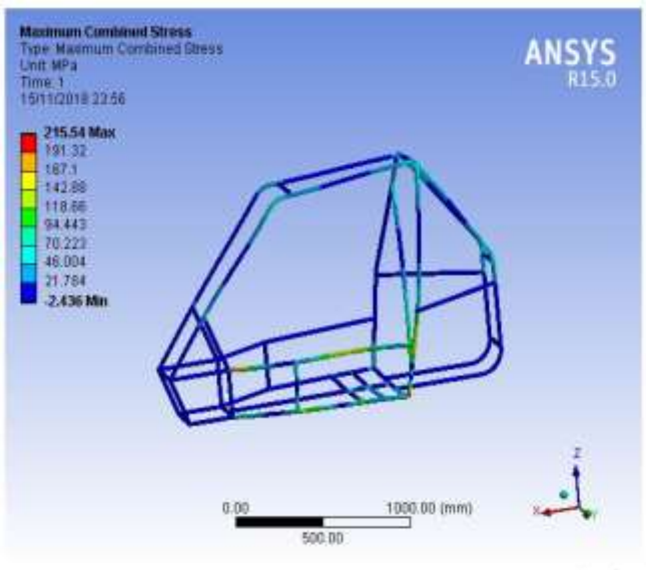

Figure 7: Max. Stress in Side Impact

C. The factor of Safety (FOS)

The factor of safety of roll cage should be greater than 1.5. From side impact analysis maximum stress obtained is 215.54 MPa. So FOS can be calculated as follows.

FOS = Maximum stress/ Allowable stress

= 460 / 215.54

= 2.13

Here FOS obtained for side impact is 2.13 which is greater than 1.5. So we can conclude that our design is safe inside impact analysis.

3.4 Front Roll Over Analysis

A. Impact force calculations

During Front Rollover Analysis impact force location is considered first at roll cage members in contact. Here also g-force is considered for application. We have applied the calculated g-force to the members which are first coming in contact with the road surface. Forces are applied normal to the curved surface of the roll cage. And the suspension mount is constrained as in all the above cases.

G-force is calculated as follows

Mass = 210 kg

Gravitational force = 10 m/s^2

Front roll over force = 3 x gravitational force x mass

Front roll over force = 3 x 10 x 210

= 6300 N

B. Front roll over Ansys 15.0 images

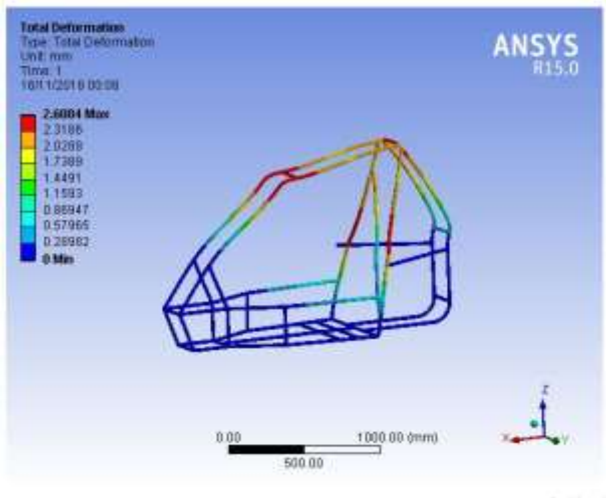

Figure 8: Total Deformation in Front rollover

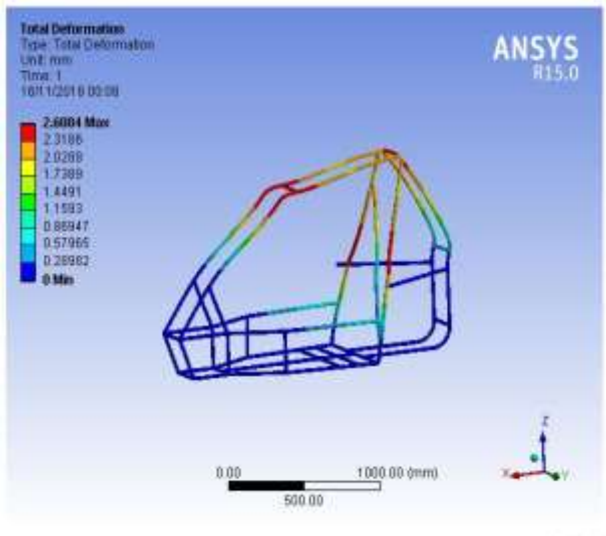

Figure 9: Max. Stress in Front rollover

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C. The factor of Safety (FOS)

The factor of the safety of roll cage should be greater than 1.5. Front rollover analysis maximum stress obtained is 165.41 MPa. So FOS can be calculated as follows.

FOS = Maximum stress/ Allowable stress

= 460 / 165.41

= 2.78

Here FOS obtained for front roll over is 2.78 which is greater than 1.5. So we can conclude that our design is safe in a front roll over analysis.

3.5 Rear Rollover Analysis

A. Impact force calculations

During Rear Rollover Analysis impact force location is considered first at roll cage members in contact. Here also g-force is considered for application. We have applied the calculated g-force to the members which are first coming in contact with the road surface. Forces are applied normal to the curved surface of the roll cage. And the suspension mount is constrained as in all the above cases.

G-force is calculated as follows
Mass = 210 kg
Gravitational force = 10 m/s^2
Front roll over force = 3 x gravitational force x mass
Front roll over force = 3 x 10 x 210
= 6300 N

B. Rear roll over Ansys 15.0 images

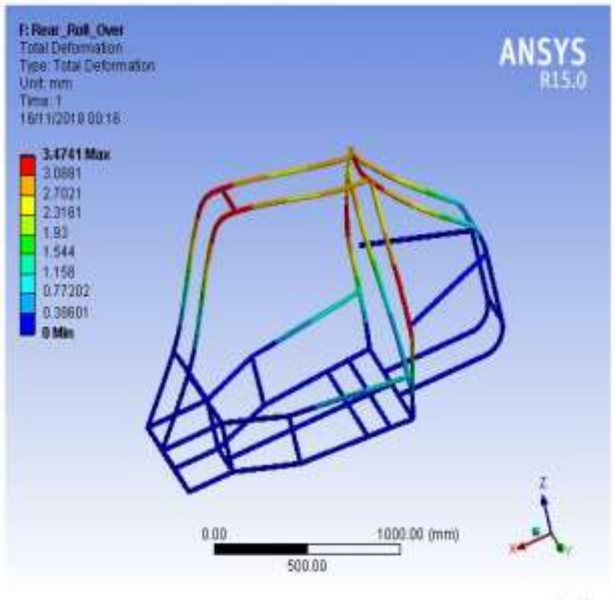

Figure 10: Total Deformation in Rear rollover

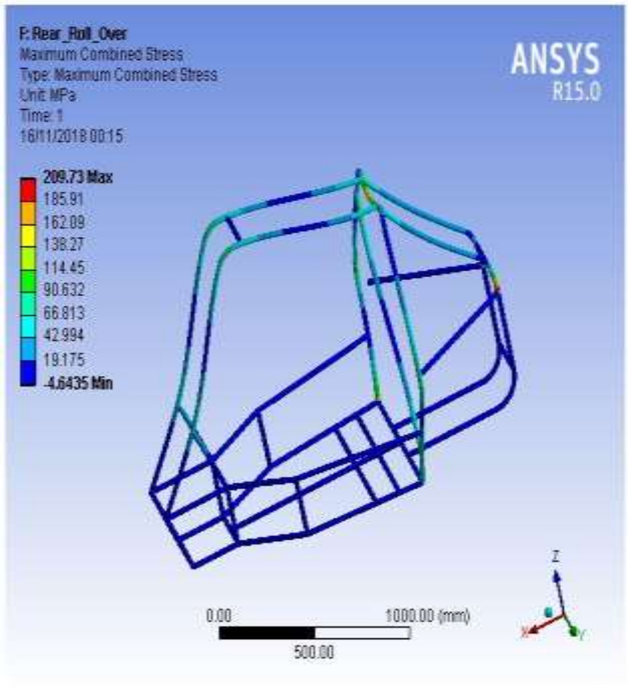

Figure 11: Max. Stress in Rear rollover

C. The factor of Safety (FOS)

The factor of the safety of roll cage should be greater than 1.5. Rear rollover analysis maximum stress obtained is 209.73 MPa. So FOS can be calculated as follows.

FOS = Maximum stress/ Allowable stress

= 460 / 209.73

= 2.19

Here FOS obtained for rear roll over is 2.19 which is greater than 1.5. So we can conclude that our design is safe in rear rollover analysis.

IV. CONCLUSION

We have successfully analyzed the roll cage structure in ANSYS 15.0. The factor of safety for all the cases is in the safe limit, so we can conclude that our design is safe in front, rear and side impact analysis and also in front and rear rollover analysis. Stresses obtained are below yield stresses and also under safe range for the pipes used. The thickness of the pipe is above required thickness as mentioned in BAJA SAE Rulebook [1]. Material Characteristics are suitable for our design as FOS is above 1.5 in every case. AISI 4130 (Chromoly) is also having more corrosion resistance and high strength to weight ratio. So from all the obtained results, we can say that our design is having optimum FOS. This makes the roll cage safe for driver and thus the fabrication can be started. The results obtained from the analysis are summarized in the following table:

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Type	Stress	Deformation mm	FOS
Front	276.47	0.70	1.66
Rear	202.66	0.85	2.26
Side	215.54	6.14	2.13
Front Roll Over	165.41	2.60	2.78
Rear Roll Over	209.73	3.47	2.19

Table 3: Results

Thus the results shown in the above table proves that the vehicle roll cage designed is safe. While studying all the impacts on the roll cage the factor of safety was found to be more than 1.5.

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