Static Analysis of the Roll Cage of All-Terrain Vehicle

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Abstract - *Roll-cage is multi tubular space frames, acts as a structural body for various types of automotive vehicles. It provides space for mounting of all components and gives maximum safety and comfort to driver with all required clearance. A roll cage is a skeleton of an ATV. It not only forms the structural base but also a 3-D shell surrounding the occupant which protects the occupant in case of impact and roll over incidents. The roll cage also adds to the aesthetics of a vehicle. So determining strength requirements of roll cage and stress analysis is carried out using FEA software Ansys workbench. This paper deals with Analysis of roll cage for an ATV and Various loading conditions like Front Impact, Side Impact, Roll Over, Rear Impact, Bump Analysis and Torsional Analysis have been conducted. This literature also include graph between Equivalent Stress and Factor of safety. The modelling is done using CATIA V5R20 and stress analysis is done by using ANSYS 18.1 software. The main objective of analysis is to obtain optimum factor of safety at different loading conditions which ensures that the roll cage of ATV will be safe in all conditions.*

***Key Words*: ATV, Roll cage, Modelling, CAD, FEA, Factor of safety**

INTRODUCTION

The roll cage here is designed under the guidelines of BAJA SAE rulebook. The objective of mBAJA competition is to design and fabricate an All-Terrain Vehicle. The roll- cage is a structure to protect the driver and to support all control systems like Transmission, suspension, steering, breaking system, Driver safety equipment's and Electrical component. The design factor contains safety, easy manufacturing, durability & maintenance of the frame and a compact, lightweight & ergonomic design. It is very important to check all failure modes of roll cage on multiple conditions such as Front Impact, Side Impact, Roll Over, Rear Impact, Bump Analysis and Torsional Analysis have been conducted to ensure the safety of a driver. [1][2][3] Research include static analysis for predicting failure modes of roll cage. In that they have used grid independency for selection of mesh size during analysis. This research discusses about static analysis of all possible impact cases during event site. As static analysis is done using theoretically calculated value of forces by assuming impact time.

1. Roll-cage Design

For designing the roll cage of the ATV several software's are available and it's up to you which software you select for designing. In this paper I used CATIA V5R20 develop by Dassault system[9]. The design and development process of the roll cage involves various factors; namely material selection, pipe size selection, Welding process, frames design and finite element analysis. The details of each step are given below.

1.1 Material Selection

The selection of material for chassis is done by detailed study of properties of material regarding strength and cost, results found that two materials AISI 1018 and AISI 4130 which are having similar properties. But prefer to use AISI 4130 over AISI 1018, because of its higher yield strength and high strength to weight ratio.

The material AISI-4130 is used in the chassis design because of its good weld ability, relatively soft and strengthens as well as good manufacturability. A good strength material is important in a roll cage because the roll cage needs to absorb as much energy as possible to prevent the roll cage material from fracturing at the time of high impact. AISI 4130 has chosen for the chassis because it has structural properties that provide a high strength to weight ratio.

Table No.1: Mechanical Properties of Material

Parameter	AISI1018	AISI4130
Density	8.87 g/cc	7.85 g/cc
Elastic module	205 GPa	210 GPa
Elongation	15.0 %	21.50 %
Yield strength	370 MPa	560 MPa
Ultimate strength	440 MPa	690 MPa

Table No.2: Chemical Composition Of Material (AISI4130)[4]

Carbon (C%)	0.28-0.33
Iron (Fe%)	97.03-98.22
Nickel (Ni%)	1.7-2.0

Chromium (Cr%)	0.8-1.1
Manganese (Mn%)	0.4-0.6
Molybdenum (Mo%)	0.15-0.3
Silicon (Si%)	0.15-0.3
Sulphur (S%)	0.04
Phosphorus	0.035

1.2 Welding

The material which is used AISI4130 has good weld ability. All welds on the vehicle are made using a MIG (metal inert gas) welding process. MIG welding uses an arc of electricity to create a short circuit between a continuously fed anode (+ the wire fed gun) and a cathode (- the metal being weld). MIG is selected because it provided the best control of heat affected zones while also reducing internal stress in the frame selected in order to allow the weld to flex slightly without cracking. It provides strongest welds, faster welding speed and is clean and efficient makes welding easier.[5]

1.3 CAD model

The entire Roll cage is design as par latest rulebook of BAJA SAE 2018.The main function of the roll cage frame is to provide the mechanical support to different parts of vehicle like engine, tires, suspension systems etc. It provides dynamic stability, strength, strength against vertical bending, and safety of driver against accidents and also acts as a vibration harness agent.

The following are the considerations for the design:

1. Driver Ergonomics: The emphasis of the design is on driver comfort and safety.
2. Nodal Geometry: To increase the load transfer path.
3. Mounting points for the integration of Suspension, Transmission, Steering and Brakes.

Table No.3: Rulebook Conformation [6]

Parameter	Allowable value	Design value
Maximum vehicle width (inches)	64	60
Maximum vehicle length (inches)	108	79
Minimum firewall width at 27 inches above seat	29	30
Material used	AISI4130/Chromoly	AISI4130
Vertical distance of SIM from seat (Inches)	8-14	13
FBM angle	Max. 20°	7°
Vertical distance between seat and RHO (inches)	Greater than 41	42

Member in Roll Cage

Primary member -29.2*1.65mm (shown by red color)

Secondary member - 25.4*1.65mm (shown by grey color)

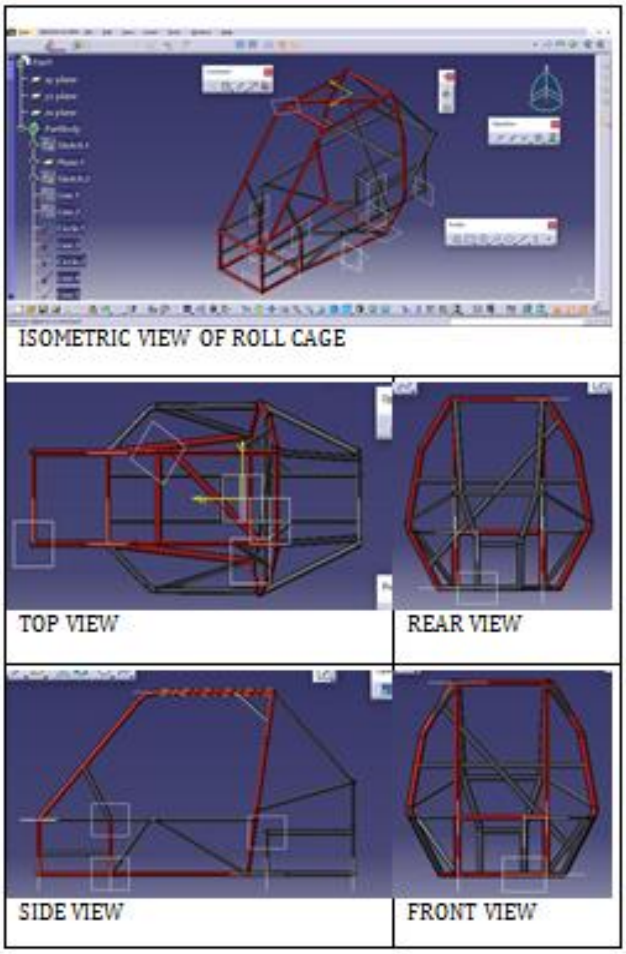

Figure No.1: CAD View of Roll Cage In CATIA

1.4 Meshing

Auto meshing (3.24mm to 16.20mm) has been done in ANSYS 18.1 Workbench software.[7]

Following data has been found after meshing of chassis –

Table No.4: Number Of Nodes Found

Statistics	
Nodes	51786
Elements	51536

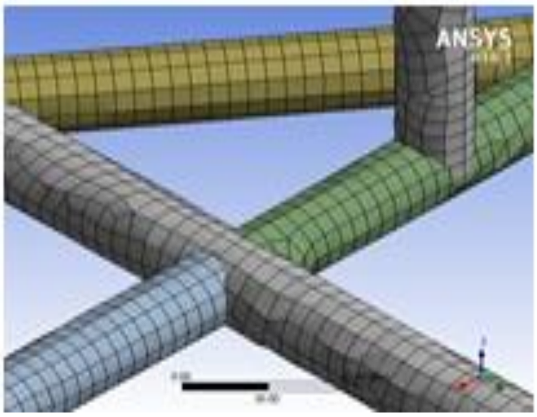

Figure No.2: Meshing

1.4 Impact Force Calculation & Analysis Images In Case Of Static Analysis

A. Condition of impact and Constrain

During impact, the ATV may hit a tree or another ATV or a wall. To properly analyse the impact force, we need to find the deceleration value of the vehicle after impact. To approximate the worst case scenario that the vehicle will undergo, momentum equations were used to determine the deceleration of the vehicle. The vehicle was considered to be at maximum speed of 60 km/hr having total weight of 230 kg and according to different scenarios the conditions of Front impact, Side impact, Rollover, Rear impact, Bump analysis and Torsional analysis were the time of impact of AVT consider to be of 1s by giving proper constrain.

The forces which were impacted on the roll cage were decelerations of g and it is calculated as follows -

Assume gravitational force = 9.8 m/s^2

g = mass of the vehicle × gravitational force acting on the vehicle[8]

g = m x g

= 230 x 9.81

g = 2256.3 N

Therefore, 3g = 6768.9 N and 4g = 9025.2 N

1. Front Impact Analysis

In case of front impact, the ATV is going to crashed on another vehicle or tree during the race. The deceleration value of the vehicle is assumed to be of 4g and varies in different conditions. The boundary conditions for frontal impact test, the roll cage is to be fixed from the rear side (i.e. Rear suspension mounting points) and the front portion of roll cage will come across the applied load.

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
4g	9	108.58	0.75	5.15
6g	13.5	162.87	1.13	3.43
8g	18	217.17	1.50	2.57
10g	22.5	271.46	1.88	2.06
16g	36.1	434.33	3.01	1.28

Table No.5: Force Applied In Front Impact Analysis

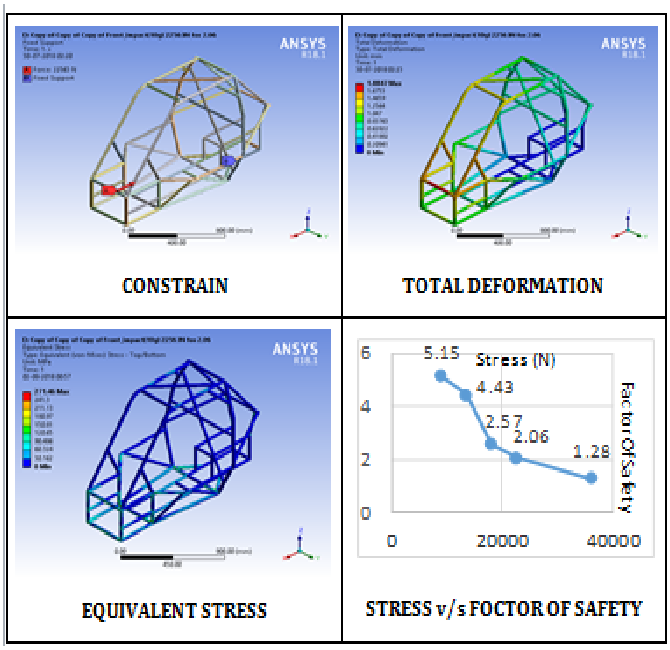

Figure No.3: Results Of Front Impact Analysis

2. Side Impact Analysis

In case of Side impact, Another ATV is going to crashed on sides of ATV during the race. The deceleration value of the vehicle is assumed to be of 5g and varies in different conditions. The boundary conditions for side impact test, the roll cage is to be fixed from the left side and the forces will come across the right side of the roll cage or vice-versa.

Table No.10: Force Applied In Side Impact Analysis

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
3g	6.7	265.45	2.07	2.10
5g	11.2	431.07	3.37	1.29

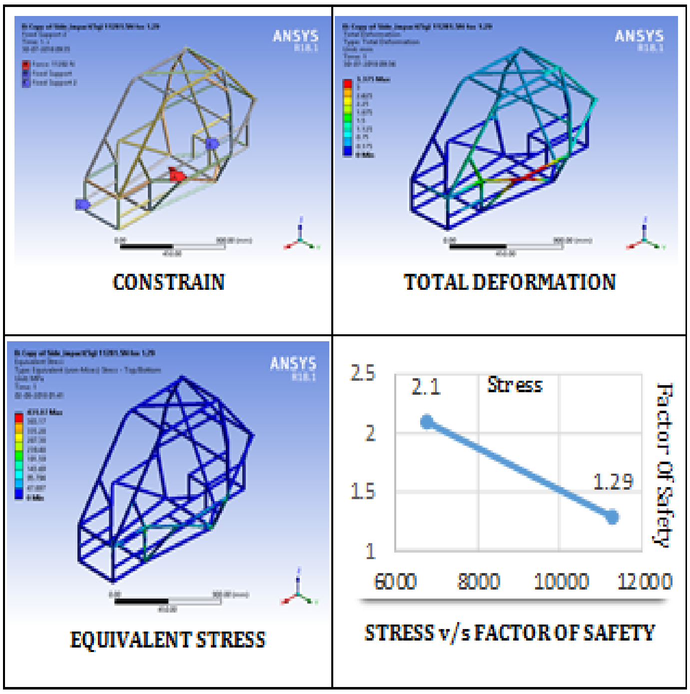

Figure No.4: Results Of Side Impact Analysis

3. Roll Over Analysis

In case of Roll over or topples impact, the ATV is going to rolls on the track at an angle of 45° during the race. In this impact, the upper and rear members of the vehicle will bear the force. The deceleration value for rollover impact is consider to be 3g and varies in different condition. The boundary conditions for Roll over test, the roll cage members are fixed from bottom side and upper portion of ATV come across the applied load.

Table No.6: Force Applied In Roll Over Analysis

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
3g	6.7	167.22	1.88	3.34
4g	9	222.53	2.35	2.51
6g	13.5	333.79	3.52	1.67
8g	18	445.06	4.70	1.25

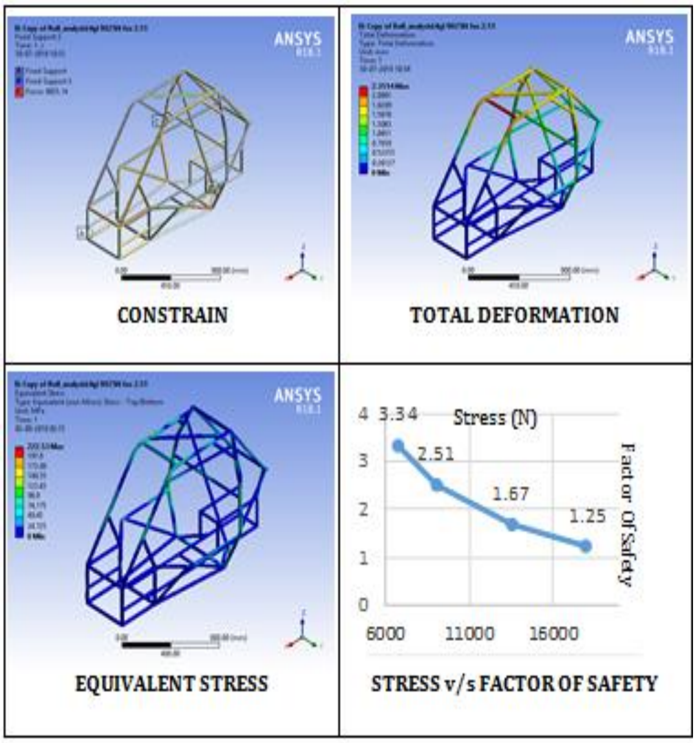

Figure No.5: Results Of Roll Over Analysis

4. Rear Impact Analysis

In case of Rear impact, the another ATV is going to crashed on back side of the vehicle during the race. The deceleration value of the vehicle is assumed to be of 4g and varies in different conditions. The boundary conditions for rear impact test, the roll cage is to be fixed from the front side (i.e. Front suspension mounting points) and the rear portion of roll cage will come across the applied load.

Table No.7: Force Applied In Rear Impact Analysis

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
4g	9	183.83	1.40	3.04
6g	13.5	275.75	2.10	2.03
8g	18	367.66	2.80	1.52
10g	22.5	459.58	3.51	1.21
16g	36.1	735.33	5.61	0.76

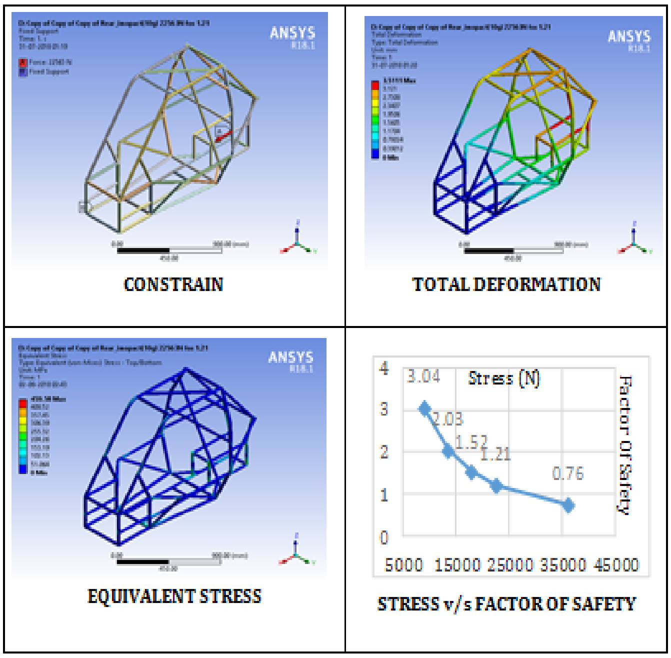

Figure No.6: Results Of Rear Impact Analysis

5. Bump Analysis

During the competition, the vehicle has to travel on uneven tracks. There are times when the vehicle moving along an upward slope travels about a curved projectile in air before landing on its wheels. The lower frontal part of the vehicle is the initial member which faces this impact. Once the front tyres touch the surface, the suspension system absorbs the initial forces exerted on it. A time comes when the suspension system is compressed to its maximum extent and act like solid member of the vehicle. The rest of the load is transferred to the roll cage members of the vehicle. In order to ensure the safety of the driver, we determine this impact force using ANSYS.

a) Front Bump Analysis

In case of bump impact, the AVT is goes under front or rear bump the during the race. The deceleration value of the vehicle is assumed to be of 4g and varies in different conditions. The boundary conditions for front bump analysis, the roll cage is to be fixed from the rear side and the front suspension mounting member will come across the applied load in vertical upward direction.

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
3g	6.7	237.59	3.59	2.35
4g	9	316.81	4.78	1.76
6g	13.5	457.18	7.18	1.17

Table No.8: Force applied In Front Bump Analysis

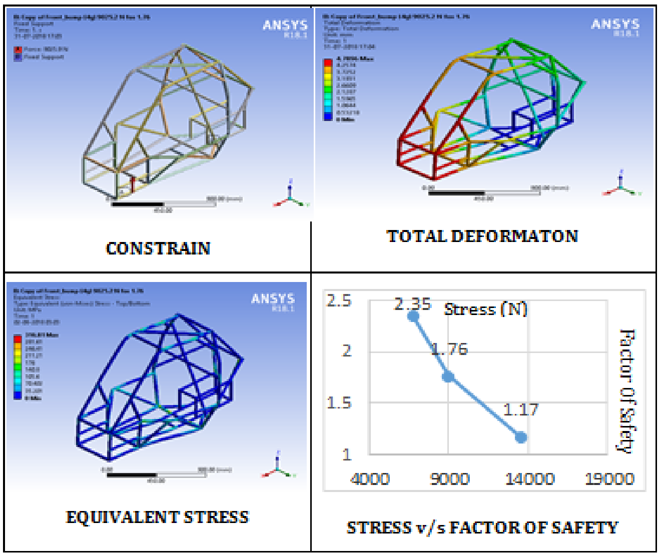

Figure No.8: Results Of Front Bump Analysis

b) Rear Bump Analysis

In case of Rear bump analysis, The deceleration value of the vehicle is assumed to be of 4g and varies in different conditions. The boundary conditions for Rear bump analysis, the roll cage is to be fixed from the front side and the Rear suspension mounting member will come across the applied load in vertical upward direction.

Table No.9: Force Applied In Rear Bump Analysis

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
3g	6.7	289.99	4.36	1.93
4g	9	386.66	5.81	1.44
6g	13.5	579.99	8.72	0.96

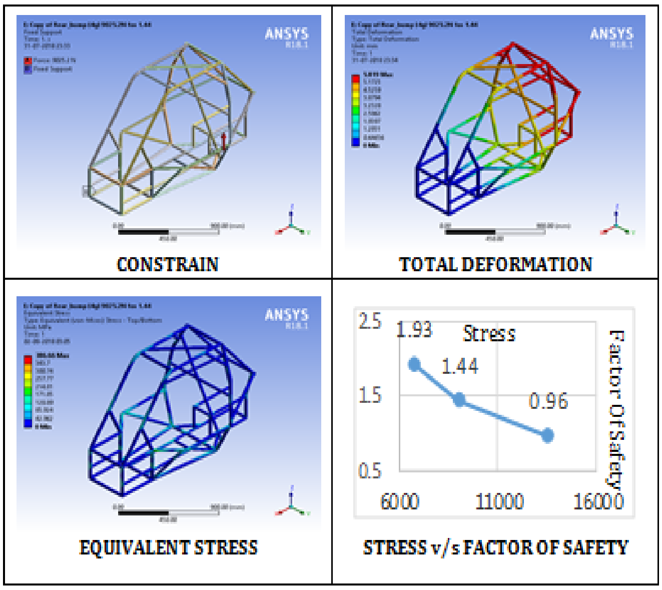

Figure No.9: Results Of Rear Bump Analysis

5. Torsional analysis

This impact is analysed taking into consideration the torsional forces acting on the frontal and Rear members of the vehicle. This type of force is exerted on the vehicle when it runs on an uneven road. The two tyres on the front and rear axle experience a moment. The torque is applied to one tyre and reacted by the other one. These forces are equal and opposite.

a) Front Torsional Analysis

The torque on the vehicle is assumed to be of 3g and varies in different conditions. The boundary conditions for front torsional analysis, the roll cage is to be fixed from the rear side and the front suspension mounting member will come across the applied load in vertical upward direction at left side (1.5g) and vertical downward direction at right side (1.5g) of the vehicle or vice-versa.

Table No.10: Force applied In Front Torsional Analysis

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
3g	6.7	191.66	0.68	2.92
4g	9	255.55	0.90	2.19
6g	13.5	383.32	1.36	1.46
8g	18	511.10	1.81	1.09

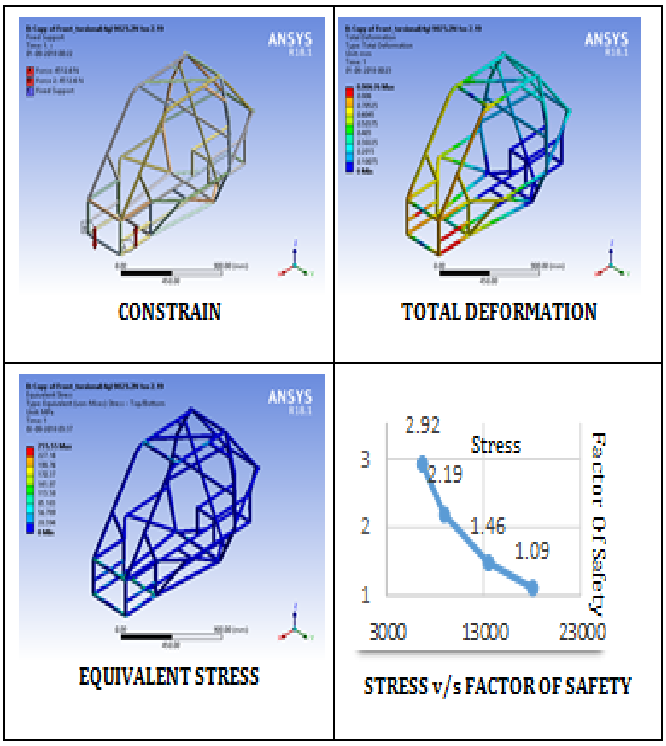

Figure No.10: Results Of Front Torsional Analysis

b) Rear Torsional Analysis

The torque on the vehicle is assumed to be of 3g and varies in different conditions. The boundary conditions for Rear torsional analysis, the roll cage is to be fixed from the front side and the rear suspension mounting member will come across the applied load in vertical upward direction at left side (1.5g) and vertical downward direction at right side (1.5g) of the vehicle or vice-versa.

Table No.11: Force Applied In Rear Torsional Analysis

g Force	Applied Force (KN)	Von-Mises Stress (MPa)	Total Deformation (mm)	FOS
3g	6.7	140.34	0.49	3.99
4g	9	187.13	0.65	2.99
6g	13.5	280.69	0.98	1.99

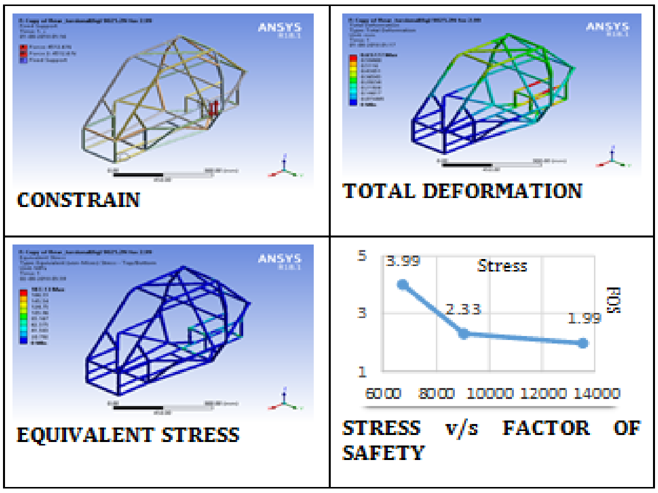

Figure No.11: Results Of Rear Torsional Analysis

CONCLUSION:

The design roll cage is analysed for Front Impact, Side Impact, Roll Over Analysis, Rear Impact, Bump analysis and Torsional analysis. The application of load is depending upon the condition face by ATV during the race. It has been found that all the values of Equivalent stress, Total deformation and Factor of safety lies below the permissible limit, So the design of roll cage is safe in all conditions. The graph between Stress and Factor of safety gives the clear idea of condition of roll cage in different loading conditions. The Factor of safety is continuously decreases with increase in load. This analysis result helps in further optimization of roll cage.

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