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Crash analysis of Roll-Cage of an All-Terrain Vehicle

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Abstract – *This paper deals with the design and analysis of Roll Cage for an All-Terrain Vehicle (ATV) car, the analysis of the ATV Roll-cage is done using Computer-Aided Engineering (CAE). Hyper works 2019 is used for the same. The ATV chosen for simulation has a space frame type chassis that encloses the driver from around using circular tubes. Thus, the significant component for analysis is to study the behavior of the Roll Cage by simulating crash analysis in different impact scenarios. The design procedure follows all the rules laid down by SAE rule book for m-Baja vehicle [1].*

Key Words: All-Terrain Vehicle, Roll-Cage, Finite Element Analysis, Factor of Safety

1. INTRODUCTION

In today's world, All-terrain vehicles are receiving broader acceptance. They are ruling the off-roading sector by the virtue of their ability to move on any type of terrain. An important area of concern spans out due to the alarming ATV related deaths and injuries. Safety of humans is the most critical concern in the design of All-terrain Vehicle (ATV). The vehicle must be structurally robust and safe to ride in all road conditions, making it essential for the vehicle structure to be checked for its crash ability [2].

The chassis forms the backbone of the vehicle; its principal function is to safely carry the maximum load for all designed parts in operating conditions. Without any considerable deflection or distortion, it must withstand the static and dynamic loads. Most importantly, it is an integral part of the design cycle and can reduce the need for costly destructive testing programs [3].

1.1 Literature Review

A significant number of research papers and thesis have been reviewed for this project. It is found that majority of the research papers about ATVs have dealt with the applications, usefulness and impacts of ATVs, but with changing design considerations, crash analysis becomes essential.

It dives into the casualties happening and derives that one out of every three deaths related to ATV is a child (non-adult). Similarly in case of injuries related to ATV, children account for nearly 30% of them.

The highlights of the fatalities that were happening due to ATV accidents every year in the United States. Since 2001, one out of every five death reported was that of a youth of less than 15 years of age [4]. Among ATV riders, 57% had been in a crash. Thus, further stressing the design to be robust and structurally stable.

It mentions the terminologies related to member names in a space frame chassis, the critical aspects in the structural design of an ATV relating to material selection, CAD modelling and finite element analysis [5].

It shows an optimized roll cage designed under a set of particular rules. These set of rules were specified by the Society of Automotive Engineers (SAE) [6]. It also contains different arrangements, analysis conditions and calculations. It provides a detailed analysis of All-terrain vehicle roll cage for all possible scenarios [7]. It helps to understand the static structural analysis of the roll cage for various collisions. It also provides information about the modal analysis of roll cage to avoid resonance at harsh conditions and obtain optimum safety factory.

2. Material Selection and Design

AISI or SAE 4130 grade is low-alloy steel, which has been used in our Roll-cage [8]. It contains chromium and molybdenum and provides good atmospheric corrosion resistance. This steel shows an overall combination of strength, toughness and fatigue strength, machinability and weldability [9].

Table -1: Materials Used

Materials Used	
Component	**Name**
Roll Cage, Arms	AISI 4130
Driveshaft and Gears	EN24T
Bushings	Brass
Rims, Wheel Assemblies, Gearbox, Casing	7075-T7 Aluminum

Characteristics of the material AISI 4130, which has been used in our Roll-cage AISI or SAE 4130 grade is low-alloy steel. It contains chromium and molybdenum. It provides good atmospheric corrosion resistance. This steel shows an overall combination of strength, toughness and fatigue strength, machinability and weldability [9].

Component(s)	Name	Yield Strength	Young's Modulus	Density	Ultimate Tensile Strength	Poisson's Ratio
Roll Cage , Arms	AISI 4130 (9)	740 MPa	210 GPa	7.85 g/cm3	820 MPa	0.29
Driveshaft and Gears	EN24T	650 MPa	1235 MPa	7.84 g/cm3	850 MPa	0.27
Bushings	Brass	250 MPa	97 GPa	8.49 g/cm3	420 MPa	0.31
Rims , Wheel Assemblies, Gearbox Casing	7075-T7 Aluminium	410 MPa	70 GPa	3 g/cm3	500 MPa	0.32

2. Meshing

Finite Element Analysis, calculations are done only at a finite number of points, and then for the entire surface results are calculated using interpolation [10]. In order to perform an analysis, the degrees of freedom must be finite. The Finite element technique involves meshing. By meshing, we reduce the degrees of freedom from infinite to finite [11].

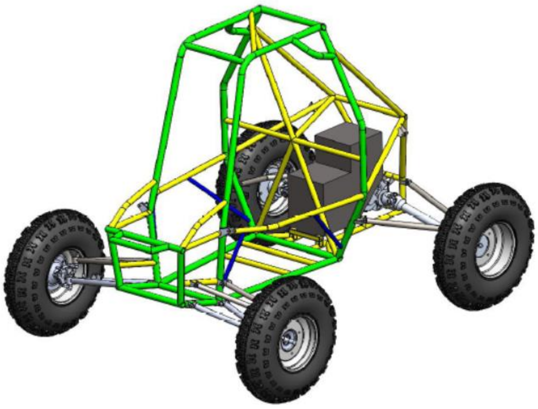


Fig -2.1: Full Vehicle Assembly

For the meshing of the roll cage, a 2D element type was used [12]. The steps involved were:

Geometry Clean up -
• The geometry was imported in Hyper Works 2019.
• To ensure connectivity of the mesh, all the free edges were removed, and errors post-importing the geometry were rectified.

Splitting -
• The entire roll cage was split according to the three different cross-sections of the comprising tubes.
• The properties were updated respectively after splitting.

Element Size Selection -
• The element size was chosen by analyzing the small piece of the tube under certain boundary conditions by decreasing the element size in each iteration.
• The convergence in results was observed, and the optimum size was chosen.

Mesh Generation -
• The mesh was generated under quality constraints for the best possible results.
• After meshing, a quality check was done, and failed elements or portions were diagnosed.

Mesh Refining -
• In this phase of meshing, all the failed portions were manually corrected.
Also, the point of junctions that had more stress flow were finely meshed to increase the accuracy.

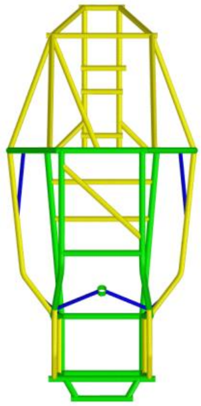


Fig -2.2: Roll Cage- Top View

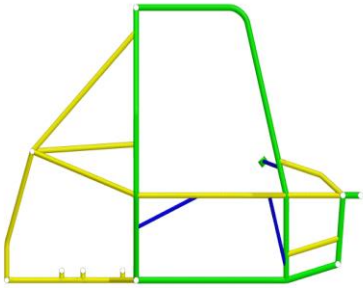


Fig -2.3: Roll Cage- Side View

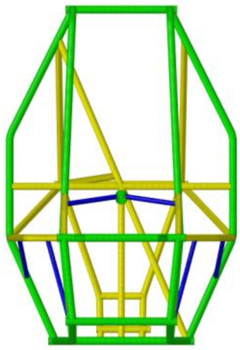


Fig -2.4: Roll Cage- Front View

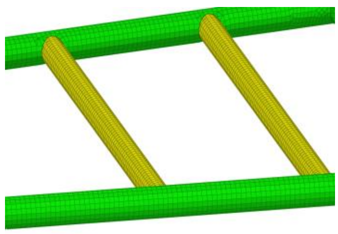


Fig -2.5: Seat Mount

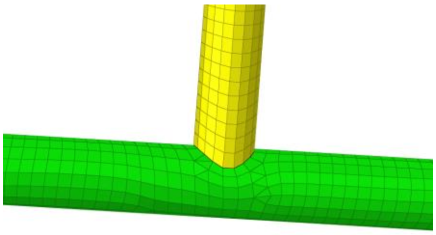


Fig -2.6: Over Head Member

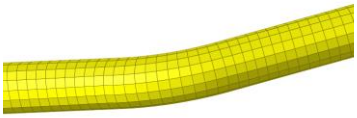


Fig -2.7: Side Impact Member

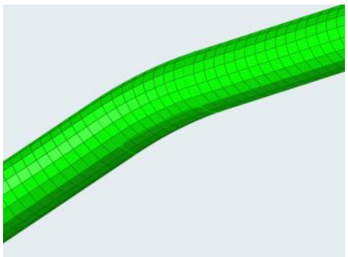


Fig -2.8: Rear Roll Hoop

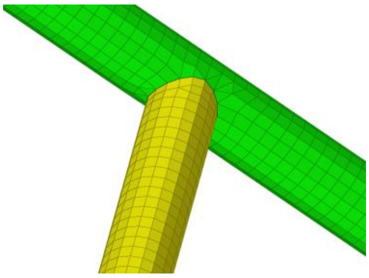


Fig -2.9: Front bracing

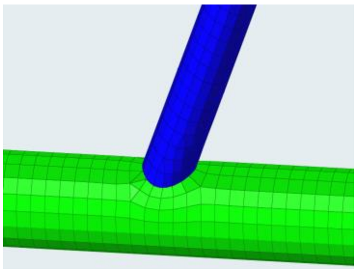


Fig -2.10: Side Bracing

3. Quality Checks

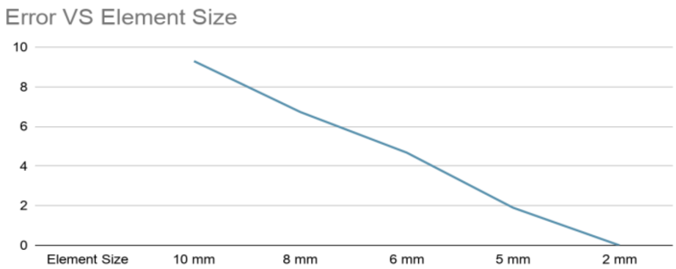
Table -3.1: Quality Checks [13]

QUALITY CHECKS	
Jacobian	> 0.6
Warpage	< 10°
Min. Length	2.5 mm
Max. Length	6.5 mm
Skew	< 45°
Aspect	< 5
Total Elements	98465

Table -3.2: Convergence

Convergence		
Element Size	**Stress**	**% Error**
10	544.1	9.3
8	559.5	6.73
6	571.8	4.68
5	588.5	1.98
2	599.85	* negligible

Chart -3.1: Quality Checks



4. Impact Analysis

Assumptions-

The roll cage acts as a deformable body. The strength of the weld joints is taken same as the material of the roll-cage. Impact time in case of a deformable object is taken as 0.3 seconds.

Front impact-

During front impact, the ATV may hit any other vehicle from the front side. As the ATV is the deformable body hence, the impact time is assumed to be 0.3 seconds. For analysis, ATV is considered to be in static state and force corresponding to velocity 60 Km/hr. with the impact time 0.3 seconds is applied to the front part of the roll cage of ATV keeping rear suspension mounting to be fixed.

Mass of ATV (m) = 210 Kg (145 Kg Vehicle + 65 Kg Driver)
Initial Velocity ($v_{Initial}$) = 16.67m/s (60 km/hr.)
Final Velocity (V_{final}) = 0 m/s.
Impact Time = 0.3 sec.

From work – energy principle,
Work done = Change in kinetic energy,
$|W| = 1/2 \times m \times (V_{final})^2 - 1/2 \times m \times (v_{Initial})^2$
$|W| = 0 - 26598.6425$
|W| = 26598.6425 J

Displacement (s) = $v_{Initial} \times t$
s = 16.67 x 0.3
s = 5.00 m

Work done (|W|) = Force (F) x Displacement (s)
26598.6425 = F x 5.00
F = 5319.73 N

Rear Impact-

During rear impact, ATV may hit any other object like another vehicle, wall etc. at the rear part. As the ATV is the deformable body hence, the impact time is assumed to be 0.3 seconds. For analysis, ATV is considered to be in static state and force corresponding to velocity 60 Km/hr. with the impact time 0.3 seconds is applied to the rear part of the roll cage of ATV keeping front suspension mounting to be fixed.

Mass of ATV (m) = 210 Kg (145 Kg Vehicle + 65 Kg Driver)
Initial Velocity ($v_{Initial}$) = 16.67m/s (60 km/hr.)
Final Velocity (V_{final}) = 0 m/s.
Impact Time = 0.3 sec.

From work – energy principle,
Work done = Change in kinetic energy,
$|W| = 1/2 \times m \times (V_{final})^2 - 1/2 \times m \times (v_{Initial})^2$
$|W| = 0 - 26598.6425$
|W| = 26598.6425 J

Displacement (s) = $v_{Initial} \times t$
s = 16.67 x 0.3
s = 5.00 m

Work done (|W|) = Force (F) x Displacement (s)
26598.6425 = F x 5.00
F = 5319.73 N

Side Impact-

During side impact, ATV may hit any other object like wall, vehicle at the side part. As the ATV is the deformable body hence, the impact time is assumed to be 0.3 seconds. For analysis, ATV is considered to be in static state and force corresponding to velocity 60 Km/hr. with the impact time 0.3 seconds is applied to the side part of the roll cage of ATV keeping front and rear suspension mounting to be fixed.

Mass of ATV (m) = 210 Kg (145 Kg Vehicle + 65 Kg Driver)
Initial Velocity ($v_{Initial}$) = 12.5 m/s (45 km/hr.)
Final Velocity (V_{final}) = 0 m/s.
Impact Time = 0.3 sec.

From work-energy principle,
Work done = Change in kinetic energy,
$|W| = 1/2 \times m \times (V_{final})^2 - 1/2 \times m \times (v_{Initial})^2$
$|W| = 0 - 16796.875$
|W| = 16796.875 J

Displacement (s) = $v_{Initial} \times t$
s = 12.5 x 0.3
s = 3.75 m

Work done (|W|) = Force (F) x Displacement (s)
16796.875= F x 3.75
F = 4479.16 N

Rollover Impact-

In the roll over impact, ATV is considered to drop on its roll over hoop members on the road or ground from a height of 10 feet. The drop height is considered as 10 feet because it is greater than any expected height in usual cases. Since the road and ground are non-deformable bodies; therefore, impact time is taken as 0.3 seconds. For analysis, ATV is considered to be in static state, the force corresponding to the calculated velocity of 7.67 m/s. For the corresponding height with the impact time of 0.3 seconds is applied to the top of the roll cage of the ATV keeping front and rear suspension mounting to be fixed.

Mass of ATV (m) = 210 kg
Impact time (t) = 0.3 sec.
Height = 3 m

Potential Energy = Kinetic Energy
$m \times g \times h = 1/2 \times m \times v^2$
$215 \times 9.81 \times 3 = 1/2 \times 215 \times v^2$
v = 7.67 m/s

Work done $|W| = 1/2 \times m \times v^2$
$|W| = 12 \times 215 \times 7.672$
|W| = 6324.10 J

Displacement (s) = v x t
s = 7.67 x 0.3

s = 2.301 m

Work done (|W|) = Force (F) x Displacement (s)
6324.10 = F x 2.301
F = 2748.41 N

5. Final Analysis Results

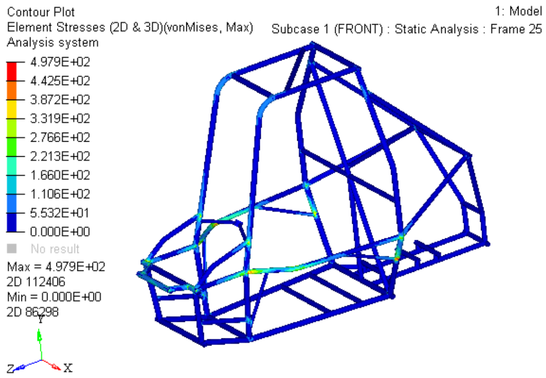


Fig -5.1: Front Impact Stress

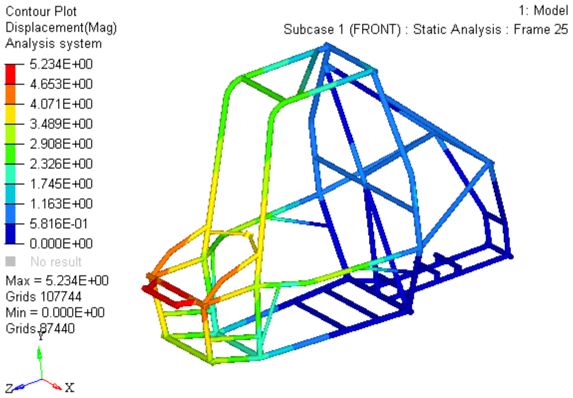


Fig -5.2: Front Impact Displacement

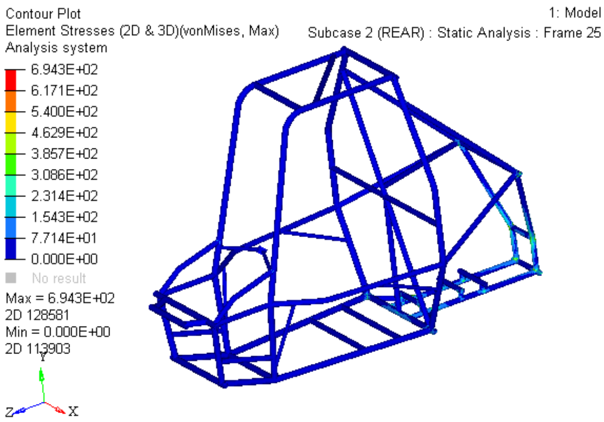


Fig -5.3: Rear Impact Stress

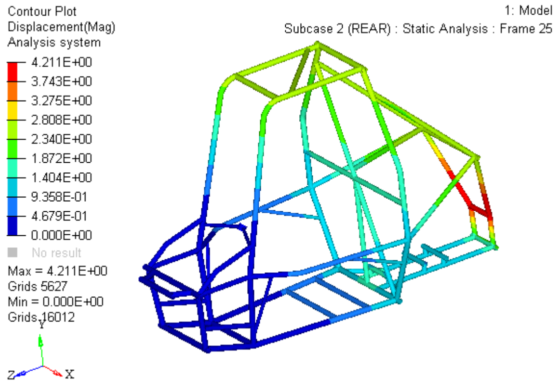


Fig -5.4: Rear Impact Displacement

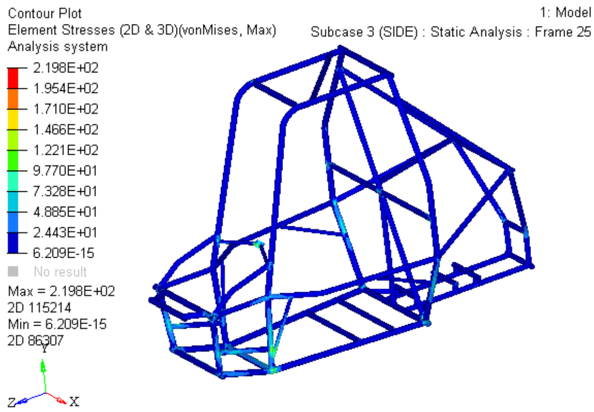


Fig -5.5: Side impact fig Stress

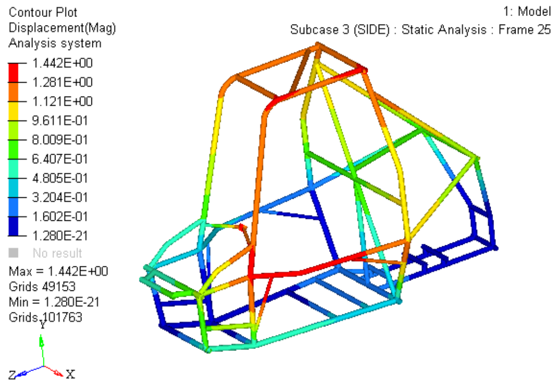


Fig -5.6: Side impact Displacement

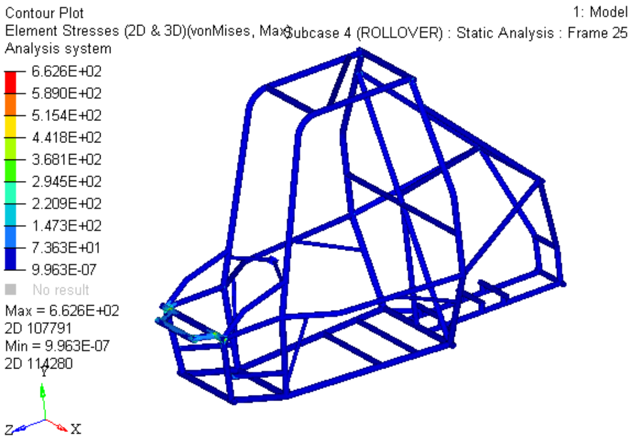


Fig -5.7: Rollover impact Stress

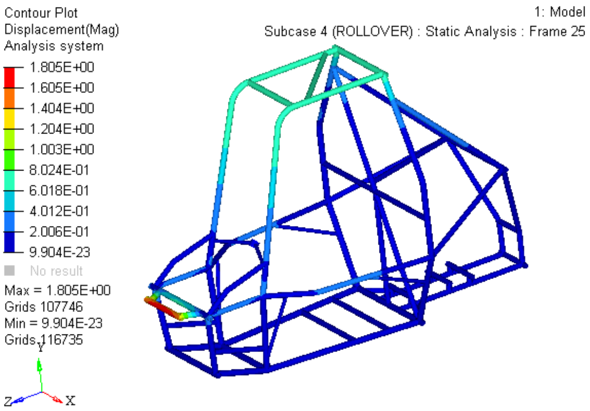


Fig -5.8: Rollover impact Displacement

Analysis	Displacement	Stress	Yield Stress	Factor of Safety
Front Impact	5.234 mm	497.9 MPa	740 MPa	1.486
Rear Impact	4.211 mm	694.3 MPa	740 MPa	1.065
Side Impact	1.442 mm	219.8 MPa	740 MPa	3.366
Rollover Impact	1.805 mm	662.6 MPa	740 MPa	1.116
Torsion	6.336 mm	669.0 MPa	740 MPa	1.106

6. CONCLUSIONS

From the results obtained in our analysis, we can see that the stresses in all the analysis performed for the ATV, namely - Front, Rear, Side, Rollover and Torsional, are well within limits, i.e., the stresses obtained are considerably lesser than the yield stress of the material.

According to the SAE Baja Rulebook [1], the clearance from the roll cage to the driver's body should be less than or equal to 75 mm. We can see that in all our analysis performed; the displacement values range from 1 mm to 7 mm, which are well within the clearance limit.

Thus, we can conclude that in case of an accident or mishappening, the ATV driver won't get hurt, and he will be safe.

Hence, we complete our objective of ensuring maximum safety for the driver.

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