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Static Analysis of the Roll Cage of an All-Terrain Vehicle (SAE BAJA)

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Abstract - *An all-terrain vehicle (ATV) as defined by the American National Standards Institute (ANSI) is a vehicle that travels on low pressure tires, with a seat that is straddled by the operator, along with handlebars for steering control. Roll cage is the structural element of the vehicle. Load coming from the road bumps, cornering etc. are taken by the roll cage. It also protects the driver from the impacts and roll over incidents. The objective of the study is to design and optimize the roll cage under a set of particular rules given by Society of Automotive Engineers (SAE). Static analysis of the roll cage is done using ANSYS Workbench (static structural) for different collisions like front, side, rear and roll over. The main objective of analysis is to obtain a roll cage which should be very strong to bear such adverse conditions and at the same time it should be light in weight to improve the performance of vehicle*

***Key Words*: SAE BAJA, ATV, Roll Cage, Static Structural, Ansys workbench, Meshing, FEA.**

1. INTRODUCTION

The objective of the study is to design and develop the roll cage for All-Terrain Vehicle. The design factor contains safety, easy manufacturing, durability & maintenance of the frame and a compact, lightweight & ergonomic design. This paper focus on various loading tests like Front Impact, Rear Impact, Side Impact, Roll over to check whether the roll cage can bear all types of impacts. A software model is prepared in Solidwork software. Later the design is analysed against all modes of failure by conducting various simulations and stress analysis with the aid of Ansys Software. Based on the result obtained from these tests the design is modified accordingly.

Following are some of the factors which are taken into account while designing the Roll Cage:

Table -1: Design Considerations

CONSIDERATIONS	PRIORITY
Human Ergonomics	HIGH
Manufacturability	ESSENTIAL
STRENGHT/WEIGHT	HIGH

2. Design and Development

The design and development process of the roll cage involves various factors; namely material selection, cross-section determination, frame design, and finite element analysis.

2.1. Material Selection

To build roll cage steel must be used according to the rules. There are many different types of steel available. Material selected for the chassis is AISI 4130 steel. The roll cage will be made from tubular sections. Tubular sections offer superior loading capabilities per kg when compared to solid sections or square sections.

Table -2: Material Properties

Material Grade	Alloy Steel AISI4130
Elastic Modulus	205GPa
(Outer Diameter)X (Thickness) (mm)	31.75mmx1.65mm 25.4mmx1mm
Tensile Strength	650MPa
Yield Strength	624MPa
Bending Strength	690MPa
Carbon Content	0.30%

2.2. Roll Cage Design

To begin the initial design of the frame, some design guidelines were required to be set. They included intended transmission, steering and suspension systems and their placement, mounting of seat, design features and manufacturing methods. It is also required to keep a minimum clearance of 6 inches between the driver and the roll cage members. It is also necessary to keep weight of the roll cage as low as possible to achieve better acceleration. It is necessary to keep the center of gravity of the vehicle as low as possible to avoid toppling.

Once modeling of the roll cage structure is done by using Solidwork, the designed roll cage is then evaluated in the Solidwork itself to have an idea of the physical parameters of the roll cage. The weight comes out to be 19.7 kg (approx).

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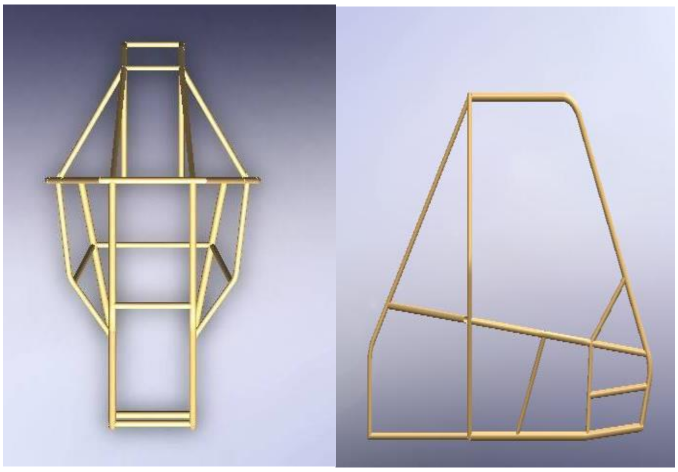

Fig -1: Top and Side View of Roll Cage

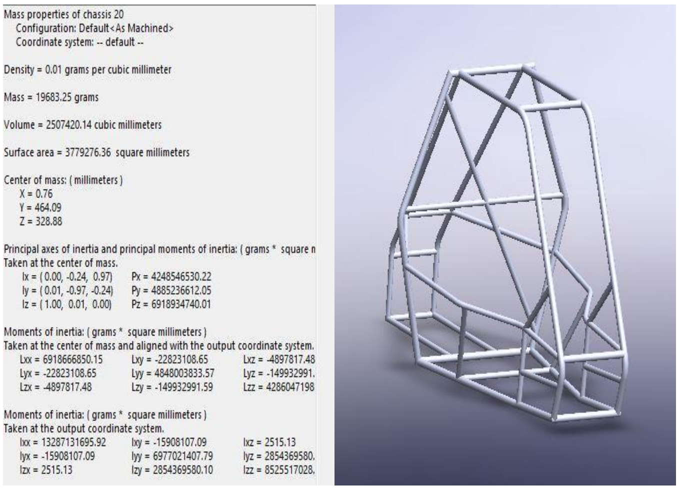

Fig -2: Physical parameters of chassis

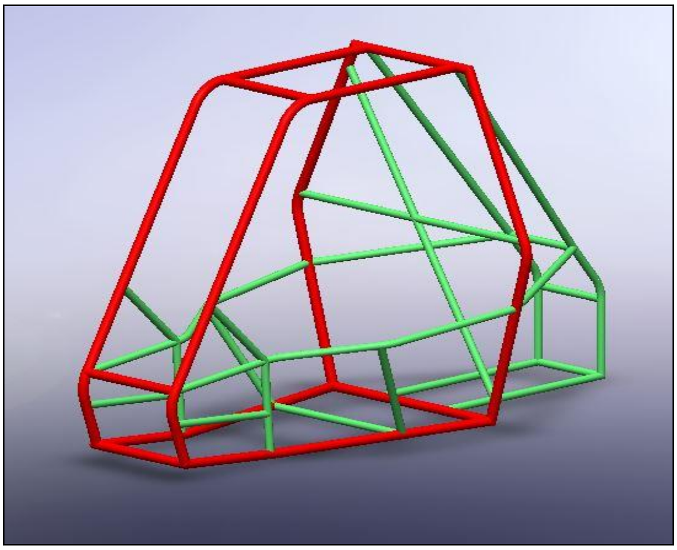

Fig -3: Design Model of the Chassis, primary tube (red), secondary tube (green)

3. Analysis Methodology

Once modeling of the roll cage structure is done by using Solidwork, this design is checked by Finite Element Analysis. Ansys Workbench has been used for this purpose. A coordinate file is created in notepad and that has been imported in Ansys via import geometry, then specified material, defined the cross-section.

4. FEM Analysis

As the Roll cage was developed by plotting key points, so every member of the roll cage is considered to be properly constrained at every joint. After finalizing the frame along with its material and cross section, it is very essential to test the rigidity and strength of the frame under severe conditions. The frame should be able to withstand the impact, torsion, roll over conditions and provide utmost safety to the driver without undergoing much deformation. Following tests were performed on the roll cage:

(1) Front Impact, (2) Rear Impact, (3) Side Impact, (4) Front roll over, (5) Side roll over, (6) Front Bump and (7) Rear Bump

4.1. Meshing

The result of any FEA software depends mainly upon the kind and the quality of the mesh. Mesh size is calculated by checking the mesh independency, mesh size has been calculated by plotting the mesh convergence curve.

Following are some points that are considered during mesh generation:

- Midside node has been used for better accuracy.
- Pipe Idealization is applied on bends to get accurate results.
- Fine meshing is done particularly in areas having higher stress gradient.

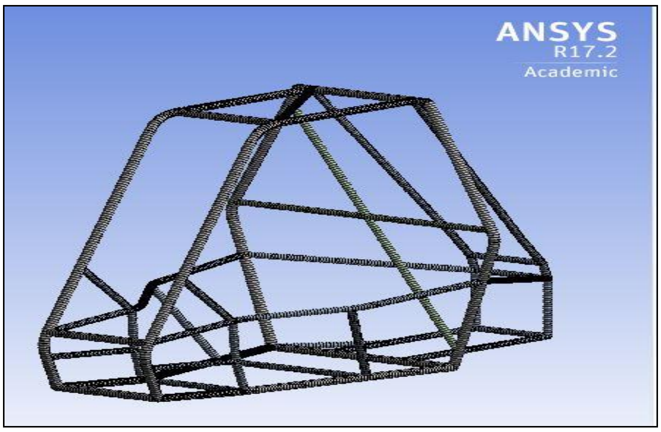

Fig -4: Meshed Model in Ansys 17.2

4.2. Front Impact Analysis

This analysis is done to simulate those conditions when the ATV may hit a tree, another ATV or a wall. Under such conditions, the amount of forces generated reacts at the front most portion of vehicle.

Analysis Condition:

- Using the projected vehicle + driver mass of 220 kg, the impact force was calculated base on a G-load of 10, was applied to the front most members of chassis.
- Rear suspension points are fixed.
- F = ma .... (1)
  10F = 220*9.81*10 = 21,582 N (approx).

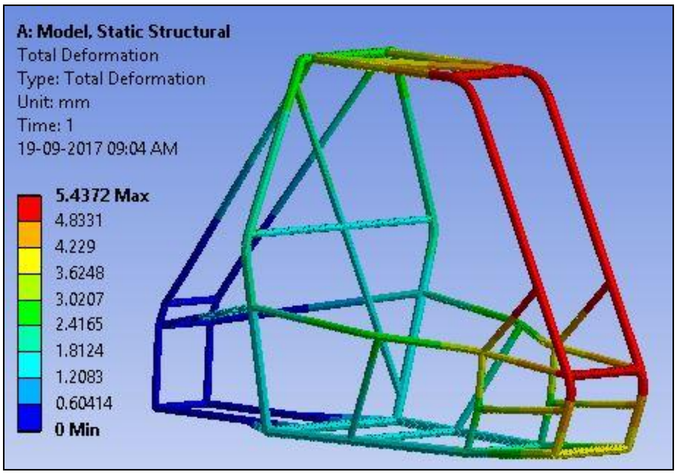

Fig -5: Front Impact Displacement

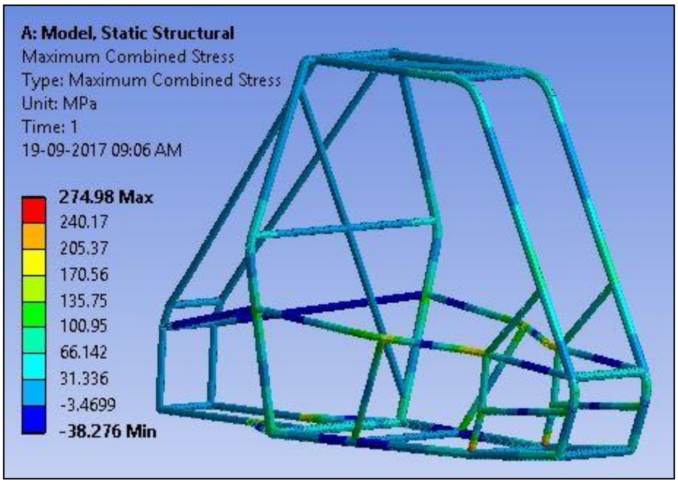

Fig -6: Front Impact Stress

Result discussion- Maximum combined stress induced is 274.98MPa. Hence FOS =2.269 with maximum deformation of 5.4372mm which is within the permissible limit.

4.3. Rear Impact Analysis

This analysis is done to simulate those conditions when another ATV is going to hit ATV on its rear part. Under such conditions, the amount of forces generated reacts at the rear most portion of vehicle.

Analysis Condition:

- Using the projected vehicle + driver mass of 220 kg, the impact force was calculated base on a G-load of 10, was applied to the rear most members of chassis.
- Front most nodes are fixed.
- F = ma .... (1)
  10F = 220*9.81*10 = 21,582 N (approx).

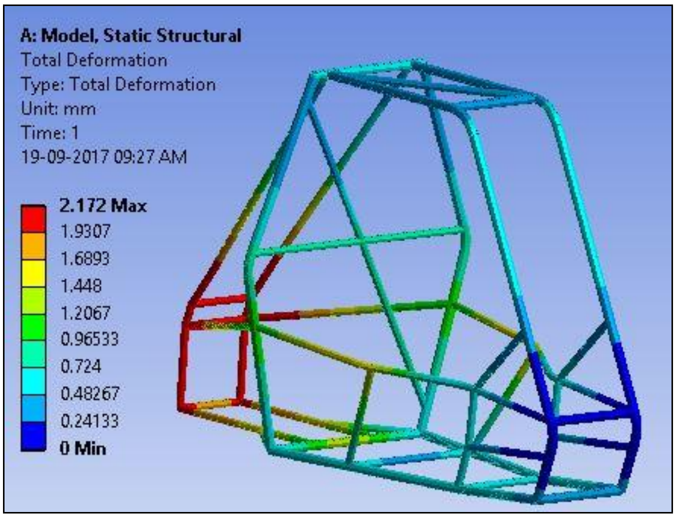

Fig -7: Rear Impact Displacement

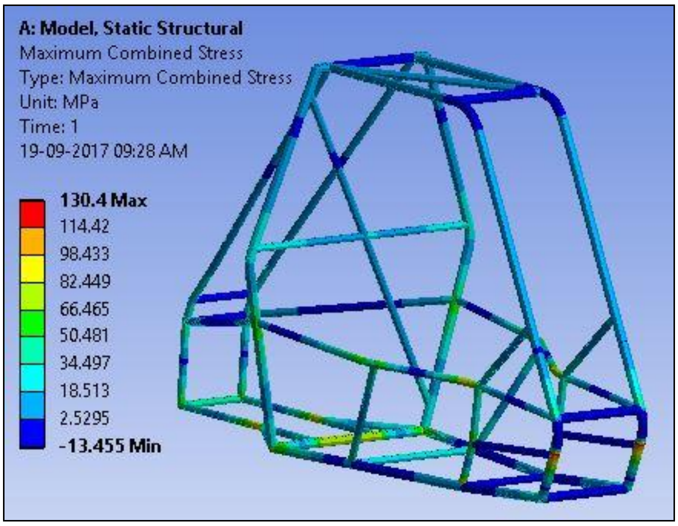

Fig -8: Rear Impact Stress

Result discussion- Maximum combined stress induced is 130.4MPa. Hence FOS =4.785 with maximum deformation of 2.172mm which is within the permissible limit.

4.4. Side Impact Analysis

This analysis is done to simulate those conditions when another ATV will hit ATV on side. Under such conditions, the amount of forces generated reacts at the side most portion of vehicle.

Analysis Condition:

- Using the projected vehicle + driver mass of 220 kg, the impact force was calculated base on a G-load of 5, was applied to the one of side most members of chassis.
- Other side of nodes are fixed.
- F = ma .... (1)
  5F = 220*9.81*5 = 10,791 N (approx).

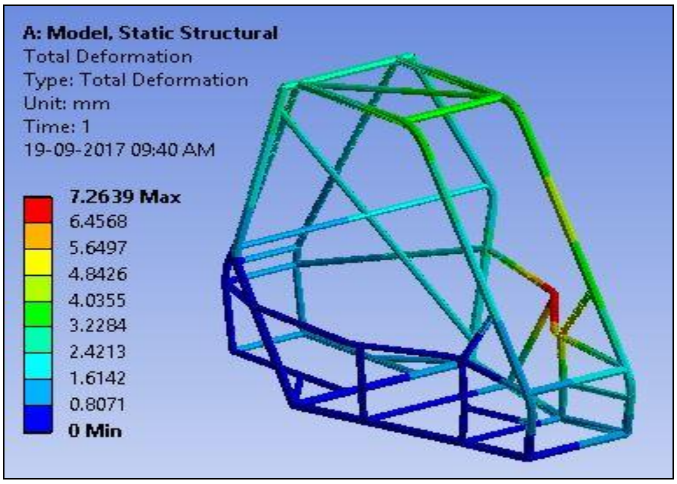

Fig -9: Side Impact Displacement

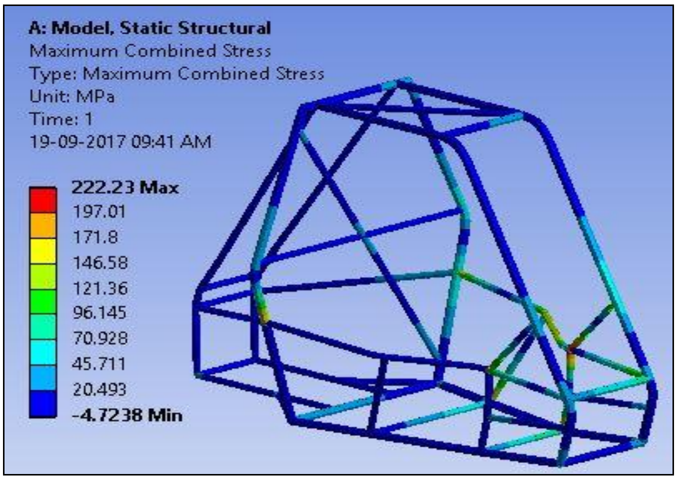

Fig -10: Rear Impact Stress

Result discussion- Maximum combined stress induced is 222.23MPa. Hence FOS =2.807 with maximum deformation of 7.26mm which is within the permissible limit.

4.5. Front Roll Analysis

This analysis is done to simulate those conditions when the ATV is considered to be dropped on its roof on road or ground from a height. Under such conditions, the amount of forces generated reacts at the top most portion of vehicle.

Analysis Condition:

- Using the projected vehicle + driver mass of 220 kg, the impact force was calculated base on a G-load of 2.5, was applied to the Front Lateral Cross members of chassis.
- Base Plane members are fixed.
- F = ma .... (1)
  2.5F = 220*9.81*2.5 = 5,395.5 N (approx).

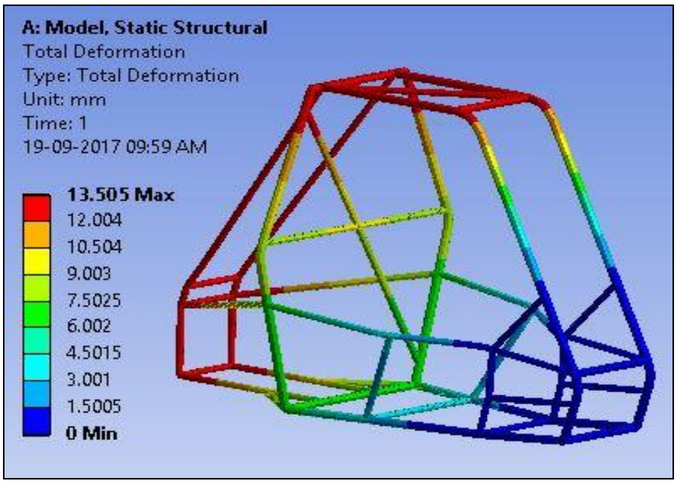

Fig -11: Front Roll Displacement

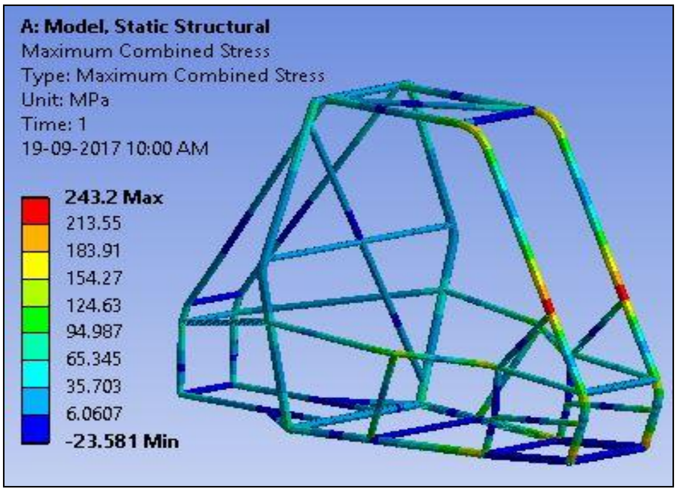

Fig -12: Front Roll Stress

Result discussion- Maximum combined stress induced is 243.2MPa. Hence FOS =2.56 with maximum deformation of 13.505mm which is within the permissible limit.

4.6. Side Roll Analysis

This analysis is done to simulate those conditions when the ATV rolls sideways due to some excessive cornering angle. Under such conditions, the amount of forces generated reacts at the Side most portion of vehicle.

Analysis Condition:

- Using the projected vehicle + driver mass of 220 kg, the impact force was calculated base on a G-load of 5, was applied to the Side members of chassis.
- Base Plane members are fixed.
- F = ma .... (1)
  5F = 220*9.81*5 = 10,791 N (approx).

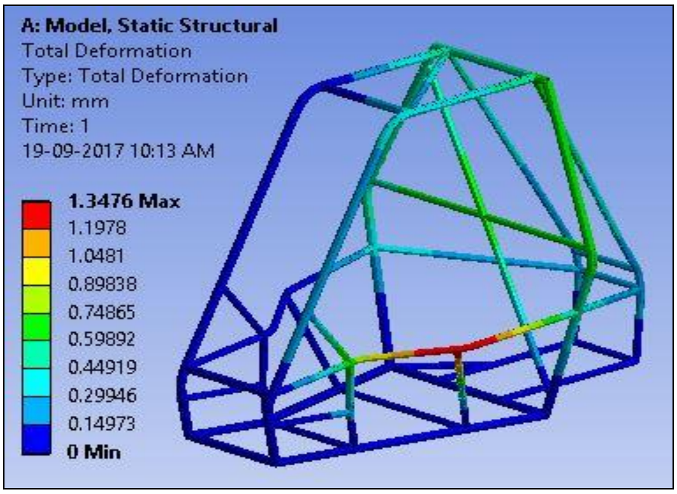

Fig -13: Side Roll Displacement

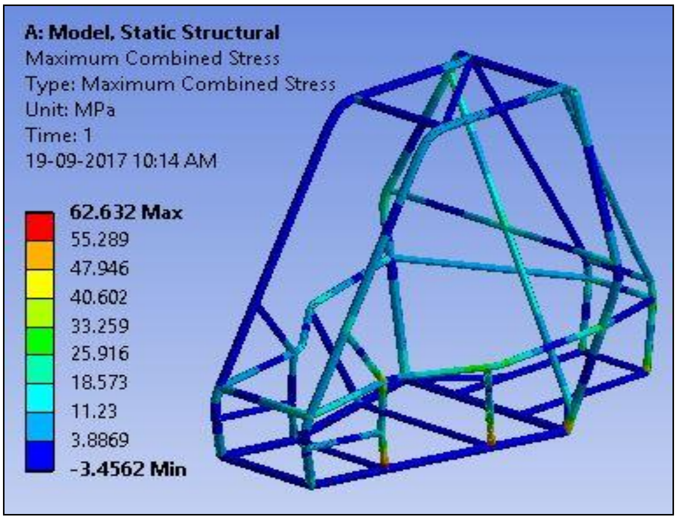

Fig -14: Side Roll Stress

Result discussion- Maximum combined stress induced is 62.632MPa. Hence FOS =9.96 with maximum deformation of 1.347mm which is within the permissible limit.

4.7. Front Bump Analysis

This analysis is done to simulate those conditions when the front wheels of ATV pass over a bump, roll cage is subjected to a moment.

Analysis Condition:

- 40% of the vehicle weight (863.28 N) is equally distributed to front suspension mounting member.
- Rear suspension mounting member of roll cage is fixed.

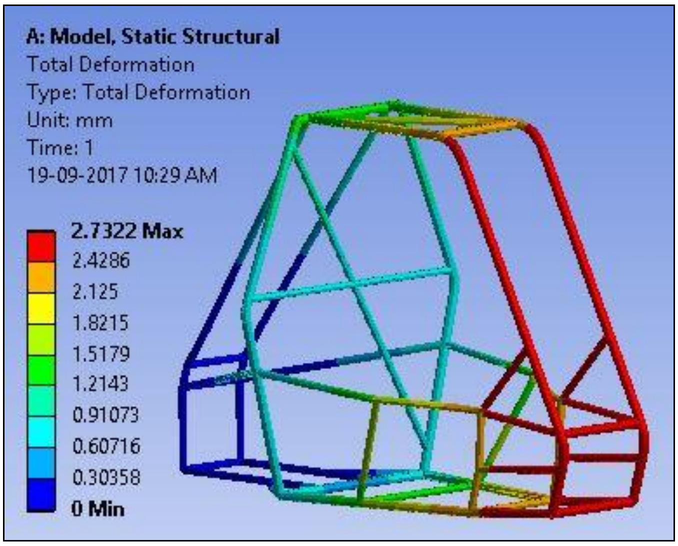

Fig -15: Front Bump Displacement

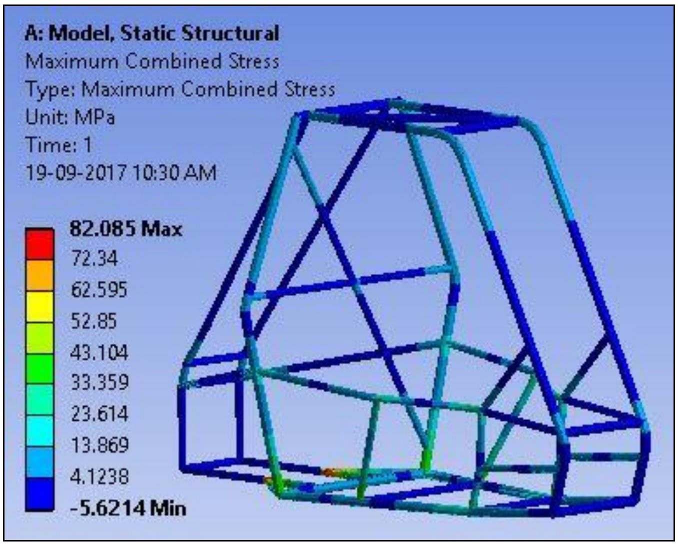

Fig -16: Front Bump Stress

Result discussion- Maximum combined stress induced is 82.085MPa. Hence FOS =7.60 with maximum deformation of 2.732mm which is within the permissible limit.

4.8. Rear Bump Analysis

This analysis is done to simulate those conditions when the rear wheels of ATV pass over a bump, roll cage is subjected to a moment

Analysis Condition:

- 60% of the vehicle weight (1,294.92 N) is equally distributed to rear suspension mounting member.
- Front suspension mounting member of roll cage is fixed.

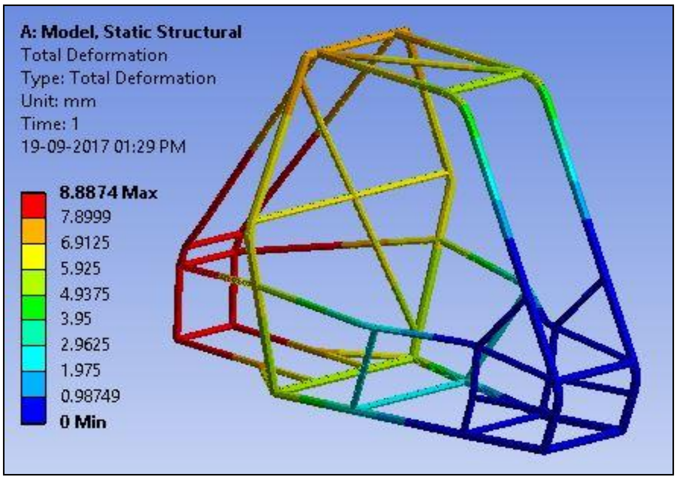

Fig -17: Rear Bump Displacement

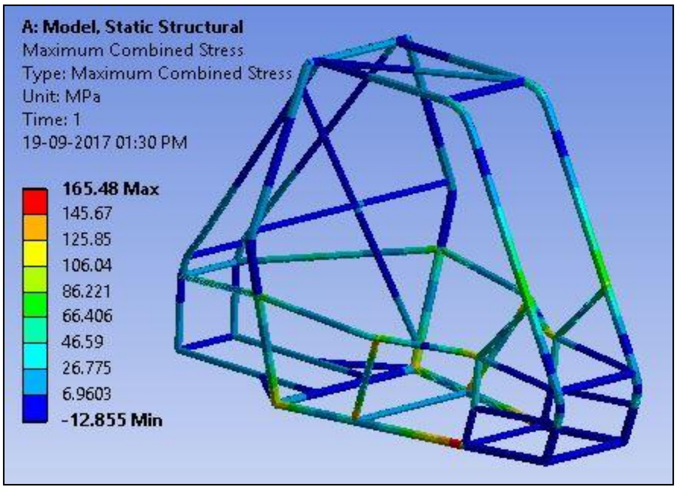

Fig -18: Rear Bump Stress

Result discussion- Maximum combined stress induced is 165.48MPa. Hence FOS = 3.77 with maximum deformation of 8.887mm which is within the permissible limit.

5. Results of Analysis

The results of the above analysis have been tabulated below:-

Table -3: Analysis Result

	Front Impact	Rear Impact	Side Impact	Front roll	Side Roll	Front Bump	Rear Bump
Stress	274.9	130.4	222.2	243.2	62.6	82.08	165.4
Displace place-ment	5.43	2.17	7.36	13.50	1.34	2.732	8.88
F.O.S	2.26	4.78	2.80	2.56	9.96	7.60	3.77

6. Conclusion

The FEA analysis demonstrated the structural superiority while maintaining a lower weight to strength ratio. Safety is of utmost concern in every respect; for the driver, crew & environment. The analysis was helpful in finding out the maximum deformation, Von Mises stress and the factor of safety.

The design of the vehicle is kept very simple keeping in view its manufacturability. The design, development and fabrication of the roll cage is carried out successfully. The roll cage is used to build an ATV by integrating all the other automotive systems like transmission, suspension, brakes, steering, etc.

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BIOGRAPHIES

Shivam Mishra is currently in 3rd year of Mechanical Engineering Program at Guru Nanak Dev Engineering, Ludhiana, Punjab, India. Mr. Shivam is a member of a number of student organizations including the SAEINDIA COLLEGIATE CLUB. In Feb 2017, Shivam participated in SAEINDIA BAJA 2017 Dynamic round after the success of Virtual round and he was the team captain and CAE head of his team in SAEINDIA BAJA 2018 Virtual and has successfully qualified for dynamic event.