DESIGN AND FINITE ELEMENTS ANALYSIS OF ATV ROLLCAGE MODELING

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Abstract: The American National Standards Institute (ANSI) defines an ATV: all-terrain vehicle, also known as a quad bike, quad, three-wheeler, or four-wheeler, as a vehicle that drives on low pressure tyres, has a seat that the operative straddles, and handlebars for steering control. An ATV's skeleton is called a roll cage. The roll cage serves as both a structural foundation and a three-dimensional shell that protects the occupant in the event of a collision or a rollover. The roll cage also improves a vehicle's appearance. The purpose of this article is to discuss the design of a roll cage for an ATV. Numerous loading tests were carried out, including front impression, side influence, and rear influence. ANSYS software was used for modelling and stress investigation. We concentrated on every area of the roll cage to increase the vehicle's performance while avoiding roll cage failure. The vehicle fixed geometry findings for the suspension mountings and the suspension mountings on the base plane, as well as the front impact (case 1), front impact (case 2), rear impact (case 2), side impact (case 2), rollover (case 2), and torsional analysis (case 3). The following frequencies were determined: 6G, 4G, 5G, 3.5G, 3.5G, and 5G. The work-energy concept was used to determine the force. The maximum equivalent stress (MPa) must be 256.3 MPa because to the difficult terrain and route. Torsion analysis limits the front and rear suspension of an ATV.

Keywords: All-terrain vehicle (ATV); roll cage; design; RULEBOOK; impact

Introduction

All-terrain vehicles were classified by the American National Standard Institute as vehicles with three or four low-pressure tyres with a driver straddling the seat and guiding the vehicle. As the name indicates, the ATV can manage a range of terrains and is more adept at driving on gravel roads than most other vehicles (Soundararajan et al., 2021). During movement, the vehicle is subjected to dynamic and static stresses. Steering on uneven surfaces generates dynamic loads on the vehicle and static loads on the stationary vehicle; braking, acceleration, cornering, and torsion generate the extreme load on the obverse axle, the maximum load of the rear axle is produced a static stress on the vehicle. The design must be ergonomic, and sufficient strength must be achieved while minimizing costs and maintaining a reasonably low weight for rough terrain use. Contemporary designs are over-configured, i.e., the sturdiness exceeds the necessity, resulting in additional weight and production costs (Aakash et al., 2020). All-terrain vehicles and snowmobiles are extensively utilized for vocational and recreational reasons across the world, and their popularity continues to grow. In the past, as vehicle use grew, fatalities and injuries caused by vehicle design, topography, crashes, and rider conduct increased proportionately. Manufacturers, associations, organizations, government agencies, and consumer groups have worked for years to enhance the design of these vehicles' safety features and riding habits (Gilkey et al., 2021).

The Society of Automotive Engineers (SAE) sponsors design contests to familiarise students with the fundamentals of mobility engineering. The SAEINDIA BAJA incident, conducted each time in Pithampur, is one such scholar to design activity. The SAE BAJA vehicle development handbook establishes limitations on the vehicle's weight, shape, and size, as well as its measurements. The SAE BAJA competition's aim is to mimic real-world engineering design projects and the problems associated with them. Additionally, it produces the highest performance vehicle possible with a robust and cost-effective vehicle structure that meets all SAE BAJA design standards. Any vehicle is subjected to loads during normal road operation that generate strains, vibrations, and noise in the various components of its structure. This needs components to have enough strength, stiffness, and fatigue characteristics in order to withstand these stresses (Raina et al., 2015). Appropriate material selection is serious in the strategy and expansion of ATV chassis. Numerous papers and theses have been produced on this subject, however the majority of the around 190 publications focused on the accidents and injuries sustained when extreme off-roading on ATVs. Consistent with safety considerations and chassis strength, it should be capable of withstanding the tremendous stresses created during ATV operation. Material selection for roll cage production includes AISI 1018, AISI 4130, AISI 1020, E-Glass epoxy, and carbon fiber, and numerous other criteria such as cross-section, vehicle design ergonomics, and factor of safety (FOS) are also addressed (Dubey et al., 2021). GeoSTAR® was utilized to demonstrate the safety of the chassis design due to its minimal memory needs. Static investigation was done on a finite element (FE) model generated in ANSYS utilizing the 'Pipe 16' element. Simulating the issue statement was the next stage, which involved selecting appropriate material characteristics, cross-sectional parameters, positioning restrictions, loading circumstances, and mesh component size. The research illustrates the Von Misses stress distribution and the deformation of the frame components under load. If it was determined that the stress created in the chassis members exceeded the material's yield point, the current frame was changed to provide a safe design. The revised design was then submitted to the same analysis, and iterations were performed until the stress and deformation remained within the required range (Khanzode et al., 2016). FEA: Finite element analysis is determined if a product will wear out, fail, or perform as intended (Dusane et al., 2016). The purpose of this project was to build the roll cage utilizing the same material for the primary and secondary frames. The roll cage was built using the BAJA SAE 2019 RULEBOOK as a guide. After developing a roll cage, it was subjected to non-destructive analysis, namely finite element analysis (FEA) simulation. This research offered simulations such as impact tests and torsional tests of roll cages that must be conducted prior to beginning roll cage production.

Materials and Methods

The research work was initiated with a thorough market study. The material selection process is a critical first step in the design and manufacture of a roll cage. The SAE BAJA RULEBOOK specifies that the chassis material must include at least 0.18 percent carbon. As a result, the market offers a diverse range of materials that are permissible for usage, and teams have a variety of grades within each type of material from which to choose the best for the application. Numerous aspects influence the material selection process, including cost, market availability, weight, mechanical and chemical characteristics, and machinability (Table 1).

Table 1: The comparison of different grades of steel.

Parameters	**AISI 1018 AISI 1040 AISI 1020**
Density kg/m3	7700, 7845, 7700, 7700, 7700
Ultimate strength N/mm2	634, 518.08, 560, 580, 394.7
Yield Strength N/mm2	388, 353.4, 480, 430, 294.8
Young’s Modulus Gap	200, 200, 200, 200, 200
Hardness BHN	197, 149, 156, 379, 111

According to the SAE RULEBOOK, the roll-cage frame was composed primarily of two types of members (primary and secondary member). Teams were chosen to build the whole roll cage using the same material grade and thickness or to use a material grade and thickness that differs. To maximize the material's cost-effectiveness and strength, both the primary and secondary components of the roll cage are made from the same material, i.e., 4130 AISI.

CAD Model Preparation

As stated in the "material procurement" section, AISI 4130 is used for the ATV roll cage's fabrication. The following specifications are used to choose the material:

ID=25.4 mm; **OD**=19.4mm

Thickness=3mm

The material specification above is chosen by optimizing the weight and maximum stress generated during simulation using the heuristic tuning approach. The roll cage model was created using SOLIDWORKS 2018, taking into account all of the dimensions specified in the BAJA RULEBOOK (Figure 1).

Figure 1: A: Top view

Fig 1: B: Isometric view.

Finite Element Analysis (FEA)

To conduct FEA on the existing and changed Knuckle, a 3D model is built in CATIA v5 and saved in IGS format. The model is then loaded into ANSYS 12.0. Engineering data has been used to give the material characteristics shown in Table 1. The model is a mesh constructed using the Solid 187 hexahedral 10-node element. Three degrees of freedom are available to solid elements, namely translation in the X, Y, and Z directions. The finite element analysis of the knuckle was performed for various boundary conditions and the stress level was determined according to the material property of the material. All findings obtained using ANSYS 12.0 are tabulated.

Calculation of Impact Force

Weight (with driver)- M kg F- force of impact N

Vi= velocity before impact m/s

Vf=0 m/s (velocity after impact) (From Newton's Second Law Of Motion F=MA)

Also we know A=dv/dt F=M(dv/dt) Where, A=acceleration

dv=change in velocity (Vi - Vf) dt= time of impact (sec)

Therefore,

In terms of G 1G=M(g)

(Where g=acceleration due to gravity So let Weight (with driver)- 240 kg F- force of impact N)

Vi= 13.88m/s

Vf=0 m/s (velocity after impact)

From Newton's Second Law Of Motion F=MA Also we know A=dv/dt F=M(dv/dt)

Where, A=acceleration

dv=change in velocity(Vi - Vf) dt= time of impact (sec)

F=9517.71N

Now force in terms of G,

Which was approximately equal to 4G.

Front Impact

In front impact testing, there were two distinct scenarios: the ATV colliding with a wall (a non-deformable object) or colliding with another ATV, tree, etc (which is a deformable object). As a result, the timing of effect was different in both situations. The impact time was longer in the deformable object scenario (say 0.25 seconds) than in the non-deformable object case (say 0.35seconds). The rear suspension mountings of the roll cage were fixed (DOF=0) during the front-impact test, and a force of 6G (for non-deformable) or 4G (for non-deformable) was applied to the roll cage's front-most member (front lateral cross-member FLC). The member's activity in response to the force is depicted in Figure 2, 3 and Table 2, 3.

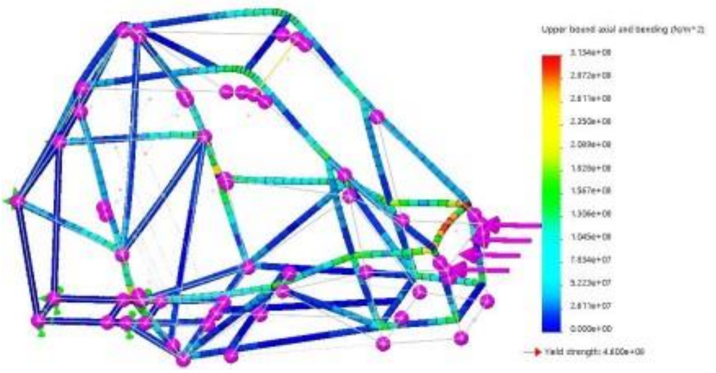

Figure 2: The front impact behavior of the member on the interaction with the force.

Fixed geometry Rear suspension mountings Force applied(G)	6G
Impact time(sec)	0.25
Max equivalent stress (MPa)	313.4
Displacement(mm)	4.955
FOS	1.5

Table 2: The front impact behavior of the member on the interaction with the force

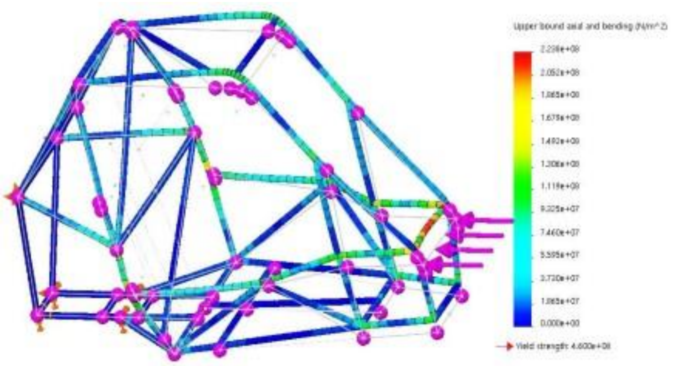

Figure 3: The front impact behavior of the member on the interaction with the force.

Fixed geometry Rear suspension mountings Force applied(G)	4G
Impact time(sec)	0.35
Max equivalent stress (MPa)	223.8
Displacement(mm)	3.539
FOS	2.1

Table 3: The front impact behavior of the member on the interaction with the force

Rear Impact

Due to the lack of a reverse gear on most SAE BAJA ATVs, it is assumed that the ATV was struck by another ATV, resulting in a deformable object. As a result, the risk of colliding with a wall is averted. As a result, in the rear impact test, the roll cage's front suspension mountings are fixed (DOF=0), and a 5G force is delivered to the roll cage's rearmost member (rear lateral cross-member RLC). The figure illustrates the member's behaviour in relation to the applied force (Figure 4 and Table 4).

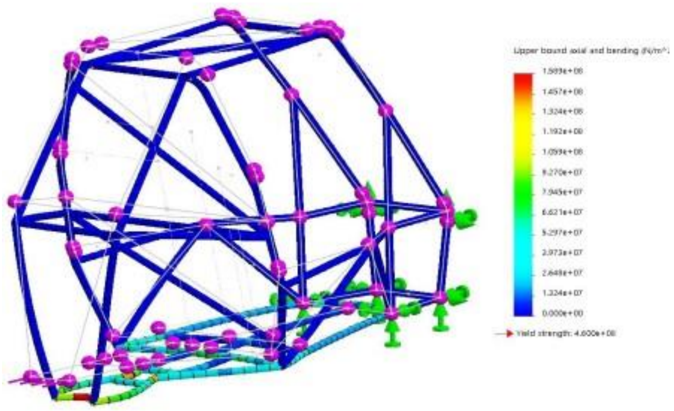

Figure 4: The rear impact behavior of the member on the interaction with the force.

Fixed geometry Rear suspension mountings Force applied(G)	**5G**
Max equivalent stress (MPa)	**158.9mpa**
Displacement(mm)	**2.55mm**
FOS	**2.89**

Table 4: The rear impact behavior of the member on the interaction with the force.

Side Impact

Both items, like the rear impact, are malleable. Thus, when a force is delivered from the left side of the ATV, the right side suspension mountings of the roll cage are fixed (DOF=0), and a 3G force is applied to the roll cage's leftmost member (side impact member SIM). The diagram depicts the member's behaviour in response to the applied force (Figure 5 and Table 5).

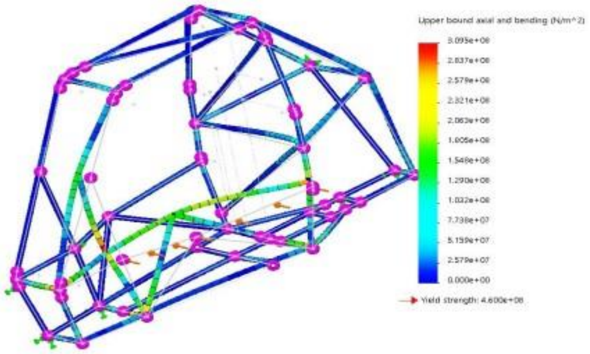

Figure 5: The side impact behavior of the member on the interaction with the force.

Fixed geometry Rear suspension mountings Force applied(G)	**3.5G**
Max equivalent stress (MPa)	309.5mpa
Displacement(mm)	**8.94mm**
FOS	1.5

Table 5: The side impact behavior of the member on the interaction with the force

Rollover

In the event of a rollover, the ATV is thrown overboard during downhill acceleration. The roll cage is designed to safeguard the occupant in the event of an accident or rollover. In the rollover test, the roll cage's suspension mountings, i.e. the base planer, are fixed (DOF=0), and a force of 4G is applied to the roll cage's upper lateral cross member (CLC). The graphic depicts the member's activity in response to the applied force ((Figure 6 and Table 6).

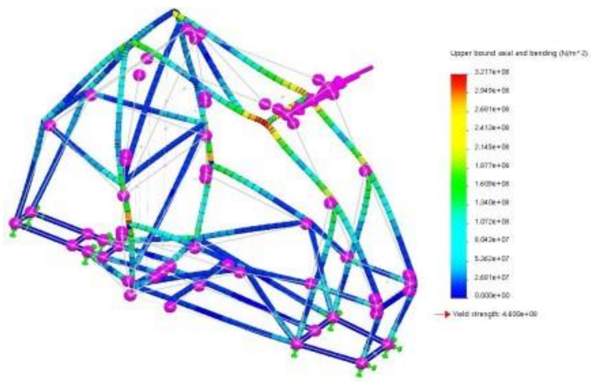

Figure 6: The rollover behavior of the member on the interaction with the force.

Fixed geometry Suspension mountings on the base plane Force applied(G)	**3.5G**
Max equivalent stress (MPa)	**321.7**
Displacement(mm)	**6.49**
FOS	**1.43**

Table 6: The rollover behavior of the member on the interaction with the force.

Torsional Analysis

The rear suspension mountings of the roll cage are fixed (DOF=0) in this torsional study, whereas a couple force of 4G is given to the front suspension mountings. The graphic depicts the member's activity in response to the applied force (Figure 7 and Table 7).

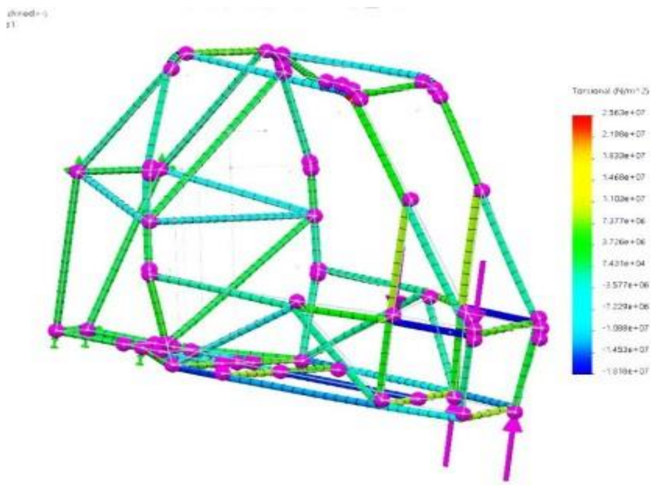

Figure 7: The torsional analysis of the member on the interaction with the force.

Fixed geometry Rear suspension mountings Force applied(G)	5G
Max equivalent stress (MPa)	256.3
Displacement(mm)	2.44 DEGREE IN X DIRECTION
FOS	1.8

Table 7: The torsional analysis of the member on the interaction with the force.

Results and Discussion

Modal analysis was the study of monitoring and evaluating the dynamic response of structures and or fluids during stimulation. The study was conducted by the Department of Transportation. Normal Modes Analysis, sometimes termed eigenvalue analysis or eigenvalue extraction, was technique used to compute the vibration forms and related frequencies that a structure was display.

It was crucial to know these frequencies because if cyclic loads were applied at certain frequencies, the structure can move into a resonance situation that was led to catastrophic failure. It was also necessary to know the forms in order to make sure that loads are not placed at locations that was causing the resonance situation.

By examining the vehicle fixed geometry of front impact (case1), front impact (case2), rear impact side impact, rollover, and torsional analysis findings were displayed as right suspension mountings and suspension mountings on the base plane. The force computed by vehicle fixed geometry of front impact (case1), front impact (case2), rear impact side impact, rollover, and torsional analysis findings were discovered as 6G, 4G, 5G, 3.5G, 3.5G and 5G. During the side impact analysis, the study is done to replicate such situations where another ATV was hit ATV on side. During the rear collision, the vehicle may get struck on the backside by other ATV during the incident. The maximum deformation for rear impact is

2.50 mm. During the roll over impact, the vehicle has high chance of rolling over its hoop member when driving on a hill or valley region. In these situations, the ATV is regarded to befallen on its top on the track or ground from a height. In this example, force was calculated using the work-energy principle, and the upper section of the ATV felt higher force. Due to the stiffness of the track and ground, the maximum equivalent stress (MPa) was determined using torsional analysis to be 256.3 MPa and the force delivered to the top portion of the ATV to be 5G while maintaining the front and rear suspension constraints constant. Torsion study was performed to determine the torsion stiffness of the chassis over the cross bump in the rear and front sections of the ATV. The primary objective of the torsional study was to identify a chassis with a wide range of stiffness capable of withstanding dynamic suspension loads. The applied forces are similar in magnitude but opposing in direction. By utilizing this loading condition, the case of pure torsion was created via the fixed constraint implemented in the back wheel (Table 8).

Parameters	**Front Impact**	**(case1) Front Impact**	**(case2) Rear Impact**	**Side Impact**	**Rollover Analysis**	**Torsional Analysis**
Fixed Geometry	Front suspension mountings	Front suspension mounting	Rear suspension mountings	Right suspension mountings	Mounting on the base plane rear	suspension mountings
Force Applied(G)	6G	4G	5G	3.5G	3.5G	5G
Equivalent stress (MPa) Max.	313.4	223.8	158.9	309.5	321.7	256.3
Deformation(mm) in X direction	2.44	3.314	3.539	2.50	8.94	6.49
FOS	1.5	2.24	2.89	1.5	1.43	1.8

Table 8: Result analysis of front impact (case1), front impact (case2), rear impact, side impact rollover and torsional analysis.

Driver safety is paramount in any motorsport event, and an analysis of fatalities revealed that the majority of fatalities occurred as a result of head-on collisions. SAE Baja requires student teams to construct an ATV vehicle from the ground up, adhering to the rules specified by the governing bodies. The FEA study established that the structural advantage was achieved while retaining a low weight-to-strength ratio. Customers' demands were prioritized because they are our ultimate aim. While maneuvering over difficult terrain, the vehicle exhibited acceptable dynamic stability (Garg and Raman, 2013). Maximum Stress, Maximum Deformation, and Factor of Safety values obtained are well within the range specified in the Baja SAE rulebook and previously published papers (Dubey et al., 2021). Torque is delivered to one tyre and responded to by the opposing tyre, generating a pair that attempts to twist the roll cage (Mishra et al., 2021).

Conclusion

It was concluded from the present research that the front impact (case 1), front impact (case 2), rear impact (case 2), side impact (case 2), rollover (case 2), and torsional analysis (case 3), the vehicle fixed geometry findings for the suspension mountings and the suspension mountings on the base plane. 6G, 4G, 5G, 3.5G, 3.5G, and 5G were determined. The side impact test was performed to simulate a collision with another ATV, and the findings are used to determine future protection measures. During the rear crash, more ATVs may hit the automobile from the back. The rear impact deformation should be 2.5 mm. When going up or down a hill, the automobile is likely to roll over the hoop member. As long as these criteria exist, the ATV is judged to have fallen from a height. The force was found using the work-energy principle. Because of the hard terrain and track, the maximum equivalent stress (MPa) must be 256.3 MPa. ATV's front and rear suspension are constrained by torsional analysis. The ATV chassis was tested for torsional rigidity on both the rear and front ends. The torsional investigation sought to establish a robust chassis with adequate shock absorber capacity to withstand dynamic suspension loads. The two forces are of equal magnitude but opposite direction. The back wheel's fixed restriction generated pure torsion.

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