Chapter 21
Modeling and Analysis of ATV Roll Cage

A. S. Shridhar, Abhilash Tukkar, Akshay Vernekar, Vinod Badderu, Arun Y. Patil and Basavaraj B. Kotturshettar

Abstract Driver safety is the main concern in any motorsport event, and evaluating the fatalities, it was observed that most of the fatalities were due to head on collision. SAE Baja competition expects the student teams to build an ATV vehicle from scratch, pertaining to the rules specified by the governing bodies. The work focuses on the safety of vehicle at the student level. The model of the roll cage was prepared according to the rule book in SOLIDWORKS 2016. The calculations necessary for the forces to be applied on the roll cage include basic mechanical formulae like bending moment, force calculations, and mass-energy conversions. The model was analyzed for two materials, namely AISI 4130 and AISI 1018 using static structural in the ANSYS Workbench. The main parameters considered for analysis were mesh sizes, mesh type, and the order of element, and various iterations were made considering these parameters. The model was further optimized for weight reduction. The simulation results were compared with analytical results, and a convergence graph was obtained to justify the design.

Keywords ATV · Roll cage · SAE · Bending moment · Mass-energy conversion · Static structural · Fatigue

A. S. Shridhar · A. Tukkar · A. Vernekar · V. Badderu · A. Y. Patil (✉) · B. B. Kotturshettar
School of Mechanical Engineering, K.L.E Technological University, Hubballi, India
e-mail: Patilarun7@gmail.com

A. S. Shridhar
e-mail: shridhar.as1997@gmail.com

A. Tukkar
e-mail: tukkarabhilash@gmail.com

A. Vernekar
e-mail: akshayv007.av@gmail.com

V. Badderu
e-mail: badderurvinod9497@gmail.com

B. B. Kotturshettar
e-mail: bbkshettar@gmail.com

C. Li et al. (eds.), *Advances in Engineering Design and Simulation*,
Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-13-8468-4_21

21.1 Introduction

SAE BAJA is an intercollegiate design competition run by Society of Automotive Engineers (SAE). Teams from various colleges build an all-terrain vehicle (ATV) and run it in the competition held at NATRAX facility, Pithampur, Indore. An ATV is a typical mini off-road vehicle powered by a 10 HP gasoline engine. The roll cage of the ATV must be equally strong and lightweight. Since the vehicle's terrain is off-road, the chances of mishaps and accidents are more, so proper analysis of the roll cage needs to be done in every aspect.

The roll cage (chassis) is the main body of a vehicle which gives support to the vehicle, protects the driver, and is the housing for all other subsystems like suspension, braking, power train, etc. The roll cage is made up of circular hollow cross section consisting of primary and secondary members. The difference between them is wall thickness, bending strength, and bending stiffness. The criterions for assigning of the member as primary and secondary are its placement in a roll cage and its severity during crashes. Front impact, side impact, rear impact, and rollover analysis are carried out in static structural function in ANSYS Workbench.

21.2 Design of Roll Cage

The design is made according to the rules of SAE Baja rule book in SOLIDWORKS 2016 [1]. The roll cage is made of tubular steel frame, which is joined together by the welding process. As per the rules, the material for roll cage must contain a minimum of 0.18% of carbon and has a particular minimum bending strength and bending stiffness. The materials shortlisted from these criteria for the roll cage were AISI 1018 and AISI 4130. The vehicle is designed as to accommodate one person 1.95 m tall weighing 113 kg (i.e., 95 percentile male) according to the rule book specification. The dimensions of the roll cage are 1.82 m length 0.9 m width and 1.2 m height (Figs. 21.1 and 21.2).

21.3 Material Selection

The material properties of AISI 4130 and AISI 1018 are as mentioned below in the table [2]. Chemical properties of the material are also listed below. The material was finalized depending on the highest bending strength with a maximum outer diameter of 1.25 inch and a maximum thickness of 2 mm as mentioned in the rule book. The material satisfying all these properties was AISI 4130 (Tables 21.1, 21.2, 21.3, 21.4 and 21.5).

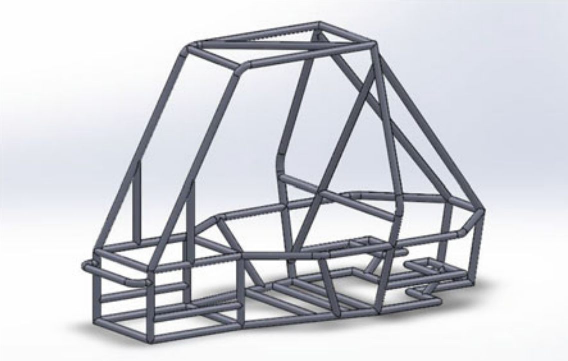

Fig. 21.1 Isometric view of the roll cage

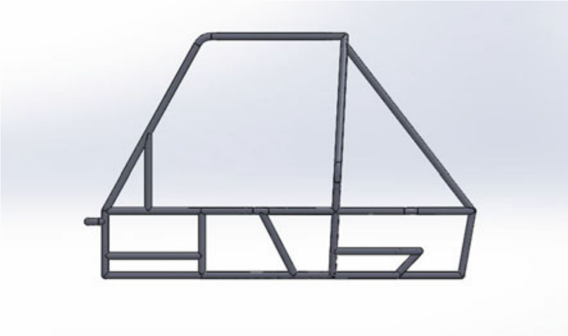

Fig. 21.2 Side view of the designed roll cage

Table 21.1 Mechanical properties of AISI4130

Property	Values
Density	7.85 g/cm^3
Yield strength	460 MPa
Poisson's ratio	0.28
Young's modulus	210 GPa

Table 21.2 Mechanical properties of AISI 1018

Property	Values
Density	7.87 g/cm^3
Yield strength	370 MPa
Poisson's ratio	0.29
Young's modulus	205 GPa

Table 21.3 Chemical composition of AISI4130

Element	Content (%)
Iron (Fe)	97.03–98.22
Chromium (Cr)	0.80–1.10
Manganese (Mn)	0.40–0.60
Carbon (Fe)	0.280–0.330
Silicon (Si)	0.15–0.30
Molybdenum (Mo)	0.15–0.25
Sulfur (S)	0.040
Phosphorous (P)	0.035

Table 21.4 Chemical composition of AISI 1018

Element	Content (%)
Carbon (C)	0.14–0.20
Iron (Fe)	98.81–99.26
Manganese (Mn)	0.60–0.90
Phosphorous (P)	$\leq$0.040
Sulfur (S)	$\leq$0.050

Table 21.5 Tabular column of physical quantities

Physical quantity	Front impact	Rear impact	Side impact	Rollover analysis
Mass of the vehicle (kg)	300	300	300	300
Final velocity (m/s)	0	0	0	0
Initial velocity (m/s)	11.11	11.11	11.11	11.11
Height (m)	0	0	0	3.04
Impact time (s)	0.3	0.15	0.15	0.15
Work done	18,514.8 N-m	18,514.8 N-m	9257.4 N-m	8969.89
Displacement (m)	1.44	3.33	3.33	1.005
Force (N)	12,857.5	5560	5560	8925.26

21.4 Analytical Calculation [3]

Formulae:

1. Work done $W = 0.5{*}\mathrm{m}{*}(v_f^2 - v_i^2)$
2. Displacement, $S = t{*}v$
3. Force, $F = W/S$
4. Velocity, $v = \mathrm{sqrt}(2\mathrm{gh})$

Table 21.6 Front impact results

Element size	Stress	Deformation
6 mm	371.20	14.7580
8 mm	359.92	7.7553
10 mm	282.02	7.5000

21.5 Analysis

The design of roll cage is finalized considering all the constraints of all the subsystem and analyzed for front impact, rear impact, side impact, and rollover analysis in ANSYS Workbench, and various iterations are carried out to increase factor of safety and rigidity without undergoing much deformation. The meshing was done for element sizes of 6, 8, and 10 mm with first-order tetrahedron and hexahedron elements, and also various functions such as the sphere of relevance and edge sizing were used where the complexity of the model arises leading to stress concentrations. Tetrahedral elements can fit better complex geometry. Since there are curved paths, acute angles in our roll cage, we decided to go with tetrahedral elements. Thus, meshing was done for three element sizes with the least size of the element being 6 mm and first-order tetrahedrons being the element type [4]. The element size was finalized from the stress versus element size graph after the convergence was achieved from the graph. The assumptions made are: (1) Weight is considered to be 300 kg; (2) maximum velocity of the buggy is 40 kmph; and (3) the material used for the roll cage is ductile and von Mises theory is considered for the analysis.

21.5.1 Front Impact

In this scenario, a buggy is considered to be moving with a speed of 40 kmph and colliding with a stationary rock or tree. Here, the rear suspension pickup points are fixed and force is applied on the front hitch members (hitch point) of the vehicle which are the ones experiencing a force as they come in contact first [5]. The force applied is 12,857.50 N. The stress induced is 358.86 MPa and deformation is 6.44 mm. The factor of safety is 1.28. Numbers of nodes are 903,185 and numbers of elements are 455,660 for 6 mm element size (Table 21.6; Figs. 21.3 and 21.4).

21.5.2 Rear Impact

In this scenario, the buggy is considered to be at rest and another buggy is considered to come and collide at the rear end of the buggy at 40 kmph. Here, force is applied on the rearmost member and the front suspension pickup points are fixed as the buggy

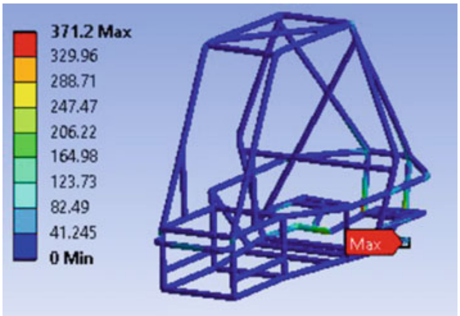

Fig. 21.3 Equivalent stress

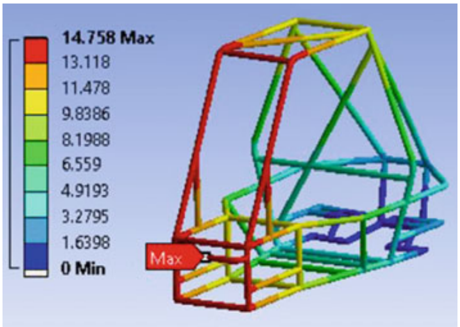

Fig. 21.4 Deformation

Table 21.7 Rear impact results

Element size	Stress	Deformation
6 mm	288.77	1.1895
8 mm	254.03	1.1706
10 mm	185.23	1.0107

would be hit at the rearmost member first. The force applied is 5560 N. The stress induced is 288.77 MPa and deformation is 1.19 mm. The factor of safety is 1.59. The numbers of nodes are 828,310 and the numbers of elements are 420,201 for 6 mm element size (Table 21.7; Figs. 21.5 and 21.6).

21.5.3 Side Impact

In this scenario, the buggy is considered to be at rest while another buggy hit the earlier buggy from the side. Thus, experience of force exerted on the side impact members and the constrain, i.e. fixed points are the opposite side suspension pickup points as they are in contact with the ground. The force applied is 5560 N. The stress induced is 333.08 MPa and deformation is 4.0077 mm. The factor of safety is 1.38.

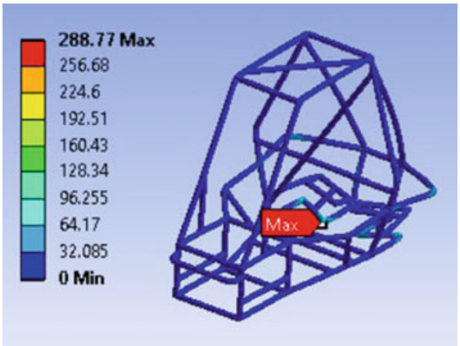

Fig. 21.5 Equivalent stress

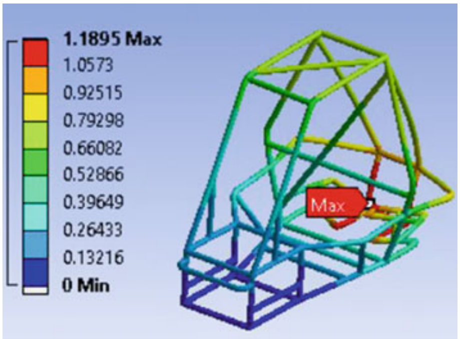

Fig. 21.6 Deformation

Table 21.8 Front impact results

Element size	Stress	Deformation
6 mm	333.08	4.0077
8 mm	324.21	3.9335
10 mm	279.81	3.8477

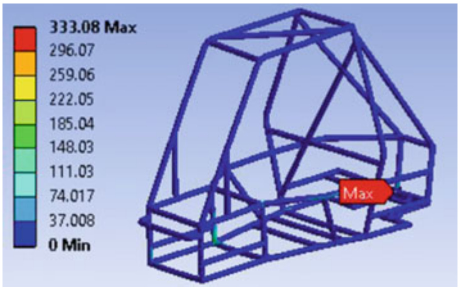

Fig. 21.7 Equivalent stress

The numbers of nodes are 829,121 and the numbers of elements are 420,653 for 6 mm element size (Table 21.8; Figs. 21.7 and 21.8).

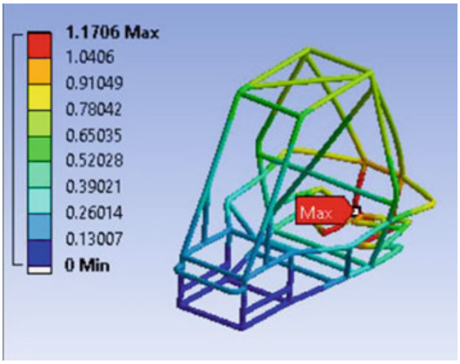

Fig. 21.8 Deformation

Table 21.9 Rollover analysis result

Element size	Stress	Deformation
6 mm	356.05	1.9855
8 mm	234.38	1.9257
10 mm	206.65	1.8565

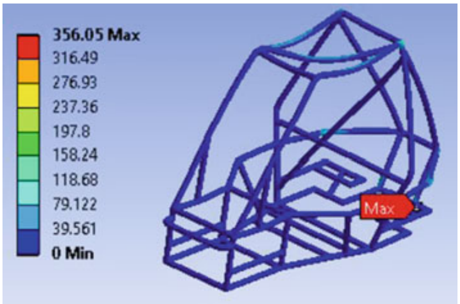

Fig. 21.9 Equivalent stress

21.5.4 RollOver Analysis

In this analysis, it is considered that the roll cage is assumed to be dropped from a height of 10 feet and to fall upside down. All four suspensions pickup points are fixed, and force is applied to the overhead members as they come in contact first. The force applied is 8969.69 N. The stress induced is 356.05 MPa and deformation is 1.9855 mm. The factor of safety is 1.29. The numbers of nodes are 829,340 and the numbers of elements are 420,574 for 6 mm element size (Table 21.9; Figs. 21.9 and 21.10).

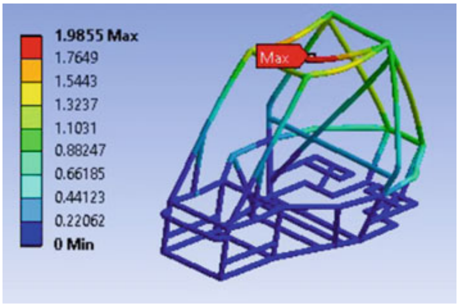

Fig. 21.10 Deformation

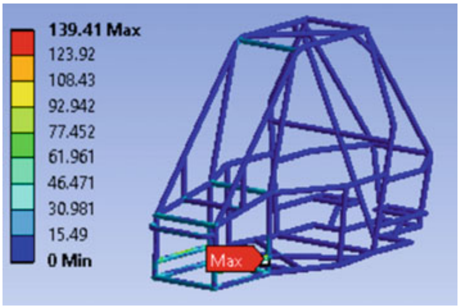

Fig. 21.11 Deformation

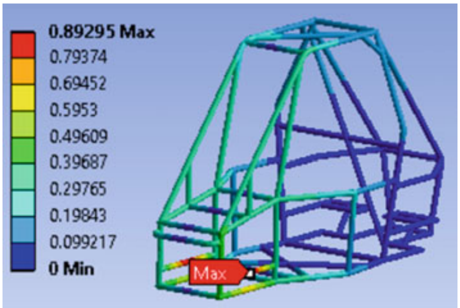

Fig. 21.12 Equivalent stress

21.5.5 Torsional Analysis

In this analysis, the roll cage is expected to undergo torsion due to bumps and the spring forces acting in conduction. The force is calculated according to it. The rear suspension pickup points are fixed, and force is applied on the front suspension pickup points applying force in the clockwise direction on the left suspension pickup point while anticlockwise on the right suspension pickup point. The force applied is 8969.69 N. The stress induced is 139.41 MPa and deformation is 0.8929 mm. The factor of safety is 3.22. The numbers of nodes are 159,618 and the numbers of elements are 28,124 for 6 mm element size (Figs. 21.11 and 21.12).

Fig. 21.13 Deformation

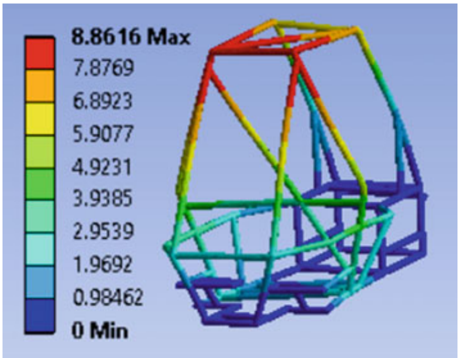

Fig. 21.14 Frequency

	Mode	Frequency [Hz]
1	1.	44.785
2	2.	63.926
3	3.	81.098
4	4.	101.04
5	5.	105.68
6	6.	129.41

21.5.6 Modal Analysis

Considering six major modes of vibrations for the frequency chart, it was found that there is no resonance as the frequency of any other subsystem does not match with the six frequency modes obtained in the analysis. The maximum deformation observed was 8.68 mm and the maximum frequency observed was 129.41 at the sixth mode (Figs. 21.13 and 21.14).

21.6 Result and Discussion

It is recommended that at least four to five iterations have to be conducted in order to arrive at the convergence of solution [7]. The roll cage was analyzed for front impact, rear impact, side impact, rollover analysis, modal analysis, and torsional analysis which are the most expected scenarios at the competition site, and the factor of safety yielded was above 1.2 in all the cases which is the primary threshold limit of the roll cage. It was also seen that resonance with all other subsystem was avoided. The yield stress of the material is 460 MPa, and equivalent stress is less than yield

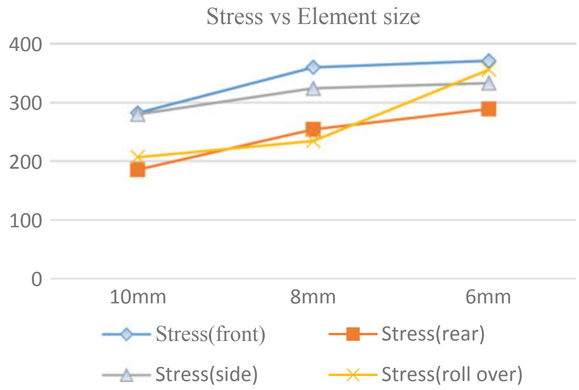

Fig. 21.15 Stress versus element size

Fig. 21.16 Deformation versus element size

stress in all the above conditions. Hence, it can be concluded that roll cage is safe in all the conditions. The graphs of stress versus element size and stress versus deformation are plotted for all the four cases, namely front impact, side impact, rear impact, and rollover [6] (Figs. 21.15 and 21.16).

21.7 Conclusion

In this paper, the design and analysis of the roll cage were completed using the finite element method. The study of analysis explores the static analysis selection of mesh size and element size. The front impact, side impact, roll over analysis, rear impact, torsional analysis, and modal analysis were carried out in this paper. The main objective of the study was to obtain an optimum factor of safety for the roll cage to ensure the safe condition of the driver in all conditions of the crash while also trying to cut down on mass for a better power to weight ratio figure. It was observed that the roll cage stresses were well within the yield limits, and hence, there was no need of addition of gussets at any of the regions. AISI 4130 was the most suitable material for our study.

References

Book

1. Rulebook BAJA SAE International (2018)

Journal Paper

2. Aru, S., Jadhav, V., Kumar, A., Angane, P.: 'Design Analysis and Optimization of a Multi_Tubular Space Frame'. (IJMPERD). ISSN(P): 2249-6890; ISSN(E): 2249-8001. **4**(4) (2014), 37_48© TJPRC Pvt. Ltd
3. Harshit, R.: Design and Analysis of the Roll Cage of an ATV. Int. J. Eng. Res. Technol. (IJERT). ISSN: 2278-0181 **6**(09) (2017)
4. Noorbasha, N.: Computational analysis for improved design of an SAE BAJA frame structure. UNLV Thesis, Disserations, Professional Papers, and Capstones Paper 736, 12 (2010)
5. Raina, D., Gupta, R.D., Phanden, R.K.: Design and Int. J. Technol. Res. Eng. (IJTRE) **2**(7). ISSN: 2347-4718 (2015)
6. Sati, B.K., Upreti, P., Tripathi, A., Batra, S.: Static and dynamic analysis of the roll cage for an All-Terrain vehicle. Imperial J. Interdisciplinary Res (IIJR) **2**(6). ISSN: 2454-1362 (2016)
7. Patil, A.Y., Hrishikesh, N.U., Basavaraj, G.D., Chalageri, G.R., Kodancha, K.G.: Influence of bio-degradable natural fiber embedded in polymer matrix, IMME17. Mater. Proc. **5**(2), 7532–7540, Part 2 (2018)