# Design And Development Of Roll Cage For An All-Terrain Vehicle

**Khelan Chaudhari, Amogh Joshi, Ranjit Kunte, Kushal Nair**

E-mail : khelanchoudhary@gmail.com, amogh_4291@yahoo.co.in,ranjitkunte@gmail.com,krockon007@gmail.com

***Abstract* -The study aims to design, develop and fabricate a roll cage for an All-Terrain Vehicle (ATV) in accordance with the rulebook of BAJA 2013 given by SAE. A roll cage is a skeleton of an ATV. The roll cage 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. The design and development comprises of material selection, chassis and frame design, cross section determination, determining strength requirements of roll cage, stress analysis and simulations to test the ATV against failure. Finally the roll cage is fabricated as per the tools and techniques available in the workshop.**

***Index Terms*— Chassis, roll cage**

## I. INTRODUCTION

The objective of the study is to design, develop and fabricate the roll cage for All - Terrain Vehicle accordance with the rulebook of BAJA 2013 given by SAE. Material for the roll cage is selected based on strength, cost and availability. The roll cage is designed to incorporate all the automotive sub-systems. A software model is prepared in Pro-engineer. Later the design is tested against all modes of failure by conducting various simulations and stress analysis with the aid of Autodesk Multi-physics. Based on the result obtained from these tests the design is modified accordingly. After successfully designing the roll cage, it is fabricated.

## II. DESIGN AND DEVELOPMENT

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

### *A. Material Selection*

As per the constraint given in the rulebook[1], the roll cage material must have at least 0.18% carbon content. After an exhaustive market survey, the following materials which are commercially available and are currently being used for the roll cage of an ATV are shortlisted. A comparative study of these shortlisted materials is done on the basis of strength, availability and cost. The shortlisted materials are as follows.

- AISI 1018
- AISI 4130
- AISI 1026

### *B. Frame 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 3 inches between the driver and the roll cage members. The engine used is a Piaggio Ape diesel engine and its specifications were also obtained. 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. Mounting heavier components such as engine, driver seat etc. directly on the chassis[2] is one way of achieving low center of gravity. Also it is imperative to maintain the integrity of the structure. This is done by providing bends instead of welds which in turn reduces the cost. A layout of the chassis within the given geometrical constraints is as shown in Fig.1.

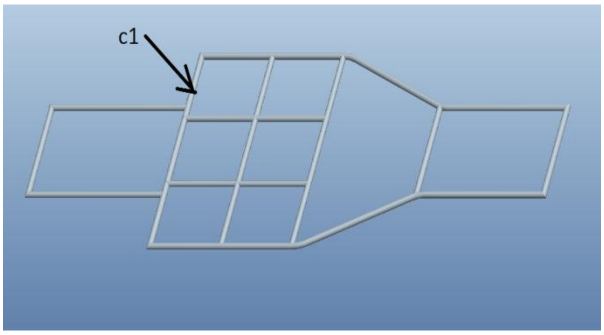


Fig.1. Layout of the chassis

The wheel base (distance between center lines of front wheels and rear wheels) is kept as 71’. Combined weight of the driver and seat of 100 Kg acts at 10’ from member C1 to the right. C.G. of the cage structure is at 15.4’ from member C1 to the right. Engine and gearbox weighing 50 Kg is placed at 13’ from member C1 to its left. Steering system comprising of rack and pinion and tie rods weighing 7 Kg is mounted 6’ to the left of front axle. Using these distances a bending moment diagram representing the vertical loading of the chassis is generated.

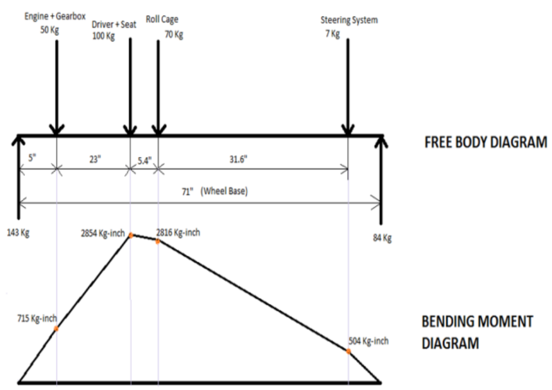


Fig.2. Free body and bending moment diagram

The maximum bending moment (M) is equal to 2854 kg-inch i.e. 711.14 N-m

This bending moment i.e. bending strength is calculated for two beams of the chassis. Therefore for one beam i.e. one cross-section, bending strength is M/2 = 355.57 N-m.

After designing the chassis, the cockpit area is designed. A pilot seat is taken for reference. All the measurements such as seat position from rear roll hoop, foot pedals, roof members with sufficient head clearance, side impact members[1] are determined by placing the driver in the driving position. Also by taking into consideration the engine, gearbox and exhaust system, the rear of the roll cage is designed. The nose of the roll cage is designed by taking into consideration the steering system, foot pedals and brake cylinders. Additionally, members are provided to mount the suspension and the wheels.

1) Frame Cross Section Determination

After finalizing the design, it is a very important to define the cross-section of the structural members. It is strictly mentioned in rulebook to incorporate only circular tubing. While deciding the cross section, bending strength and ease in fabrication processes is taken into consideration.

As per the material requirements specified in rulebook, bending strength should be greater than or equal to that of 1018 steel of 25mm OD and 3mm thickness. Also there are fabrication limitations regarding welding and bending processes. Welding becomes difficult for thickness less than 1mm. After considering all these factors, cross section of 25.4mm (OD) ×3mm (wall thickness) is selected.

Now, from bending equation[3], we have

$(\sigma/y) = (M/I)$

Where

$I$ = Moment of Inertia = $\frac{\pi(D^4-d^4)}{64} * 2$ ,

As there are two cross sections supporting the load,

$y = D/2$

On calculation

$\sigma = 334$ MPa = 215.48 KN/in$^2$

After an iterative process, the following design is selected as shown in Fig.3.

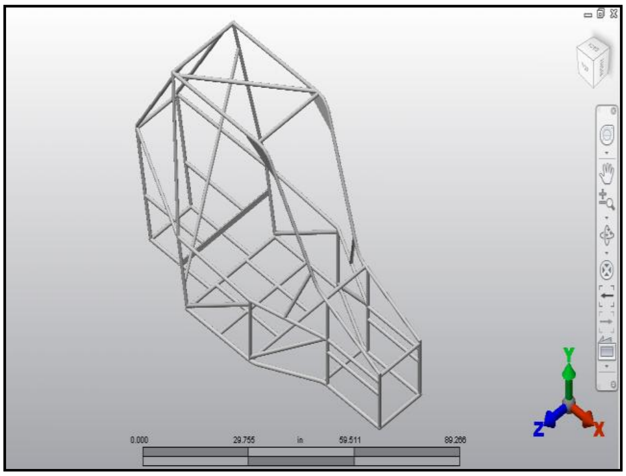


Fig.3. Design version 1 of roll cage

This design is tested for the shortlisted materials and the following results are obtained.

For AISI 1018 - Total Weight of the Roll Cage: 80 kg

Total Cost: Rs. 4400

For AISI 1026 - Total Weight of the Roll Cage: 70 kg

Total Cost: Rs. 4620

For AISI 4130 - Total Weight of the Roll Cage: 55 kg

Total Cost: Rs. 8250

A balance is struck between the strength, weight and cost of the materials and AISI 1026 with carbon content 0.2% is selected as the roll cage material.

For AISI 1026, $\sigma = 414$ MPa = 267 KN/in$^2$.

For AISI 1018, $\sigma = 365$ MPa = 235.5 KN/in$^2$.

Thus AISI 1026 has greater yield strength than AISI 1018.

Bending strength for AISI 1026 is 440 N-m. Bending strength required equal to 355.57 N-m is calculated earlier..

Also for AISI 1018 bending strength is equal to 388 N-m which is less than that for AISI 1026.

Therefore design is safe under bending. Hence the selected cross section and material is finalized.

### *C. Finite Element Analysis*

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) Frontal impact test
2) Wheel bump test
3) Longitudinal Torsion test

1) Frontal Impact Test

Load calculations: The mass of the vehicle is 350kg. The impact test or crash test is performed assuming the vehicle hits the static rigid wall at top speed of 60kmph. The collision is assumed to be perfectly plastic i.e. vehicle comes to rest after collision.

Initial velocity u=16.67m/s

Final velocity v=0

In automotive industry, the impact time is of the range 0.15 to 0.2 s. Taking time of impact as 0.18 s[4].

By applying Newton's 2nd law,

F = change in momentum/time

F= (m*(v-u))/t

F= (350*(0-16.67))/0.18

F = 32413N

Hence a gross load of 32kN is applied at the front corners constraining the rear members as shown in the Fig.4.

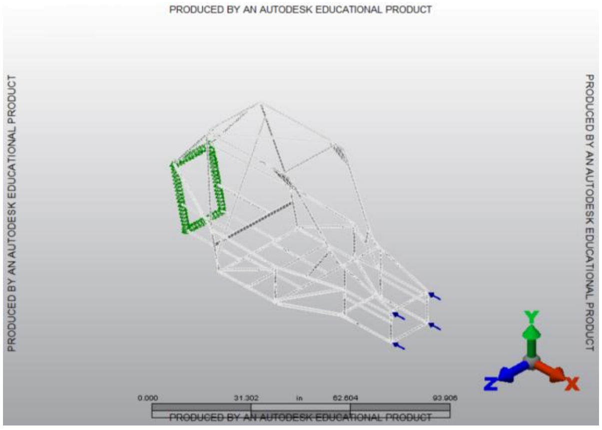


Fig.4. Constraint for frontal impact test

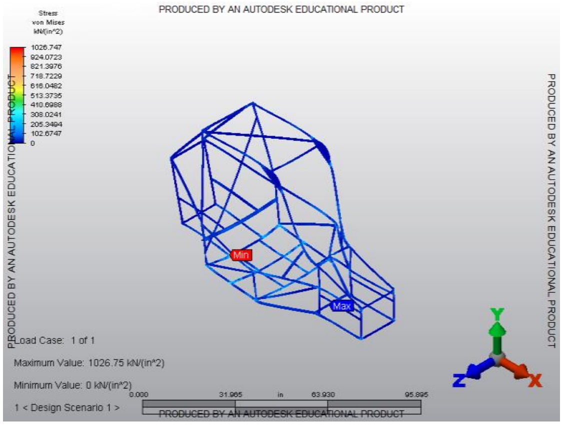


Fig.5. Stress analysis for frontal impact test

It is seen from Fig. 5 that the maximum stress value in the roll cage equals 1026.75KN/in$^2$ (1590.3 MPa) which exceeds the safe value of 267KN/in$^2$. Hence modifications are made in the design. Bracing members are added to the chassis. Also other members are added to the frame to channelize the stress throughout the members of the roll cage. Also the positioning of the engine, gearbox and suspension is modified resulting in changes to the roll cage. The revised chassis is as shown in Fig.6.

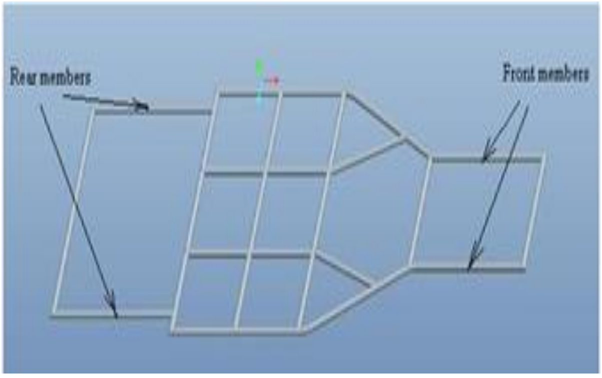


Fig.6. Revised chassis

The revised bending moment diagram is generated as shown in Fig.7. and calculations are performed on the same.

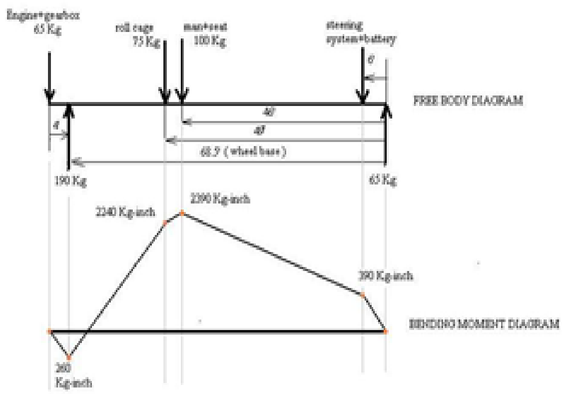


Fig.7. Revised chassis

From Fig.7.

$R_R$ = 190 kg = 1.9 KN (74.5% load)

$R_F$ = 65 kg = 0.65 KN (25.5% load)

Max Bending Moment (M) = 2390 kg-inch = 595.52 N-m

This bending moment i.e. bending strength is calculated for two beams of the chassis. Therefore for one beam i.e. one cross-section bending strength is M/2 = 297 N-m, which is less than the permissible value of AISI 1026.

Thus design is safe.

The revised design of the roll cage is as shown in Fig.8.

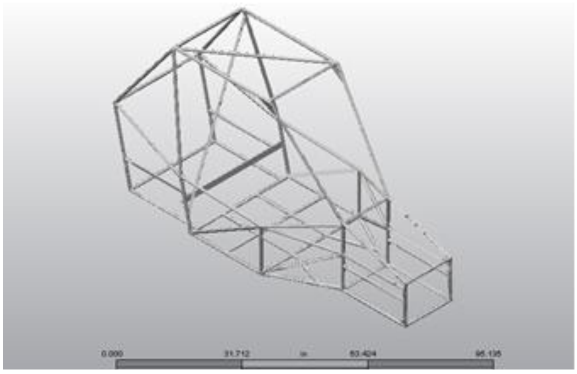

Fig.8. Design version 2 of roll cage

Frontal impact test is again carried out on this design.

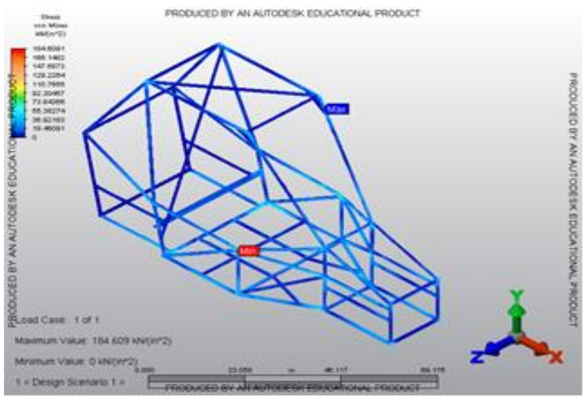


Fig.9. Stress analysis for frontal impact test

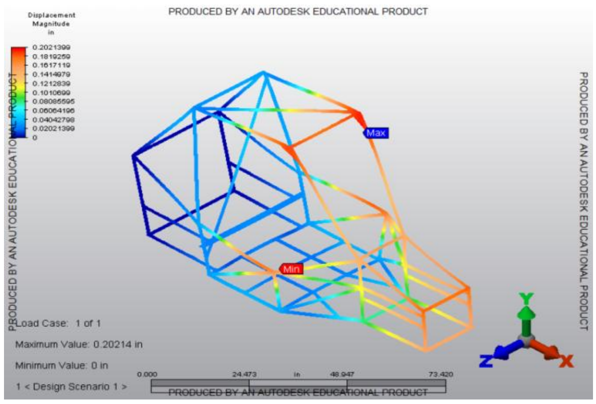


Fig.10 Deformation for frontal impact test

The maximum stress value obtained is 184.609 KN/in$^2$ (286.144 MPa). Therefore the design is safe.

2) Wheel Bump Test

This test is performed to check the strength of the nose area. While traveling over a bump, if the suspension fails, it transfers the entire road reaction to the nose of the roll cage. In this situation the nose should not fail. Situation considered for this test is that one of the front wheels of the vehicle gets lifted due to the bump while rests of the wheels maintain contact with the level ground[5]. A force equal to gross weight of the ATV is applied on the member to whom the lifted wheel is connected and rest of the members is constrained as shown in Fig.11.

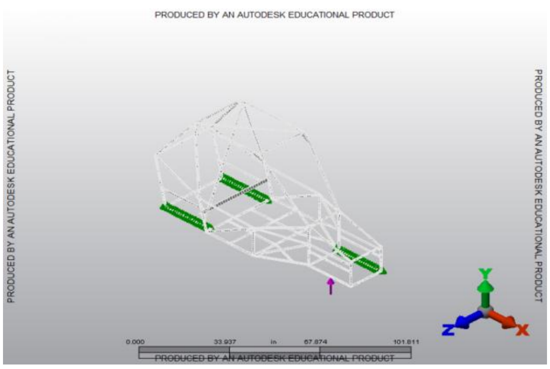


Fig.11. Constraint for wheel bump test and Fig.9.

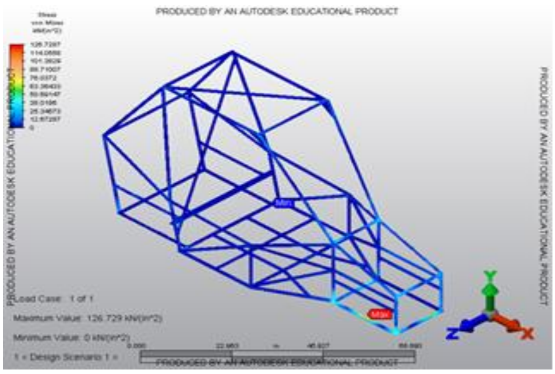


Fig.12. Stress analysis for wheel bump test

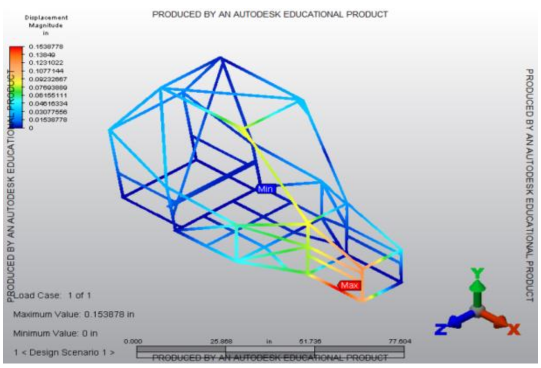


Fig.13. Deformation for wheel bump test

The maximum stress value obtained is 126.729 KN/in$^2$ (196.43 MPa). Therefore the design is safe.

3) Longitudinal Torsion Test

This test is performed to examine the structure under twisting loads. In this situation one of the front wheels and the diagonally opposite rear wheel pass over the road hump. Thus the diagonally opposite wheels are lifted and the other pair of wheels maintains contact with the level road as weight on the wheels will restrict them to lift up. The frame can be thought of as a torsion spring connecting the two ends where suspension loads act.[6] The two diagonally opposite members to whom the wheels which maintain contact with the ground are constrained. A force equal to 2000N is applied to the rear left wheel and a force equal to 1200N is applied to the front right wheel. This is calculated according to the load distribution on the vehicle shown earlier. The constraints and the stress analysis are as shown.

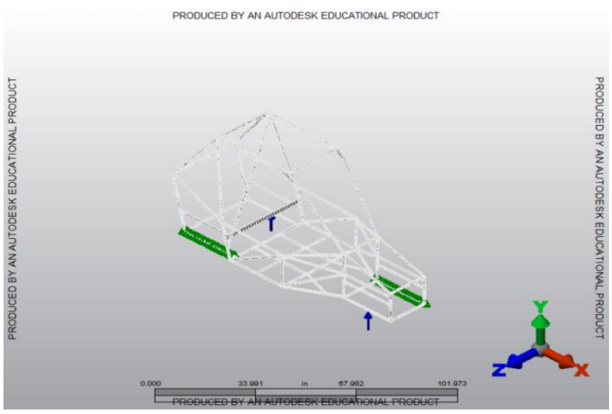


Fig.14. Constraint for longitudinal torsion test

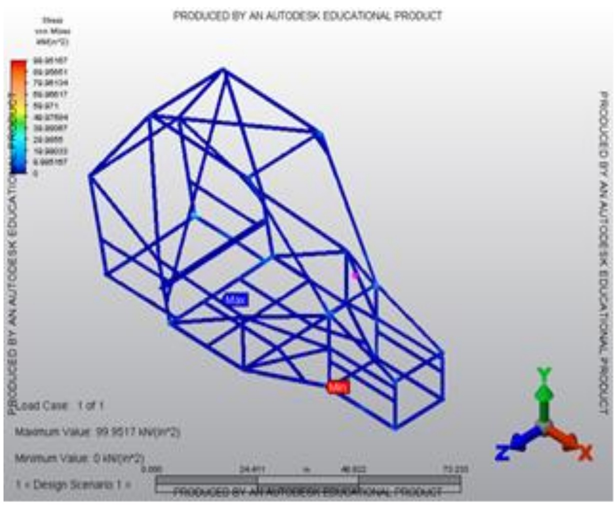


Fig.15. Stress analysis for longitudinal torsion test

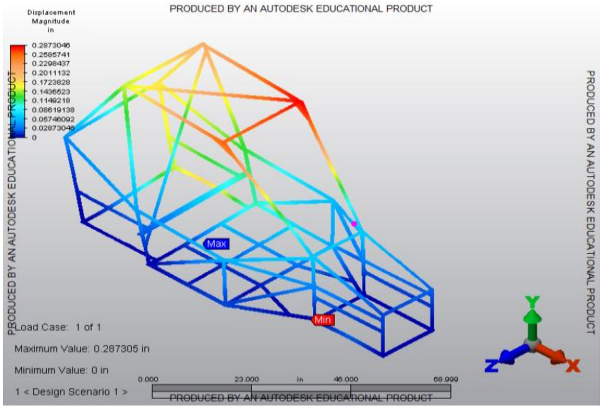


Fig.16. Deformation for longitudinal torsion test

The maximum stress value obtained is 99.9517 KN/in$^2$ (154.92 MPa). Therefore the design is safe.

## III. FABRICATION

From the results of the above tests it is concluded that the roll cage is safe under severe conditions.

After the static analysis of the roll cage, material procurement was done. Total 7 tubes of 6m length each were procured at a cost of Rs.5000. The cost per kg was Rs.70.

The material was cut and machined to required dimensions.

Rail cutter available in the workshop was used to serve the purpose.

After analyzing the material joining techniques available in the college workshop, metal arc welding was selected.

All the members of the roll cage can be joined by this technique.

The advantages of this welding technique are as follows:

- It is the simplest of all arc welding processes.
- The equipment is portable and the cost is fairly low.
- A big range of metals and their alloys can be welded.

Plastic fiber is used as firewall material. Checkered aluminium plate is used as base for the ATV. The ATV is manufactured by incorporating all the automotive subsystems.

Fig.17. Photograph of fabricated ATV

## IV. CONCLUSION

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, steering, brakes and other miscellaneous elements.

## V. REFERENCES

[1] Rulebook BAJA SAE INDIA 2013, ver. 00.

[2] Herb Adams, “Chassis Engineering”, Berkley Publishing Group New York.

[3] F. L. Singer , “Strength of Materials”, Harper and Row Publishers, New York.

[4] Linder, Astrid; Avery, Matthew. “Change of Velocity and Pulse Characteristics in Rear Impacts: Real World and Vehicle Tests Data,” The Motor InsuranceRepair and Research Centre. Thatcham, United Kingdom.' http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv18/cd/files/18ESV-000285.pdf

[5] William B. Riley and Albert R. George, “Design, Analysis and Testing of a Formula SAE Car Chassis”, SAE TECHNICAL PAPER SERIES 2002-01-3300.

[6] Dr. N.K.Giri, “Automobile Mechanics”, Khanna Publishers.

❖❖❖