Design, Development and Analysis of the Roll Cage for All – Terrain Vehicle

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Abstract — **We have tried to design an all terrain vehicle that meets SAE INDIA standards and is also cost effective at the same time. In the present investigation, the performance of ATV roll cage is studied against crashes that can be encounter in the real life scenario and its consequences on the individual components. The roll cage structure which must be designed to ensure the safety of the driver while not compromising the ergonomics. 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 using 1 Dimensional Analysis**

Index Terms –Roll cage, Factor of Safety, Material, FEA

I. Introduction

In this Era the automobile industry has changes drastically so the importance of safer vehicle increased day by day. The main objective of this paper was to test the ATV Roll Cage against the collision The chassis is the component in charge of supporting all vehicle's subsystems with the plus of taking care of the driver safety at all time The chassis design need to be prepared for impacts created in any certain crash or rollover. It must be strong and durable taking always in account the weight distribution for a better performance.

During actual road performance, any vehicle is subjected to loads that cause stresses, vibrations and noise in the different components of its structure. This requires appropriate strength, stiffness and fatigue properties of the components to be able to stand these loads. On top of that, quality of a vehicle, as a system, which includes efficient energy consumption, safety, riding dampness and provision of comfort to the driver is highly desired. Roll Cage is the structural basis of an All-terrain vehicle. The components of a vehicle like a Power Source, Transmission system, Axles, Wheels and Tyres, Suspension System, Controlling systems like Braking , Steering etc. , and also electrical system parts are mounted on the chassis frame. It is the main mounting for all the components including the body. So it is also called as a carrying unit.

The vehicle is required to have a combination frame and roll cage consisting of steel members. As weight is critical in a vehicle powered by a small engine, a balance must be found between the strength and weight of the design. To best optimize this balance the use of solid modelling and finite element analysis (FEA) using Altair HyperWorks v12.0 software is extremely useful in addition to conventional analysis. The following paper outlines the design and analysis of the roll cage design

II. 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

A. Material Selection

One of the key design decisions of our frame that greatly increases the safety, reliability and performance in any automobile design is material selection. A low cost roll cage was provided through material selection and incorporating more continuous members with bends rather than a collection of members welded together to reduce manufacturing costs. While selecting the material there are some limitations. These limitations include the method of fabrication and industry standards for the material.

The frame will be built using a bent tube construction and ARC welded joints. ARC welding becomes difficult at wall thicknesses less than 0.035 inches. The tubing bender that will be used for the fabrication can bend a maximum of 1.5 inch diameter tube with a 0.120 inch wall thickness. As per the rule book constraint there should be at least 0.18% of carbon content in metal [Rulebook BAJA SAEINDIA® 2016].Our initial step was to conduct a market survey to have an idea of the availability of the material. Based on market survey we have chosen following material namely: - AISI 1018 steel having the properties as given below:

TABLE I.
MATERIAL PROPERTIES

Property		1018 STEEL
Physical Properties	Density (kg/m3)	7880
	Tensile Strength (MPa)	370
	Yield Strength (MPa)	440
Chemical Properties	Carbon, C	0.14-0.20
	Iron, Fe	98.81-99.26
	Manganese, Mn	0.60-0.90
	Sulphur, S	≤0.50

B. . Pipe Size Selection

As per guidelines, the primary members must be Circular steel tubing with an outside diameter of 25.4 mm (1 inch) and a wall thickness of 3 mm (0.120 in) [Rulebook BAJA SAEINDIA® 2016]. Also, we were having a constraint in selection of size for secondary members of the frame that the minimum wall thickness should be 0.89 mm (0.035 in) and min outside diameter should be 25.4 mm (25.4 in). The bending strength and ease of fabrication is also taken into consideration while deciding the cross section of pipe. To keep the weight of roll cage as low as possible, we used the circular tubes with following dimensions:

Primary Members: 25.4 x 3 mm

Secondary Members: 25.4 x 0.89 mm

C. 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. 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 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

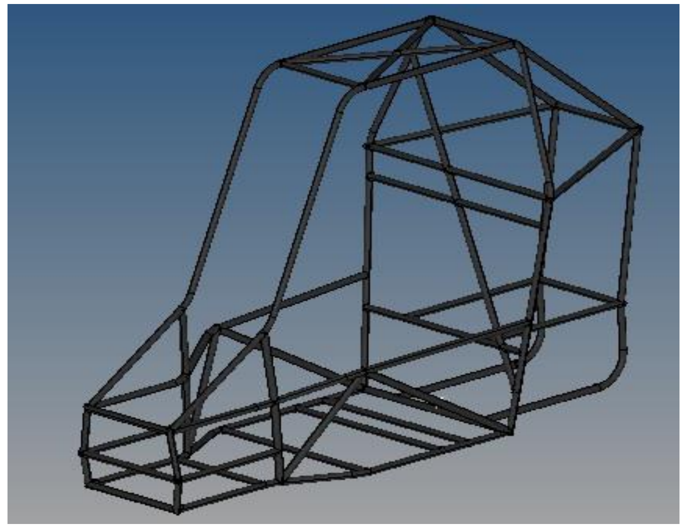

Fig. 1 Isometric View of Roll Cage

III. FINITE ELEMENTAL ANALYSIS

FEA is a powerful design tool that has significantly improved both the standard of engineering designs and the methodology of the design process. The introduction of FEA has substantially decreased the time to take products from concept to the production line. It is primarily through improved initial prototype designs using FEA that testing and development have been accelerated. In summary, benefits of FEA include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue This section includes FEA tools used in the present research and describes briefly the features and capabilities of each tool.

Finite element is a method for the approximate solution of partial differential equations that model physically problems such as: solutions of elasticity problem, determine displacement, stress and strain fields. Static, transient dynamic, steady state dynamic i.e. subject to sinusoidal loading, modes and frequencies of vibrations, modes and loads of buckling. Roll cage analyzed at much higher forces than in real case scenario. Following tests are performed on the roll cage:

- Front Impact
- Side Impact
- Bump
- Roll over

A. Force calculation

I) Front Impact Force Determination for Worst case Scenario: According to research, a human body will pass out at forces much higher than 7.9 G"s. Therefore, a value of 10 G"s was considered for an extreme worst case collision. Therefore for static frontal impact analysis, the load on the vehicle is calculated from Eqn. (1).

$$F = m \times a \ldots (1)$$

Where, $m = 300$ kg, $a = 10 \times 9.8\ m/s^2$

And Force = 29430 N

$$F \approx 30000\ N$$

Thus a force of **30000 N or 10G** is applied in the frontal impact analysis. The impact forces, as defined by automobiles industry, for other tests are given in result table.

B. Loading Conditions

The forces are applied on the impacted part of the Roll Cage as it is the first point of contact in case of a collision eg. In case of front Collision, forces are applied at front part and during side impact, forces are applied at Side Impact Members (SIM) of Roll Cage. For Roll-over analysis, forces are applied at an angle of 45° to the impacted member. The Suspension mounting Points on roll cage are fixed for all the static tests. For Front Bump, Forces are applied at the Front Suspension Points and rear suspension points are fixed to analyse the situation; and vice-versa for rear bump. A lot of failures brought about by resonance and excessive vibration of components and systems. Therefore, Modal Analysis is done, in which the frame is fixed at the lower base of the vehicle frame to know the different mode shapes of the upper substructure.

C. Front Impact

Loading = 30000N on front corners which will first comes in contact.

Boundary conditions: All DOF are fixed at rear corner points.

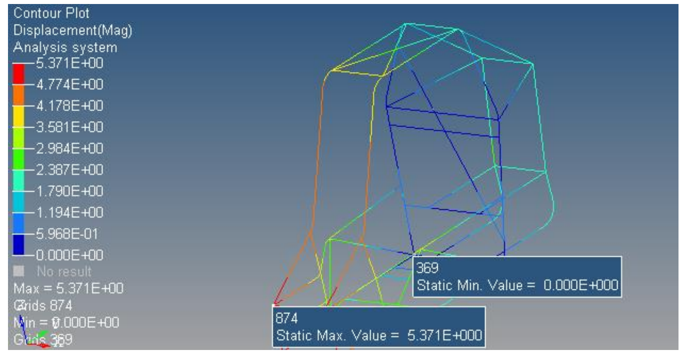

Fig 2 Displacement Plot

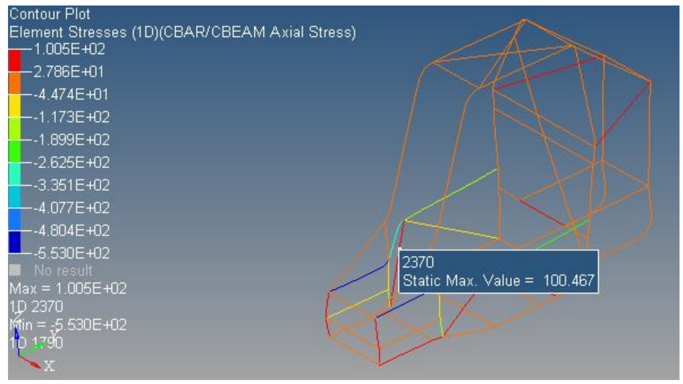

Fig. 3 Stress Plot

D. Side Impact Test

Loading = 6000N on left Side Impact Member(SIM) at the outmost point of the roll cage which will first come in contact at the time of impact.

Boundary Condition: All DOF of lower suspension mounting points assuming that wheels are in contact with ground at the time of impact

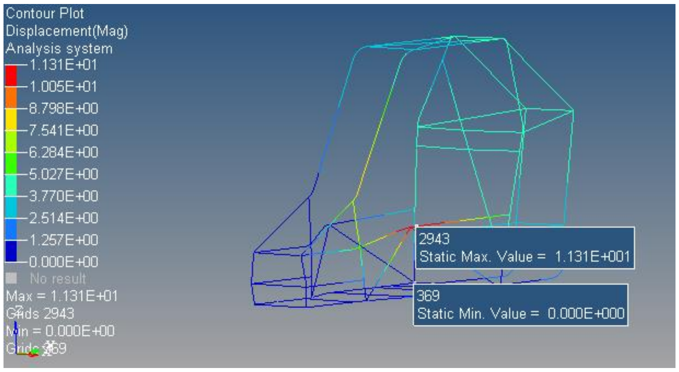

Fig 4 Displacement Plot

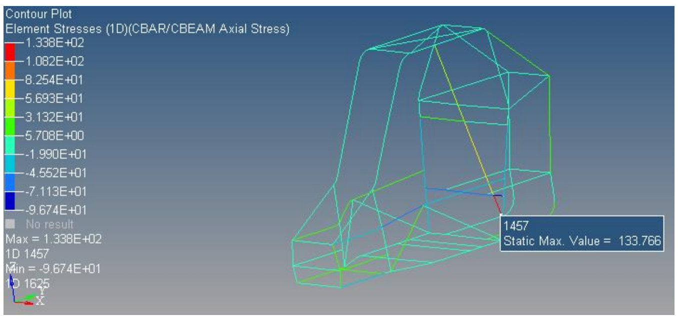

Fig 5 Stress Plot

E. Bump Impact Test

Loading = 9000N on front suspension points in upward direction.

Boundary Conditions: All DOF of rear suspension mounting points assuming rear wheels are in contact with the ground.

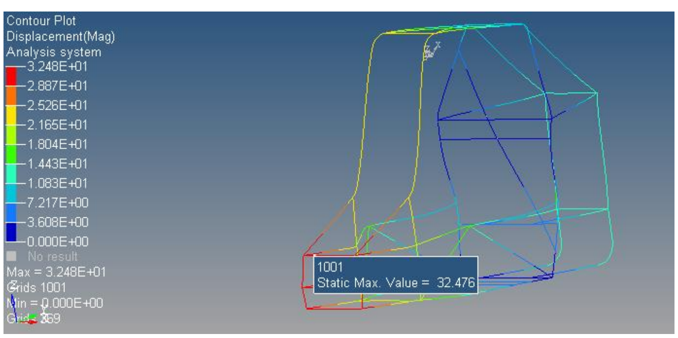

Fig 6 Displacement Plot

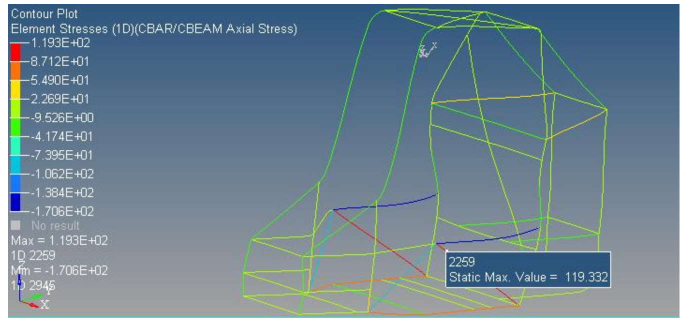

Fig 7 Stress Plot

IV. Result

Type of Impact	Maximum displacement ***(mm)***	Maximum stress *(*Mpa*)*	FOS	Applied force in ***G's***
front	5.73	100.46	3.67	10
side	11.31	133.76	2.36	2
bump	32.47	119.332	3.09	3

V. Conclusion

Safety is of utmost concern in every respect; for the driver, crew & environment. A considerable Factor of Safety (FOS) or design factor is applied to the roll cage design to minimize the risk of failure and possible resulting injury. The FEA analysis demonstrated the structural superiority while maintaining a

weight to strength ratio. The design of the vehicle is kept very simple keeping in view its manufacturability. There is lot of future work such as 2 dimensional analysis as well as dynamic analysis which is essentially required to fine tune the performance. 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.

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