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DESIGN AND ANALYSIS OF A SINGLE SEATER RACE CAR CHASSIS FRAME

D.LAVANYA[1], G.GURU MAHESH[2], V.AJAY[3] , Dr. C.YUVARAJ[4]

[1]P.G student, Department of Mechanical Engineering, MITS, Madanapalle.

[2,3,4] Department of Mechanical Engineering, MITS, Madanapalle.

lavanya.mech312@gmail.com[1], gurumaheshg@mits.ac.in[2], ajayv@mits.ac.in[3]

Abstract

This paper describes the design and analyses of a single seater race car chassis frame, according to the specifications of 2014 Formula SAE rule book. The work focuses on the important design parameters around the driver instead of designing the car and the quantitative predictions of different dimensions and mechanical parameters, using the given information and relevant approximations.

Design model was prepared using anthropometric parameters of tallest driver as 95th percentile male was selected to SAE rules book. In this description CATIAV5, HYPERMESH, ANSYS14.5 software's are utilized in order to design and analysis the chassis frame. Based on this design part deformation occurred on the chassis frame at different load conditions and Stress distribution along the each element can be determined.

Keywords- Chassis frame, Deformation, Bending moment, FEA(Finite Element Analysis).

1. Introduction

Formula SAE is an understudy rivalry, supported by the Society of Automotive Engineers (SAE), in which understudies plan, fabricate, and complete with a little equation style race auto. The FSAE rivalry was made to give an instructive experience to school understudies that are practically equivalent to the sort of undertakings they will confront in the work energy. The opposition likewise incorporates some static plan occasions, where the expense and outline of the auto is judged by a board. A chassis is the component in a car that everything else attaches to. The most basic, common chassis design is referred to as the "Ladder Frame" due to its resemblance to a conventional lean-to ladder (Adams, 1992). A "Ladder Frame" consists of two long members that run the length of the automobile and are joined by a set of smaller member perpendicular to the two long members. The other components that make up the vehicle are then mounted to this chassis. In the case of the Ladder Frame, the body and engine are usually mounted to the top of the chassis with the suspension being mounted below. In more recent times the chassis has evolved and in some cars it can be hard to distinguish between what makes up the body of a vehicle and what makes up the chassis. A monologue chassis uses the body as the load carrying component and means that no separate chassis structure is needed. Entire panels carry the load rather than specific members, often these panels are the outermost parts of the body which means that a higher polar moment of Inertia (about the axis running from the front to the rear of the car) is achievable.

2. Chassis Loading

Chassis is a fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single welded structure, multiple welded structures or a combination of composite and welded structures .The first step to designing a chassis is to understand the various loads acting on the structure. The main deformation modes occurring on the chassis is as follows

i. Longitudinal Torsion
ii. Vertical Bending
iii. Lateral Bending
iv. Horizontal Lozenging

i. Longitudinal Torsion

At the point when the connected burdens following up on one or two oppositely contradicted corners of the auto torsion happens. This will encounter while moving an auto on street subjected to compels of distinctive sizes. The edge could be thought as a torsion spring interfacing the two finishes where suspension burdens act. Torsional stacking and undesirable redirections of suspension springs can influence the taking care of and additionally execution of the auto. The imperviousness to tensional misshapening is called solidness spoke to in name. In the execution of a FSAE race auto this is the essential determinant.

ii. Vertical Bending

In this case the frame is act as a simply supported beam and the four wheels as supports and the weight of the driver and components mounted to the frame, such as the engine and other parts are acting at the centre of the frame. Under the effect of gravity produce sag in the frame. Hence the vertical damping force due acceleration or deceleration can increase the vertical deflections.

iii. Lateral Bending

Lateral bending loads are induced in the frame for various reasons, such as road camber, side wind loads and centrifugal forces caused by cornering. The sideways forces will act along the length of the car and will be resisted by the axles, tires and structural members.

iv. Horizontal Lozenging

This deformation is caused when the forward and backward forces applied at opposite wheels. These forces tend to distort the frame into a parallelogram shape. If torsional and vertical bending stiffness are satisfactory, then the structure will generally be satisfactory. The magnitude of these load changes with the operating mode of the car.

3. Load Estimation

As per the standards of the FSAE car parts are designed to withstand 3.5g bump, 1.5g braking and 1.5g lateral forces. The total mass of the car components and driver are listed below:

	Components	Mass (kg)
1	Driver	100
2	Engine	80
3	Drive-train	20
4	Steering	10
5	Battery	04
6	Chassis	30.2
Total		**234.2**

4. Material selection

The chassis material must perform in a high speed environment, with the sharp bend and twist that generate 5-8g forces. In addition to these forces the chassis must be robust and offer some flexibility. Lightweight and stiffness are the most important properties of a chassis and the stiffness of the completed chassis will be affected by the stiffness of the material. After reviewing mechanical properties, availability, cost and other significant factors, following material was selected.

Mechanical Properties of Chassis Material

STEEL GRADE: AISI 4130 steel		
S.No	**Properties**	**Values**
1	Young's modulus	2.05e+011 N/m2
2	Poisson ratio	0.285
3	Density	7850 kg/m3
4	Yield Strength	4.6e+008 N/m2

5. Design requirements (Based on 2014 FSAE Rules Book)

The design of the chassis must work around a number of parameters and constraints in order for it to perform well and for it to be eligible to compete in the competition. These requirements can be broken into several categories which will be discussed below. If any of these requirements are not met, the consequences range from sub-optimal performance to not being eligible to compete in the competition or even chassis failure. So it is clear that all requirements must be carefully considered and even re-visited when designing and building the chassis.

Rules:

The first thing that must be considered when designing the chassis is the 2014 FSAE rules, there is no point in designing a chassis if it will not be allowed to compete in the competition for which it is designed. The FSAE rules require a front and rear roll hoop, a side impact structure, a front bulkhead and supports for the aforementioned components be integrated into the chassis. By representing graphically these 12 requirements one may create a "minimum chassis' Figure 1 which shows the simplest possible configuration of members that include the required components mentioned above. Figure 2 is a side view diagram of what this "minimum chassis" looks like, it does not consider driver ergonomics, cockpit entry or suspension points etc, and is merely a pictorial representation of some of the required members.

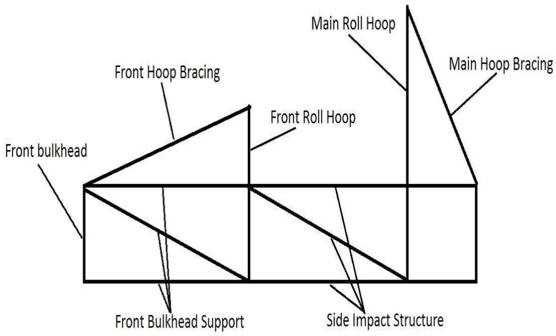

Fig 1. Pictorial representation of the members required by the FSAE rules.

The FSAE rules define a minimum size for all the chassis members shown in Figure 2 and for some other members not shown. To avoid adding un-necessary weight, the chassis design should make best use of the required members so that as few possible additional members are needed. This is where much of the design work needs to be done for the project because as the rules limit many of the members, little design work can be done in optimizing the size of the chassis members.

ITEM or APPLICATION	OUTSIDE DIMENSION X WALL THICKNESS
Main & Front Hoops, Shoulder Harness Mounting Bar	Round 1.0 inch (25.4 mm) x 0.095 inch (2.4 mm) or Round 25.0 mm x 2.50 mm metric
Side Impact Structure, Front Bulkhead, Roll Hoop Bracing, Driver's Restraint Harness Attachment (except as noted above) EV: Accumulator Protection Structure	Round 1.0 inch (25.4 mm) x 0.065 inch (1.65 mm) or Round 25.0 mm x 1.75 mm or Round 25.4 mm x 1.60 mm or Square 1.00 inch x 1.00 inch x 0.049 inch or Square 25.0 mm x 25.0 mm x 1.25 mm metric or Square 26.0 mm x 26.0 mm x 1.2 mm metric
Front Bulkhead Support, Main Hoop Bracing Supports EV: Tractive System Components	Round 1.0 inch (25.4 mm) x 0.049 inch (1.25 mm) or Round 25.0 mm x 1.5 mm or Round 26.0 mm x 1.2 mm "

Fig 2 .2014 Formula SAE Rules for Member size. Adapted from 2014 Formula Student rules (SAE, 2013)

The FSAE rules also require a firewall barrier to isolate the batteries from the driver, it must cover the vertical and horizontal portions of the battery box that face the driver. 2.6mm aluminium sheet is suggested for this firewall but 1mm steel has been approved as an alternative by the FSAE-A rules committee. The chassis must also provide sufficient space for cockpit entry, where the driver enters the cockpit. FSAE rules require a template shown in Figure 4 be able to pass vertically through the cockpit opening until it reaches the height of the top bar in the side impact structure.

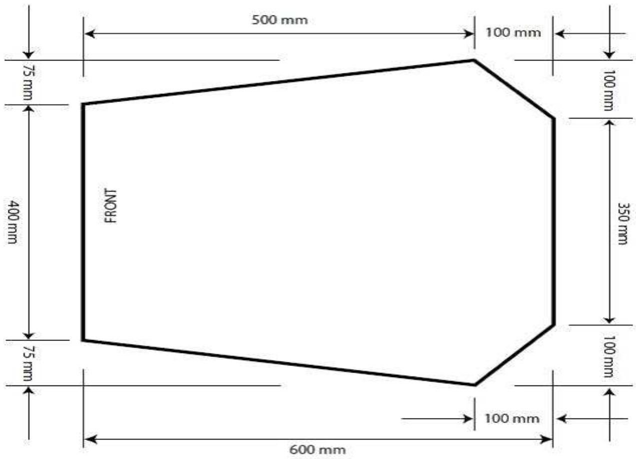

Fig 3: Cockpit entry template

A sufficiently large foot-well area must also be present in the chassis for the driver's legs and feet. The foot-well is the area where the accelerator and brake pedals are located and is where the driver's legs lie when driving. The foot-well area lies between the front suspension pivots so the design will have to work around this area carefully so that the suspension loads are adequately supported, to avoid damaging the chassis and potentially injuring the driver. Fig 4 shows the template that must be able to pass horizontally through the foot-well according to the FSAE rules.

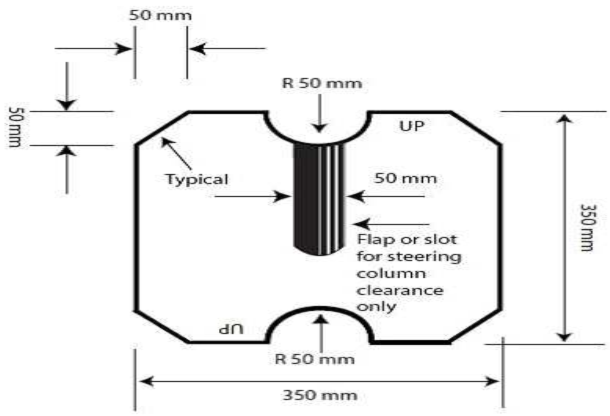

Fig 4: Foot-well clearance template

6. Wire Frame Model

A space frame is designed in several steps that are based on the design considerations. A methodical plan must be followed so that all parameters are considered and the design incorporates every part of the car correctly. The chassis wire frame model is designed by using CATIA V5R20 Generative Shape Design Tool.

Initial Setup – First, baseline dimensions like wheelbase, overall length, width, and height were selected. Stemming from these dimensions were roll hoop locations, bulkhead location, engine mounting location, and wheel centrelines. Once these dimensions were selected, a series of planes were created in CATIA V5 at these points so that these locations could be visualized.

Modelling of Fixed Elements – Fixed elements include roll hoops, front bulkhead, suspension points, and engine mounts. These features will not be moved around during chassis wire frame design iteration so that the number of variables able to be manipulated may be decreased. This allows for a quicker design period so that construction may begin sooner than usual.

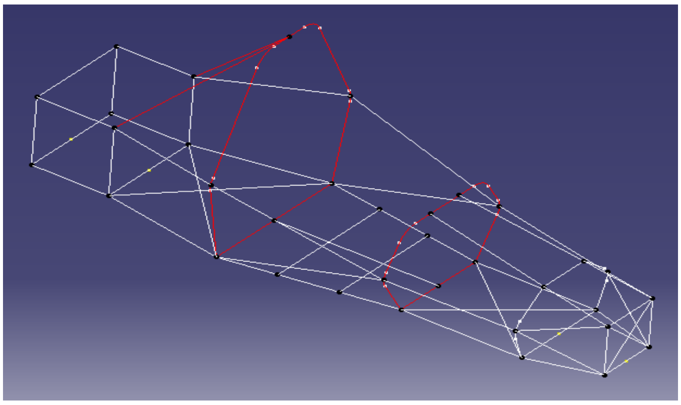

Fig 5: 3D Chassis frame

GENERAL SPECIFICATIONS		
Parameter	**Value**	**Units**
Wheel base	1700	mm
Track width	1120	mm
Ground clearance	160	mm

6.1. Mesh The Wire Frame Model

Altair Hyper Mesh is a high-performance finite element pre-processor that provides a highly interactive and visual environment to analyze product design performance. There are two methods of mesh refinement.

H-refinement- refers to the process of increasing the number of elements used to model a given domain, consequently, reducing individual element size.

p-refinement- element size is unchanged but the order of the polynomials used as interpolation functions is increased.

Steps to be followed to do 1-D mesh

- Import the Chassis wire frame model into the Hypermesh.
- Connect all the lines of the chassis frame.
- Create two components and move the lines into the components by using organise tool bar (because the chassis frame having two variable cross sections).
- create a 1D line mesh (Beam188,element size 10).
- Check the connectivity of the elements.
- Correct the free 1D elements.

- Export the meshed model to the Ansys.

6.2. Finite Element Analysis

The Finite Element Analysis (FEA) is a numerical method for solving problems of manufacturing and mathematical physics. Design geometry is a lot more difficult and the accuracy requirement is a lot higher. We require

– To understand the physical behaviours of a complex entity (strength, heat transfer capability, fluid flow, etc.)
– To predict the performance and behaviour of the design.
– To calculate the safety margin.
– To identify the limitation of the design perfectly.
– To identify the optimal design with confidence.

Steps to be followed to do static analysis

- Import the meshing model from hyper mesh to Ansys.
- The material properties of linear isotropic such as young's modulus= 2.05e5 N/mm^2 and poisons ratio= 0.285 have been defined
- Define cross sections shown in below figs.

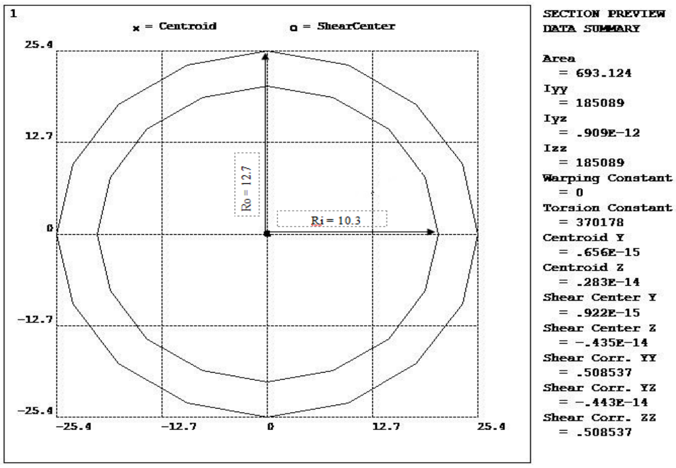

Fig 6: Main and front roll hoop cross sectional area of a chassis frame

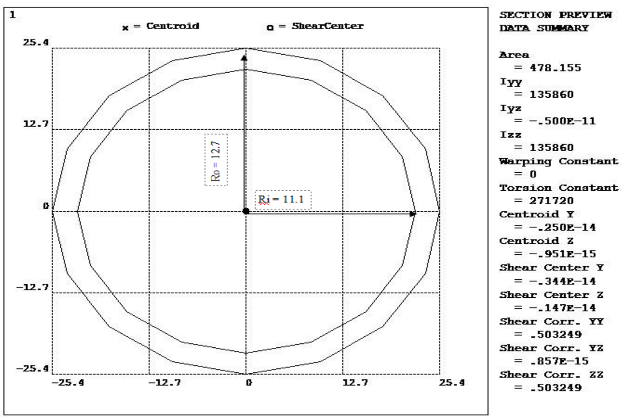

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Fig 7: Other sectional members cross sectional area of a chassis frame

- Apply boundary conditions.
- Select type of analysis.
- The problem is solved by using current LS command from the solution menu bar

a. Longitudinal torsion test

Let us consider frame acts like a cantilever beam and its one end is made fixed and other end is subjected to vertical downward force. In this case rear side is fixed and the force is applied at the bulkhead. The force applied is 1480N which is the sum of weight of impact attenuator, driver legs and steering weight.

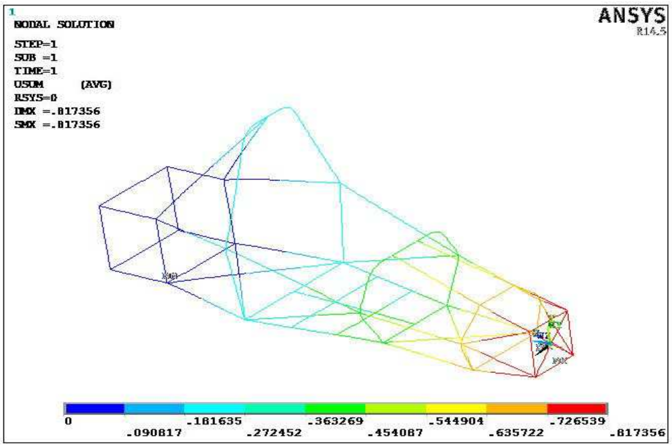

Fig 8: Deformation during longitudinal torsion (load applied at bulk head)

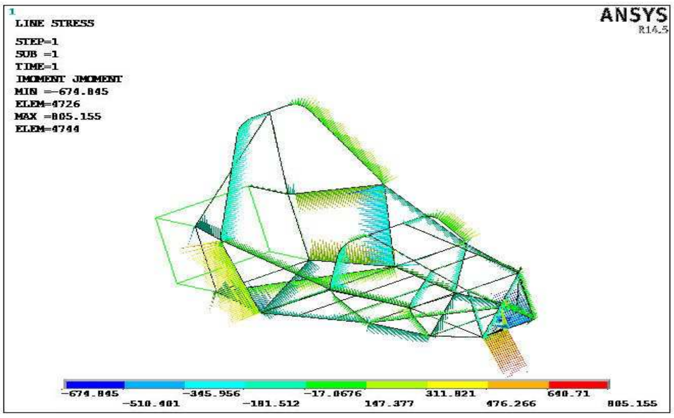

Fig 9: Bending moment during the longitudinal torsion (load applied at bulk head)

In the fig red colour shows the maximum deformed areas and corresponding values is shown in red colour in displacement tree in the bottom. The maximum displacement at the bulk head is 0.81mm and the maximum bending moment 805.15 N-mm and maximum stress occurred in the structure 295.8N/mm^2 .

b. vertical bending

In this case frame is assumed to be in both front and rear suspension is clamped and vertically downward force of 1580N were applied equally in driver cabin.

In the fig red colour shows the maximum deformation and bending moment areas and corresponding values is shown in red colour in stress tree in the left. The maximum deflection and bending moment occurred in the frame is 0.21575mm and 1520.19N-mm respectively. the maximum strain energy capability of chassis frame is 0.143Joules.

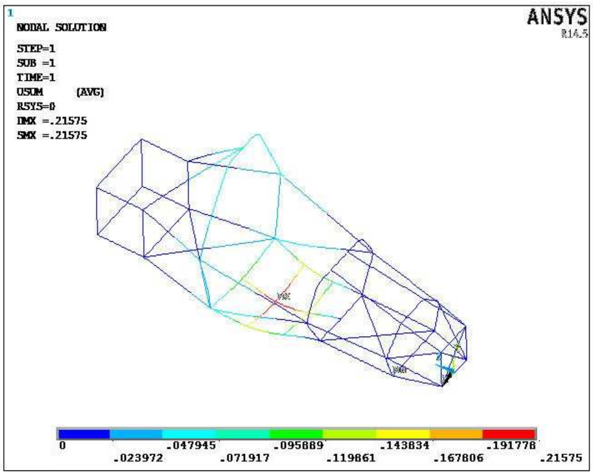

Fig 10: Deformation during vertical bending test (load applied at driver cabin)

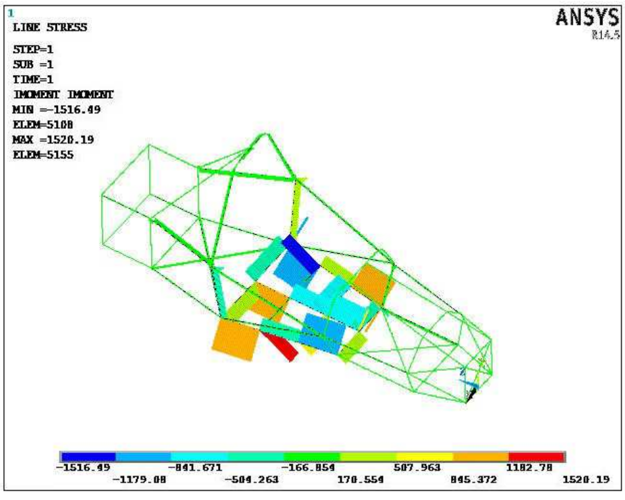

Fig 11: Bending moment during vertical bending test (load applied at driver cabin)

C. Lateral loading

Lateral bending loads are induced in the frame for various reasons, such as road camber, side wind loads and centrifugal forces caused by cornering. the sum of engine and driver mass is act like a lateral cornering force i.e.,2300N applied at side impact bracing of driver cabin.

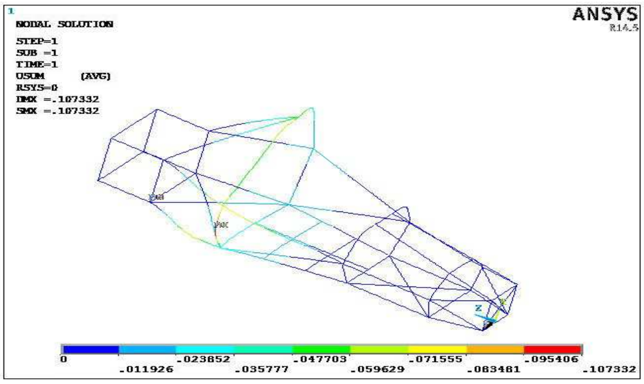

Fig 12: Deformation during lateral bending test

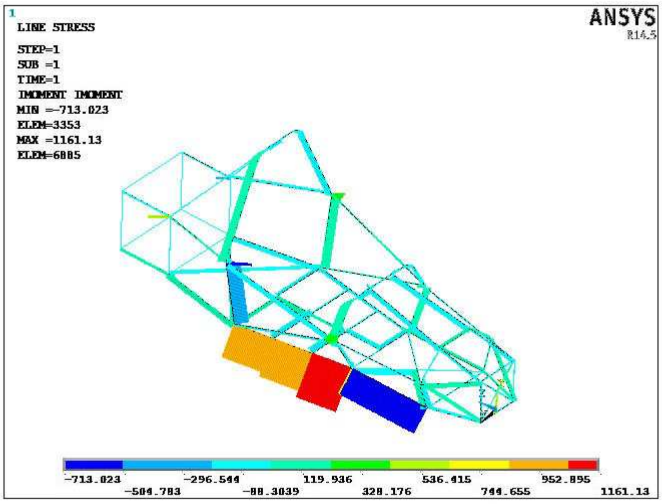

Fig 13: Bending moment during lateral bending test

The maximum deflection 0.107mm and the bending moment 1161 N-mm was observed. The maximum vonmises stress 222.7 N/mm^2 was observed which are in within the permissible limit.

d. Acceleration test

Accelerated testing is an approach for obtaining more information from a given test time than would normally be possible. Generally accelerated testing is in two categories one is acceleration life testing is used for to estimate the life and the other one is acceleration stress testing is used to identify the problem. Due to inertia effect, acceleration forces tend to act in the opposite direction to the motion of the body.

*acceleration of the vechical = force/mass of the vehicle * deltaTime.*

The acceleration force 1150N is applied to the structure in backward direction and the load 1550N was applied downward direction in the driver cabin. The maximum deformation 0.303mm and the bending moment 1692.2N-mm was observed. The resultant von mises stress occurred in the structure is 446.5N/mm^2

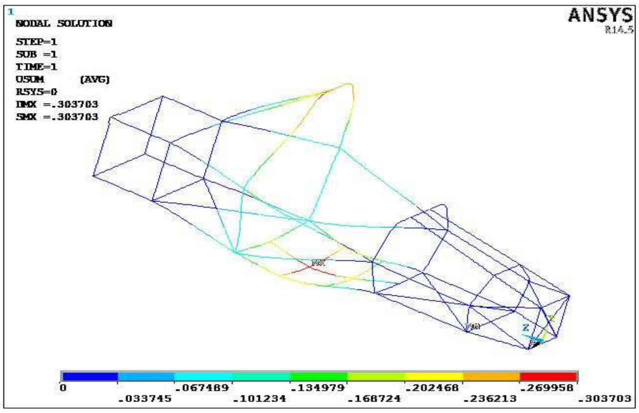

Fig 14: Deformation during Acceleration test (load applied in the driver cabin and apply to the structure in backward direction)

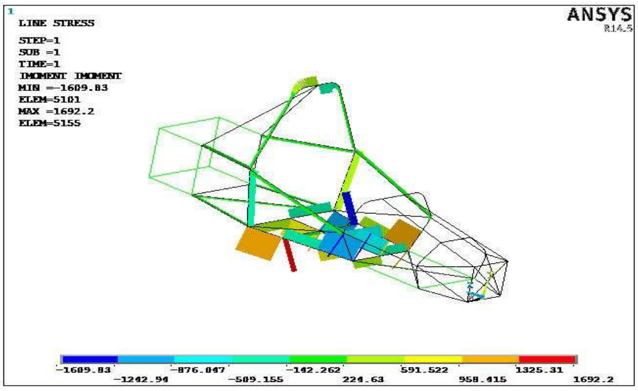

Fig 15: Bending moment during Acceleration test (load applied in the driver cabin and apply to the structure in backward direction)

7. CONCLUSION

S.No	Test	Deflection (mm)	Bending moment (N-mm)	Vonmises stress (N/mm^2)	FOS
1	Longitudinal torsion test	0.81	805.15	295.8	15.55
2	Vertical bending	0.215	1520	267.3	17.2
3	Lateral loading	0.107	1161	222.7	20.6
4	Acceleration test	0.303	1692.2	4465	10.3

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In this project I conclude that the chassis frame is with stands for four types of loading conditions and satisfying the FSAE rules and constrains. Thus I would conclude by observing the above results and analyzation that the chassis space frame structure depend on the stiffness and stresses in that particular frame. The stresses obtained above are the well deserved in order to manufacture a chassis space frame as the stresses are very much lower as compared to that of the yield point of the material.

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