CHAPTER 1.0
INTRODUCTION

1.1 Overview

The chassis of an automobile is defined as a frame supported on springs and attached to the axle that holds the body and engine of the vehicle. Chassis is a French word and was initially used to denote the frame parts or basic structure of an automobile. It is the backbone of the vehicle. It is the main mounting for all the components. So it is also called a Carrying Unit.

The chassis of an automobile consists of following components suitably mounted:

1. Engine and the radiator.
2. Transmission system.
3. Suspension system.
4. Wheel Assembly.
5. Steering System.
6. Brakes System.
7. Fuel Tank.
8. Other Miscellaneous Components.

All the components listed above are mounted in either of the two ways, viz., the conventional construction, in which a separate frame is used and the frameless or unitary construction in which no separate frame is employed. Out of these, the conventional type of construction is being used presently only for the heavy vehicles. While for the car the same has been replaced by the frameless type or the monocoque chassis.

1.2 Problem Statement

This project has been set up to design the Space frame Chassis for the FSAE Competition. In terms of performance and weight.

1.3 Objectives

- The objective of the frame design is to satisfy functions while meeting the Formula Student rules and regulations with special considerations taken for safety of the driver, built up quality, ergonomics along with aesthetics.
- The design should be compact and lightweight. The complexity of design and the arrangement results in creating waste space in the chassis.

1.4 Functions of the Chassis Frame

1. To carry loads of passengers or goods carried in the body.
2. To support the load of the body, engine, gearbox etc.
3. To withstand the forces caused due to the sudden braking or acceleration
4. To withstand the stresses caused due to the bad road condition & to withstand centrifugal force while cornering.

1.5 Layout of Chassis and Its Main Components

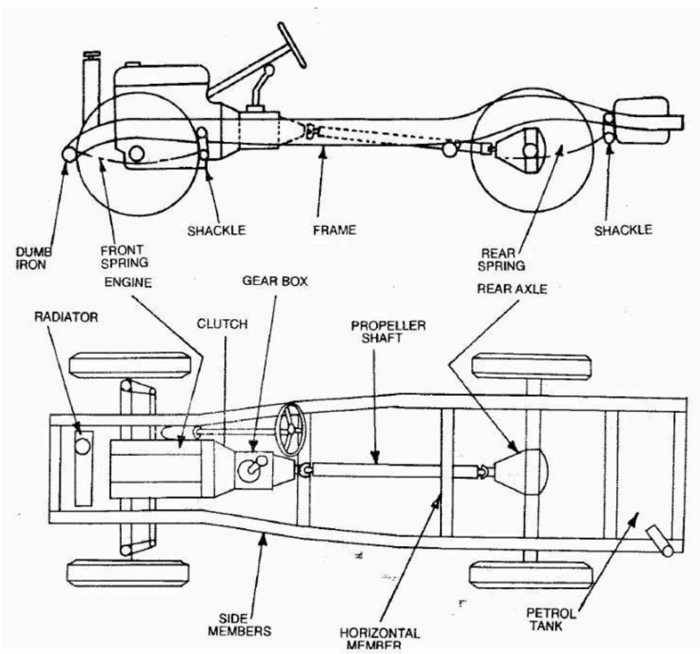

Fig 1.5.1 General Layout of Chassis

1.6 Types of Chassis Frames

There are three types of frame:

1. Conventional frame
2. Integral frame
3. Semi-integral frame

1. Conventional frame:

It has two long side members and 5 to 6 cross members joined together with the help of rivets and bolts. The frame sections are used generally.

a. Channel Section - Good resistance to bending

b. Tabular Section - Good resistance to Torsion

c. Box Section - Good resistance to both bending and Torsion

2. Integral Frame:

This frame is used nowadays in most cars. There is no frame and all the assembly units are attached to the body. All the functions of the frame are carried out by the body itself. Due to elimination of long frames it is cheaper and due to less weight most economical also. Only disadvantage is repairing and maintenance is difficult.

3. Semi - Integral Frame:

In some vehicles half frame is fixed in the front end on which engine gearbox and front suspension is mounted. It has the advantage that when the vehicle is met with an accident the front frame can be taken easily to replace the damaged chassis frame. This type of frame is used in FIAT cars and some of the European and American cars.

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CHAPTER 2.0
LITERATURE REVIEW

2.1 The Chassis

The chassis is possibly the most important part of any vehicle. Its main role is to provide the vehicle with a main structure which all other components can be fixed to. The chassis must be rigid in both torsion and bending and must be able to resist twisting and sagging. The chassis must be able to accommodate and support all the components of the vehicle and any occupants and must absorb all loads without excessive deflection.

The development of chassis having adequate torsional stiffness is a fairly recent one. The early sports car chassis was constructed on massive lines, and its design owed more to bridge-building than to light engineering. Even today the chassis of many production sports cars are stiff only in bending. The history of the development of the more advanced types of chassis is an interesting one. Prior to the Second World War almost all sports car chassis were of the girder type, generally with live axles at both front and rear. In 1934 Auto Union initiated a change to twin tube chassis on racing cars, with a layout of this type composed of round-section tubes. In the same year Mercedes-Benz used box-section members in a similar layout but, in 1937, they too went over to tubes-in this case of the oval section. At the same time they also "progressed" from independent rear suspension to a de Dion layout, of the type first used in the late nineteenth century.

The need for increased chassis stiffness was recognized by the addition of tubular superstructure to the basic twin tube layout, but this contributed more to ease of body mounting than to torsional capacity. Early attempts at chassis of the space frame type also appeared at this time, but lacked the triangulation necessary to form complete structures. Two chassis designed on general space frame principles appeared in 1952 in cars: the Lotus Mark Six and the Mercedes-Benz 300SL.

Unitary construction has also become fashionable for single-seaters since the introduction, in 1962, of the Lotus 25. The term "monocoque" is widely used to describe this type of structure, and means simply, that chassis and body are one and the same thing. The modern rear-engine racing car is admirably suited to monocoque construction. The general requirements of the area ahead of the driver's feet can also be met by this type of structure, but it is not well suited for use in the engine bay, the chief problems being lack of torsional stiffness, interference with the exhaust layout and accessibility the latter being far more important than some designers seem to think. As regards torsional stiffness, a great deal can be gained in this sphere by making the engine a structural member. However, this practice is not to be recommended unless the crankcase has been designed for this purpose-in addition to its major function of providing positive location for the crankshaft and cylinder head(s). Furthermore, a complex series of mountings at both front and rear is required to deal with both torsional and bending loads. Whereas only two fronts and one rear mountings are normally necessary when the engine is not used as a structure. The practice of using the power unit as a structural member was taken to its logical extremes on the first monocoque built by Ferrari in which the engine (aided by a fabricated bulkhead bolted to it in the vicinity of the rear suspension) being the only structural component behind the seat back bulkhead. However, the 1964 Ferrari has vestigial "wheelbarrow arms" beneath the engine, which presumably take some of the bending loads and help to locate the rear bulkhead. With a wide engine, the only satisfactory alternative to the use of rigid mountings may well be the use of a tubular structure for the engine bay. It may be necessary to make some members detachable, to facilitate installation and removal of the engine, but it is possible to do this without any loss of torsional capacity.

An alternative to the monocoque chassis for a two-seater vehicle is the backbone chassis, as used for the Lotus Élan (front-engine) and the Lotus 30 (rear engine). Also this type of chassis requires separate bodywork. The space frame chassis is, of course, a direct alternative to unitary construction, its small diameter tubes transmitting loads in much the same way as the under frame and body panels of such a structure. The tubular space frame, although involving little in the way of tooling costs, is relatively expensive to manufacture, requiring a great deal of skilled welding. The only comparable alternative, unitary construction involves very considerable tooling costs and is less satisfactory for open cars than saloons owing to lack of bracing in the cockpit area. But it has the great advantage over all other designs that separate bodywork is not required. By comparison, the conventional chassis is much simpler to make and involves far fewer snags in the fitting and servicing of mechanical components.

2.2 Types of chassis design

1. Ladder Frame Chassis

The ladder frame chassis was the earliest type of chassis used. It was widely used for the earliest cars until the early 60s. The design is, as the name suggests, similar to a ladder. There are two longitudinal rails running the length of the vehicle which are connected together by several lateral and cross braces.

The longitudinal members act as the main stress members in this type of chassis and deal with the load as well as the longitudinal forces caused by accelerating or braking. Torsional rigidity is further increased by the lateral and cross braces which also deal with any lateral forces.

The ladder frame type chassis is not used for the majority of modern cars as it has low torsional rigidity especially when encountering asymmetric loads; however it is still used for some pick-up trucks and SUVs.

Fig 2.2.1 Ladder frame Chassis

2. Space Frame Chassis

The space frame was the next logical step up from the ladder frame. A space frame has a number of features that distinguish it from a ladder frame and add massive advantages. A perfectly designed space frame would have the tubular sections arranged so that the only forces on them are either tension or compression. This is a massive advantage as materials have much better resistance to tensile and compressive loads than they do to bending loads. Many high end sports cars have been designed with a space frame due to the major advantages it gives in weight reduction while maintaining its rigidity. Space frames have some disadvantages

however, they can be enormously time consuming and costly to build, due to the fact they can be very complex. Also, production cannot currently be done using robotic arms- due to the complexity of the structure and so large scale production is impossible.

Fig 2.2.3 Space frame Chassis

3. Monocoque Chassis

The Monocoque style of chassis is used by almost all car manufacturers today. A Monocoque is a one-piece structure that defines the overall shape of the vehicle. This type of chassis is very attractive to mass production as the process can be automated very easily. The structure also has very good crash protection as crumple zones can be built into the structure itself. A Monocoque chassis has a few disadvantages however that make it unsuitable for use by the Warwick Formula Student team. The main one of these is that a Monocoque chassis is much heavier than other types of chassis due to the amount of metal used. It is also very expensive to produce on a small scale as the tooling costs to produce the chassis are very high. Image shows an example of an early Monocoque from Chrysler and how the safety aspect was used to market the cars. Image shows a modern example of a Monocoque built by Jaguar.

Fig 2.2.3 Monocoque chassis

4. Backbone Chassis

A backbone chassis is a simple style of frame that uses a central backbone running the length of the chassis that connects to the front and rear suspension attachment areas. The backbone usually has a rectangular cross section. The body of the vehicle is then placed onto the structure. This type of chassis is used sometimes for small sports cars however it provides little or no protection against a side impact and so requires the body to be designed to accommodate this. This can often lead to heavy reinforcing beams being needed in the body frame adding extra weight to the vehicle. One of the most well-known uses of the backbone chassis was for the DeLorean DMC-12.

Fig 2.2.4 Backbone Chassis

CHAPTER 3.0

DESIGN CONSIDERATIONS

3.1 Why we choose space frame chassis

In all frames till now length in one dimension is very less compared to the other two dimensions so

- Increasing depth increases bending strength
- Used in race cars
- All planes are fully triangulated
- Beam elements carry either tension or compressive loads
- Ring frame depends upon bending of elements
- Stiffness is provided by diagonal element

3.2 Various Loads Acting On Chassis

1. Weight of the vehicle and passengers, which causes vertical bending of the side members.

2. Vertical loads when the vehicle comes across a bump or hollow, which results in longitudinal torsion due to the wheel lifted (or lowered) with other wheels at the usual road level.

3. Loads due to road camber, side wind, cornering force while taking a turn, which result in lateral bending of side members.

4. Load due to wheel impact with the road obstacles may cause that particular wheel to remain obstructed while the other wheel tends to move forward, distorting the frame to parallelogram shape.

5. Engine torque and braking torque tend to bend the side members in the vertical plane.

6. Sudden impact loads during collision, which may result in a general collapse.

3.3 Estimated Load of the Vehicle

The various loads which are acting on the vehicle are estimated according to the center of gravity of the vehicle. As the various loads acting on the vehicle are distributed are shown in the below table.

Sr.No.	Components	Mass (Kg)
1.	Driver	70
2.	Engine & Radiator	45
3.	Drive train	25
4.	Chassis	40
5.	Steering & Suspension	25
6.	Body work	25

By consideration of miscellaneous masses such as the wishbones (front & rear), wheels, fuel tank etc. The weight of the car is considered to be approximately 250 kg.

3.4 Vehicle loading

The first step to designing a vehicle frame, or any structure, is to understand the different loads acting on the structure. The main deformation modes for an automotive chassis are given as:

1. Vertical Bending
2. Longitudinal Torsion
3. Lateral Bending
4. Horizontal Lozenging

1. Vertical Bending

The weight of the driver and components mounted to the frame, such as the engine and other parts, are carried in bending through the car frame. The reactions are taken up at the axles. Vehicle acceleration can raise or lower the magnitude of these forces.

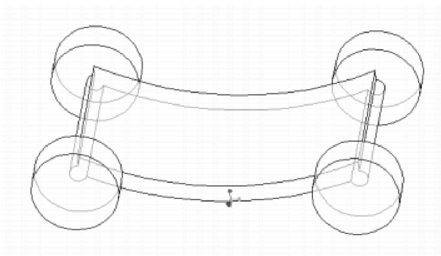


Fig 3.4.1 Vertical Bending Deformation Mode

2. Longitudinal Torsion

Torsion loads result from applied loads acting on one or two opposite corners of the car. The frame can be thought of as a torsion spring connecting the two ends where the suspension loads act. Torsional loading and the accompanying deformation of the frame and suspension parts can affect the handling and performance of the car. The resistance to torsional deformation is often quoted as stiffness in foot-pounds per degree.

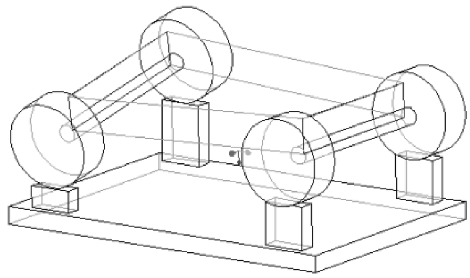


Fig. 3.4.2 Longitudinal Torsion Deformation Mode

3. 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 at the tires. This causes a lateral load and resultant bending.

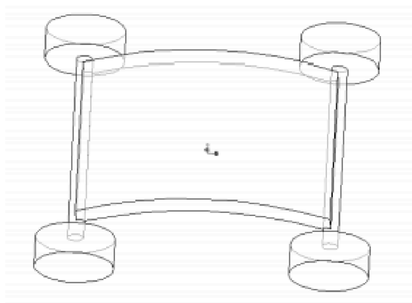


Fig. 3.4.3 Lateral Bending Deformation Mode

4. Horizontal Lozenging:

Forward and backward forces applied at opposite wheels cause this deformation. These forces may be caused by vertical variations in the pavement or the reaction from the road driving the car forward. These forces tend to distort the frame into a parallelogram shape as shown in the figure.

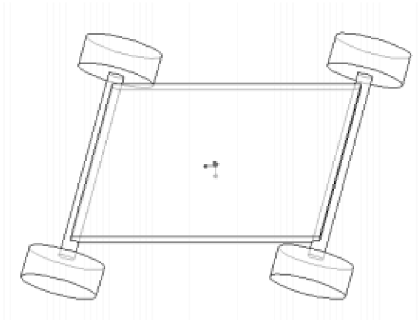


Fig. 3.4.4 Horizontal Lozenging Deformation Mode

It is generally thought that if torsional and vertical bending stiffness are satisfactory then the structure will generally be satisfactory. Torsional stiffness is generally the most important as the total cornering traction is a function of lateral weight transfer.

3.5 Other Design Consideration

There are several factors that must be considered when designing the frame.

1) **Safety**

Fortunately, the FSAE rules committee has set up a group of rules requiring certain tubing sizes in areas of the frame critical to driver safety in the event of an accident. These rules define outer diameters and wall thicknesses for the front bulkhead, front roll hoop, main roll hoop, side impact tubing, roll hoop bracing, and front impact zones. The stated rules are adhered to without deviation so that the driver may be safe and the car can pass technical inspection at competition.

2) **Stiffness**

Normally, a race car chassis should be as stiff as possible to withstand torsion. This is to facilitate easier suspension tuning. When determining the handling qualities of a race car, one of the most effective methods of adjusting the amount of oversteer and under-steer is the adjustment of roll stiffness, front-to-rear. By increasing front roll stiffness while decreasing rear roll stiffness, both rear tyres are more equally weighted than the front tyres. The force on the outside front tyre quickly overwhelms the traction available to it, and the car under-steers. Conversely, with a large amount of rear roll stiffness and a small amount of front roll stiffness, the inside rear tyre is lifted during a turn, the amount of available rear traction is reduced, and the car oversteers. By tuning the stiffness of the anti-roll bars, it is possible to affect the balance of the car.

3) **Torsional Stiffness**

Torsional order to design a car of maximum torsional stiffness the basis or generalized equation for torsion must be examined.
Stiffness is the resistance of the frame to torsional loads. FEA was used to analyze the torsional stiffness of the chassis.

$$T = \frac{G\theta J}{L}$$

The above equation is a simple formula that relates the angle of twist to the applied torque, with J representing the shafts polar moment of inertia, with θ denoting the resultant twist of the shaft, G representing the shear modulus of the material and L being the length of the shaft. Now a chassis can be made extremely stiff by adding significant amounts of material to the frame. However, this additional material might degrade the performance of the car because of the added mass. Therefore while designing a race car chassis it is important to get a balance between the weight and stiffness of the chassis.

4) **Weight**

As discussed earlier, wherever possible, weight should be minimized. All tubing sizes not dictated by the rules were chosen to be as light as possible while remaining structurally sound and suitably stiff. Just as important as weight, is mass moment of inertia. A car with a lower mass moment of inertia will be able to turn more quickly. In order to reduce mass moment of inertia, all weight on the chassis is pushed as far as possible towards the centre of the vehicle.

5) **Triangulation**

Triangulation can be used to increase the torsional stiffness of a frame, since a triangle is the simplest form which is always a structure and not a mechanism. Obviously, a frame which is a structure will be torsionally stiffer than a mechanism. Therefore, an effort should be made to triangulate the chassis as much as possible. Visualizing the frame as a collection of rods which are connected by pin joints can help frame designers locate the mechanisms in a design.

6) Ergonomics

Ergonomics, or the study of human-machine interfacing, is important to vehicle design because the ultimate control of the vehicle belongs to the driver. When designing this 'interface' between person and machine, several aspects should be taken into account so that the best system of control is produced.

7) Seating Position/Field of View

A key input to the interface is the driver's vision and that of any co-driver (i.e. Rally). The field of view, as shown in diagram below, should include visibility ahead and to the sides of the vehicle (Approximately 180 degree arc–more is even better) and visibility of the road surface.

The driver needs a sufficient level of information about the nature of the oncoming road surface and what is occurring beside them through peripheral vision to drive confidently. If the driver must strain their neck to see enough to feel confident, their field of view is inadequate.

8) The design goals of the seating position are:

- To enable the driver (and co-driver) to see clearly ahead and beside themselves through standard and peripheral vision.
- To provide a position of comfortable leverage for the driver so they do not become tired due to operating the controls from an awkward position.
- To enable the driver to adequately see the side mirrors in their peripheral vision (At a minimum) so that the driver need not continuously take their eyes off the road ahead to gauge an opponent's position behind them. Ideally the side mirrors should be far enough forward to enable direct viewing by a driver glancing at them.

- To enable easy visual access to gauges and other visual feedback in the forward looking line of sight.
- To minimize CG height to optimize handling

9) Control Positions

Vehicle controls should be within a comfortable reach of the driver (and co-driver if applicable) and be comfortable to operate. Controls that are awkward to reach or difficult to operate will distract the driver/co-driver and potentially result in more driving mistakes.

CHAPTER 4.0

3D MODELING OF CHASSIS

4.1 Design Process

The design process of any road worthy vehicle begins with the tires; the tires are the only point of contact between the vehicle and the road. Each tire has a different compound and different material properties. The task for the engineer is to find the tire's optimal range of operation considering slip angle, inclination angle, loading, road conditions, tire pressure, as well as several other factors. Once this range is clearly depicted, the suspension hard points are determined to make sure the tire operates within the specified range. The hard points are directly correlated to the basic suspension parameters such as wheelbase and track width. Track to wheelbase ratio should be typically a 1.2 - 1.5 ratio; for rapid steering response an optimal ratio of 1.3 should be targeted. The tire data also includes the slip angle of the tire, pneumatic trail of the tire and optimal camber of the tire. With all these factors studied and set, the suspension geometry can now start taking place. A-arms connect the wheel uprights to the chassis. Once the suspension geometry is designed for specific vehicle goals, the A-arm pickup points are given coordinates. Now the frame design begins. Typically, one would want to optimize for the lowest and most central center of gravity for your vehicle. To do so, major components of the vehicle, like the driver and engine, are mapped out. With the suspension pickup points and driver and engine sitting in free space, all components are connected while adhering to that season's FSAE rules. Once the first iteration of the frame is complete, FEA analysis can be run and frame members can commence alteration to optimize weight and rigidity

4.2 Rulebook Compliance

- General Requirements

Among other requirements, the vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system and Impact Attenuator, and side impact structures.

- Wheelbase

  The car must have a wheelbase of at least 1525 mm (60 inches). The wheelbase is measured from the center of ground contact of the front and rear tires with the wheels pointed straight ahead.

- Vehicle Track

  The smaller track of the vehicle (front or rear) must be no less than 75% of the larger track.

- Visible Access

  All items on the Inspection Form must be clearly visible to the technical inspectors without using instruments such as endoscopes or mirrors.

- Node-to-Node triangulation

  An arrangement of frame members projected onto a plane, where a co-planar load applied in any direction, at any node, results in only tensile or compressive forces in the frame members. This is also what is meant by "properly triangulated".

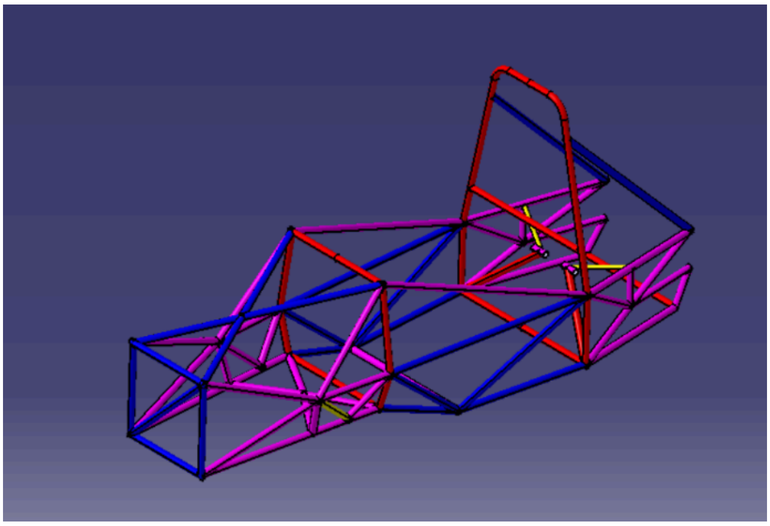


Fig. 4.2.1 Node-to-node triangulation

- When seated normally and restrained by the Driver's Restraint System, the helmet of a 95th percentile male (anthropometric data) and all of the team's drivers must:

a. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the top of the front hoop.

b. Be a minimum of 50.8 mm (2 inches) from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing if the bracing extends rearwards.

- In the side view of the vehicle, the portion of the Main Roll Hoop that lies above its attachment point to the Major Structure of the Frame must be within ten degrees (10°) of the vertical.

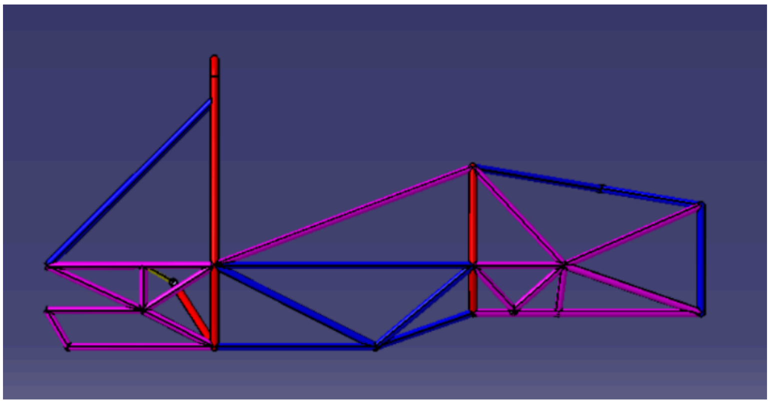


Fig. 4.2.2 Satisfying rule

- In the front view of the vehicle, the vertical members of the Main Hoop must be at least 380 mm (15 inch) apart (inside dimension) at the location where the Main Hoop is attached to the Major Structure of the Frame.
- In the side view, no part of the Front Hoop can be inclined at more than twenty degrees (20°) from the vertical.
- The Main Hoop must be supported by two braces extending in the forward or rearward direction on both the left and right sides of the Main Hoop.

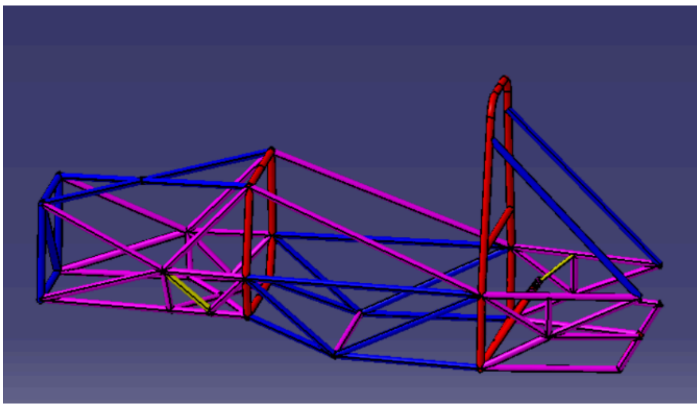


Fig. 4.2.3 Bracing rule

- In the side view of the Frame, the Main Hoop and the Main Hoop braces must not lie on the same side of the vertical line through the top of the Main Hoop, i.e. if the Main Hoop leans forward, the braces must be forward of the Main Hoop, and if the Main Hoop leans rearward, the braces must be rearward of the Main Hoop.
- The Main Hoop braces must be attached as near as possible to the top of the Main Hoop but not more than 160 mm (6.3 in) below the top-most surface of the Main Hoop. The included angle formed by the Main Hoop and the Main Hoop braces must be at least thirty degrees (30°).
- The top-most surface of the Front Hoop must be no lower than the top of the steering wheel in any angular position.
- The Front Hoop must be no more than 250 mms (9.8 inches) forward of the steering wheel. This distance shall be measured horizontally, on the vehicle centerline, from the rear surface of the Front Hoop to the forward most surface of the steering wheel rim with the steering in the straight-ahead position.
- The attachment of the Main Hoop braces must be capable of transmitting all loads from the Main Hoop into the Major Structure of the Frame without failing. From the lower end of the braces there must be a properly triangulated structure back to the lowest part of the Main Hoop and the node at which the upper side impact tube meets the Main Hoop. Structure must meet the minimum requirements for Main Hoop Bracing Supports or an SES approved alternative.
- The Front Hoop must be supported by two braces extending in the forward direction on both the left and right sides of the Front Hoop.

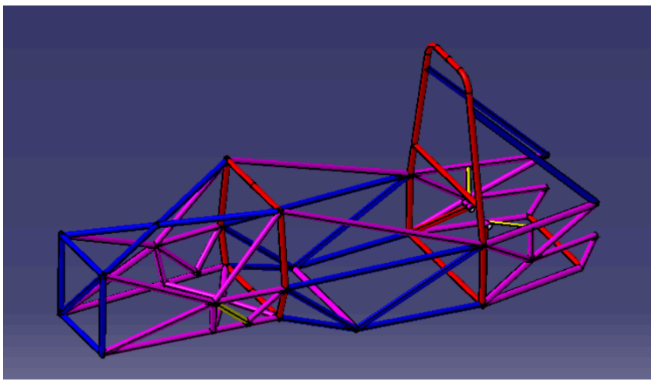


Fig. 4.2.4 Satisfying rule

- The Front Hoop braces must be constructed such that they protect the driver's legs and should extend to the structure in front of the driver's feet.
- The Front Hoop braces must be attached as near as possible to the top of the Front Hoop but not more than 50.8 mm (2 in) below the top-most surface of the Front Hoop.

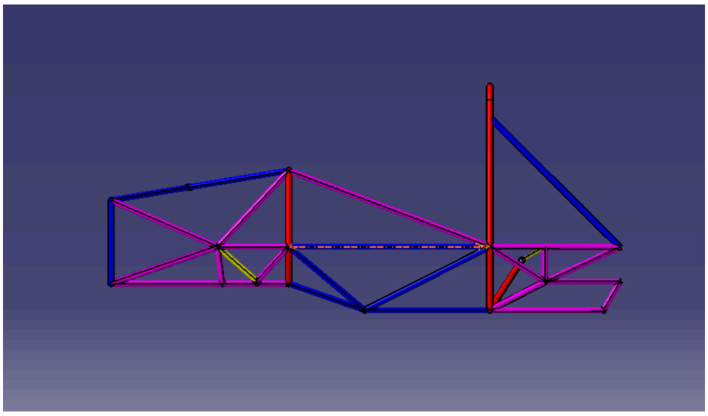


Fig. 4.2.5 Satisfying T3.14.4 rule

- The driver's feet and legs must be completely contained within the Major Structure of the Frame. While the driver's feet are touching the pedals, inside and front views no part of the driver's feet or legs can extend above or outside of the Major Structure of the Frame.
- The Front Bulkhead must be constructed of closed section tubing.
- The Front Bulkhead must be supported back to the Front Roll Hoop by a minimum of three (3) Frame Members on each side of the vehicle with one at the top (within 50.8 mm from its top-most surface), one (1) at the bottom, and one (1) as a diagonal brace to provide triangulation.

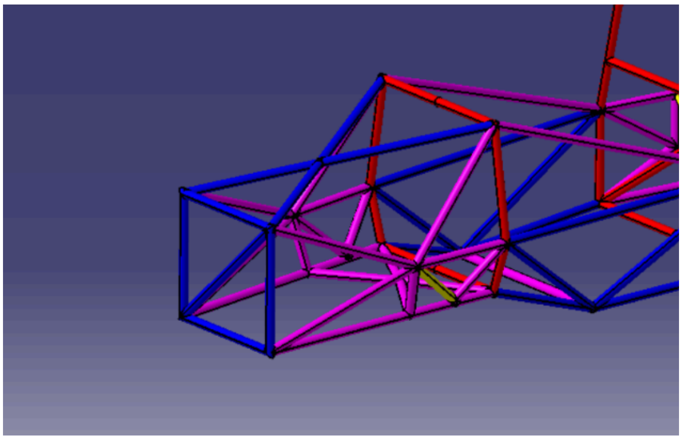


Fig. 4.2.6 Satisfying T3.20.2 rule

- **Cockpit Opening**

In order to ensure that the opening giving access to the cockpit is of adequate size, a template shown in Figure 8 will be inserted into the cockpit opening. It will be held horizontally and inserted vertically until it has passed below the top bar of the Side Impact Structure.

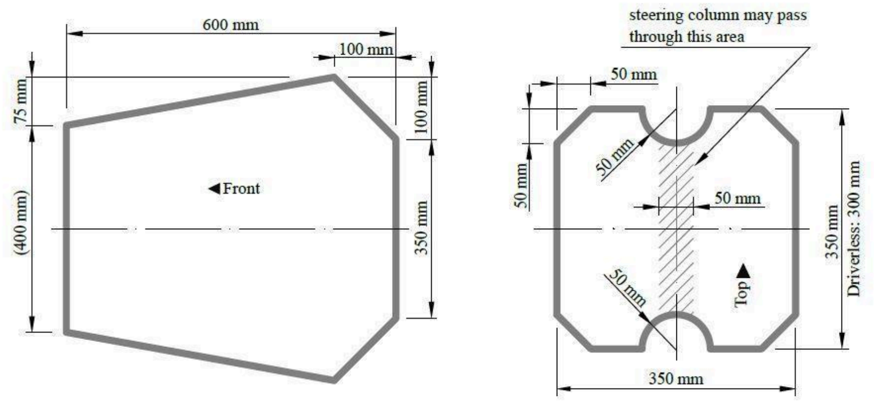


Fig. 4.2.7 Cockpit opening and Cockpit Internal Cross Section template

- **Cockpit Internal Cross Section**

A free vertical cross section, which allows the template shown in Figure 9 to be passed horizontally through the cockpit to a point 100 mm rearwards of the face of the rearmost pedal when in the inoperative position, must be maintained over its entire length. If the pedals are adjustable, they will be put in their most forward position.

- **Side Impact Structure for Tube Frame Cars**

The Side Impact Structure for tube frame cars must comprise at least three tubular members located on each side of the driver while seated in the normal driving position.

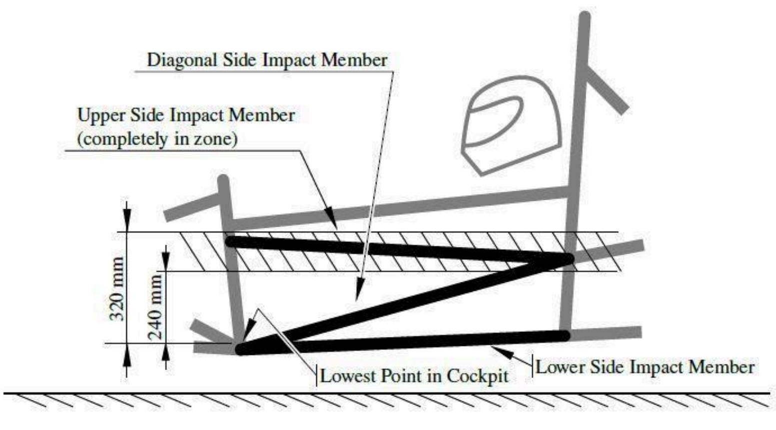


Fig. 4.2.8 Cockpit Internal Cross Section

4.3 Benchmarking and CAD modeling

1. **Basic layout of the chassis**

   This step includes fixing main components of the vehicle. The vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system and Impact Attenuator, and side impact structures.

2. **Measurements and fixing fundamental parameters**

   This step decides the approximate dimensions of the two roll hoops i.e. Front hoop, Main hoop that is braced, a front bulkhead with support system and side impact structure.

3. **Selection of frame**

   The selected frame may be of Channel section, Tubular section or Box section. The Channel Section is good in resistance to bending, while the Tubular Section is good in resistance to Torsion. The Box Section is good in resisting both bending and Torsion.

4. **Drawing of wireframe on CAD software**

   Wireframing is one of the methods used in geometric modeling systems. A wireframe model represents the shape of a solid object with its characteristic lines and points.

5. **Checking whether it is satisfying design goals**

   This step is to cross verify the design with the Formula Student Rulebook. And to check whether the design is satisfying the design goal.

6. **Final 3D model on software.**

   After completing the final structure of the Chassis the 3D model is drawn on the CAD software such as Catia V5, SolidWorks and Siemens NX etc.

6.4 Initial Setup

A tubular space frame is designed in several steps that are based on the design considerations previously stated. A methodical plan must be followed so that all parameters are considered and the design incorporates every part of the car correctly. We designed the FSAE race car Chassis in Catia V5, to model tubes easily and accurately.

The design was initiated by determining the height, track width, wheel base, and overall length dimensions of the vehicle. Stemming from these dimensions were roll hoop locations, bulkhead location, cockpit location, engine mounting location, and wheel centerlines for an estimation of weight distribution. Once these dimensions were selected, a series of planes were created in Catia V5 at these points so that these locations could be visualized. Some thought was given to the placement of other important or hard-to-package systems. For example, the fuel system had to be packaged near the center of gravity to reduce the effects of its varying mass during the race.

6.5 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 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. The roll hoop and bulkhead shapes are decided upon to minimize the length of tubing for the elements. Since the roll hoops and bulkhead are required to be at least 1” OD .095” wall and 1” OD .065” wall, respectively, the lengths of this heavy tubing need to be minimized to reduce weight. Once shapes of the features are decided upon, they are drawn on their respective planes. A structural member feature is added to the sketch and the first tubes of the model are drawn.

The suspension mounting points are the next to be designed. These are drawn as fixed points in space in the Solid works model. During suspension design, an optimal a-arm span was determined and this dimension must now be integrated into the chassis. Suspension mounts need to be welded to the chassis so the position of this mounts are needed to be acquired from the suspension calculation. Engine mounting locations are also decided upon and fixed so that the engine design team can accurately place their individual part models in the car assembly without having to change their parts. This keeps the team from making drastic changes when farther along in the design process.

6.6 Modelling of Variable Elements

The next step is to model the tubes that connect the fixed elements to each other. Arrangements of these tubes are variable and careful consideration of weight, manufacturability, and chassis stiffness must be taken, so that the chassis does not become heavy and too flexible.

The competition rules must also be taken into account when drawing these connecting tubes. Since the weight of the chassis is critical to car performance, connecting tubes must be kept short and thin. All the connecting tubes must be of the dimensions specified in the rule book i.e., 1” .049” wall. The only connecting tubes that may not be of this size are the required roll hoop bracing tubes which must be 1” .065” wall. These bracing tubes are kept to a minimum length.

The chassis design had a lot of structural members which in-fact increased the weight of the chassis. The main intention of increasing the number of structural members was to increase torsional stiffness. By Finite Element Analysis the members which weren’t of any use were removed and hence it reduced the weight without affecting the torsional stiffness.

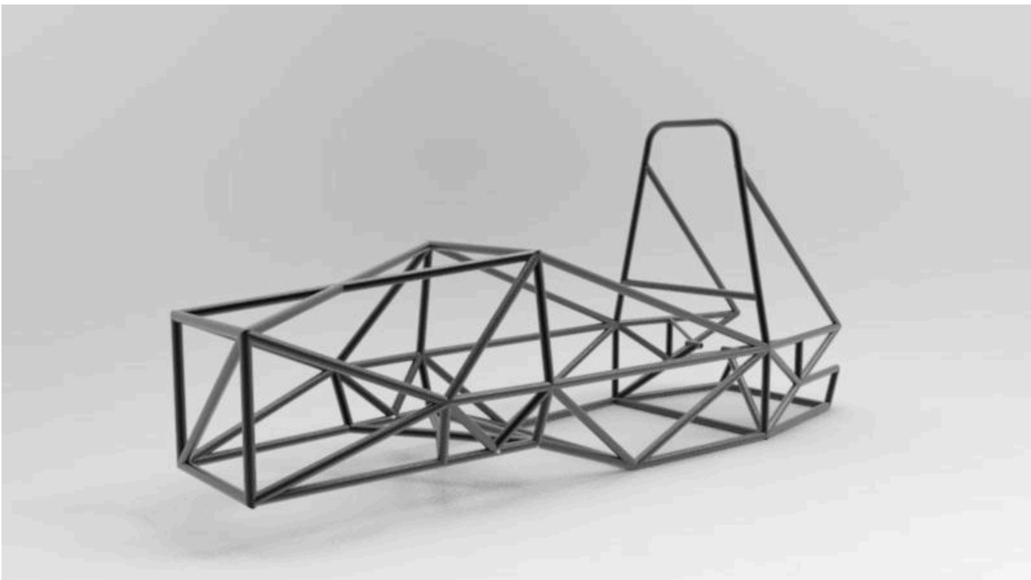


Fig. 6.6.1 CAD Model of Chassis

CHAPTER 5.0

MATERIAL SELECTION

- After load approximation, the next step was the selection of material to construct a chassis.
- The Primary Structure of the car must be constructed of either Round, mild or alloy, steel tubing (minimum 0.1% carbon) of the minimum dimensions specified in the following table,

ITEM or APPLICATION	OUTSIDE DIMENSION X WALL THICKNESS
Main & Front Hoops,	Round 1.0 inch (25.4 mm) x 0.095 inch (2.4 mm)
Side Impact Structure, Front Bulkhead, Roll Hoop Bracing,	Round 1.0 inch (25.4 mm) x 0.065 inch (1.65 mm)
Front Bulkhead Support, Main Hoop Bracing Supports,	Round 1.0 inch (25.4 mm) x 0.047 inch (1.20mm)

Table no. 5.1

- Minimum requirement of strength for non-welded continuous material:
  - Young’s Modulus (E) = 200 GPa
  - Yield Strength (Sy) = 305 MPa
  - Ultimate Strength (Su) = 365 MPa
- Minimum requirement of strength for welded material such as joint:
  - Yield Strength (Sy) = 180 MPa
  - Ultimate Strength (Su) = 300 MPa
- Availability is one of the main factors which dominate the material selection process. Working on this single list of different desirable and available material was prepared. Steel and aluminum alloys are always the choice most of the time. After reviewing mechanical properties, availability, cost and other significant factors, Steel AISI 4130 was selected.

- AISI or SAE 4130 grade is a low-alloy steel containing chromium and molybdenum as strengthening agents. The steel has good strength and toughness, weldability and machinability.
- AISI/SAE 4130 grade is a versatile alloy with good atmospheric corrosion resistance and reasonable strength up to around 600º F (315º C). It shows good overall combinations of strength, toughness and fatigue strength.
- The following datasheet provides comparison of available material.

PROPERTIES	**AISI 1010**	**AISI 1018**	**AISI 4130**	**AISI 4140**
Tensile Strength (MPa)	365	440	560	655
Yield Strength (MPa)	305	370	460	415
Elastic Modulus (GPa)	190-210	210	190-210	190-210
Poisson's Ratio	0.27-0.30	0.29	0.27-0.30	0.27-0.30
Brinell Hardness	105	126	217	197
Density (g/cm^3)	7.87	7.87	7.85	7.85
Elongation (%)	20	15	22	26

Table no. 5.2

When selecting materials for motorsport applications the most common factors considered are cost and weight and other parameters as optimum design point of view are stiffness, torsional rigidity and vibration frequency. In order to design a competitive vehicle it must be light and yet strong. Some of the common material candidates include but are not limited to cold-rolled steel, aluminum, and 4130 chrome-alloy steel. The three materials mentioned will be the main considerations for the project.

The chassis will be constructed using normalized 4130 alloy steel, which is often referred to as "chrome alloy". This material is stronger and more ductile than its lower costing alternative of cold rolled steel. It also exhibits better welding properties leading to simpler manufacturing of the chassis.

The following datasheet provides more detail about AISI 4130 carbon steel.

Properties of AISI 4130

Properties	Metric
Ultimate Tensile Strength	560 MPa
Yield Strength	460 MPa
Modulus of elasticity	190 to 210GPa
Bulk modulus(typical for steel)	140 GPa
Shear modulus(typical for steel)	80 GPa
Poisson's ratio	027 to .30
Elongation at break(in 50 mm)	21.50%
Reduction of area	59.6
Hardness, Brinell	217
Density	7.85g/cm^3
Melting Point	1432^{0}C
Thermal conductivity(typical for steel)	49.8W/mK

Table no. 5.3

CHAPTER 6.0
ANALYSIS

After 3D modeling of the Chassis, different mountings for various components were finalized. As the boundary conditions will be applied to these points to analyze the deflections in the chassis. After the selection of the material for the designed frame, it is necessary to check the performance of the frame under various impact conditions. Then the model can be imported into CAE Software such as ANSYS, Hyper Works, Adams Car etc. and different boundary conditions were applied to test its durability during testing of the car. The designed frame must withstand all the impact as well as torsional conditions while providing safety to the driver and while having very less deformation of the members.

Analysis considerations

- Impact time is considered as 0.40 seconds
- Mass of vehicle is assumed to be 250 Kg.
- Forces coming from the suspension were applied
- Drivers weight was applied
- Engine weight was applied
- Forces coming from the differential were applied
- Engine was modeled in the form of rods of high stiffness because the engine also takes the loads and resists deformation of the chassis.
- Forces were applied at seat mounting points, Safety harness mounting points, engine mounting points and differential mounting points.

For 2D meshing:

Element size = the maximum element size for 2d meshing is taken from the considerations that

- Use of convergent theorems.
- There should be at least 2 elements in the smallest part of the surface.
- There should be at least 14 elements along the diameter of the roll cage tube.

E.g. Element size= 4mm for roll cage.

For 3D meshing:

- Element size for quad=4mm, tetras=2

The roll cage is a tabular design, which consists of a rectangular and circular cross section being attached to a roll cage.

6.1 Impact Test on Roll cage:

To validate that the design of the chassis is indeed stronger than the previous year's model, various tests were simulated to show the stress distribution and yield safety factor of each of the two frames. They are mainly categorized into

1) Static tests
2) Rollover test
3) Torsional test
4) Chassis to chassis impact test

Static Impact Test on Roll cage:

Static tests are carried out considering vehicles in static condition. There mainly three static tests which are carried out are;

1) Front impact test
2) Side impact test

3) Rear impact test

Last year Chassis

For analysis of impact test on roll cage, we consider some values accordingly

Mass of vehicle = 270 kg

Maximum velocity = 80km/hr.

Impact time = 0.4(according to industrial value reference for impact test)

This year Chassis

For analysis of impact test on roll cage, we consider some values accordingly

Mass of vehicle = 50 kg

Maximum velocity = 90km/hr.

Impact time = 0.4(according to industrial value reference for impact test)

1) Front Impact Analysis

A car is considered to be moving at a speed of 25 m/s and suffers a head-on collision with a rigid and non-deformable barrier. Analysis is carried out by fixing the rear bottom connections below the driver's seat.

$$Impact\ Force = \frac{Mass \times Velocity}{Impact\ Time}$$

Impact force we get = 34687.5 N

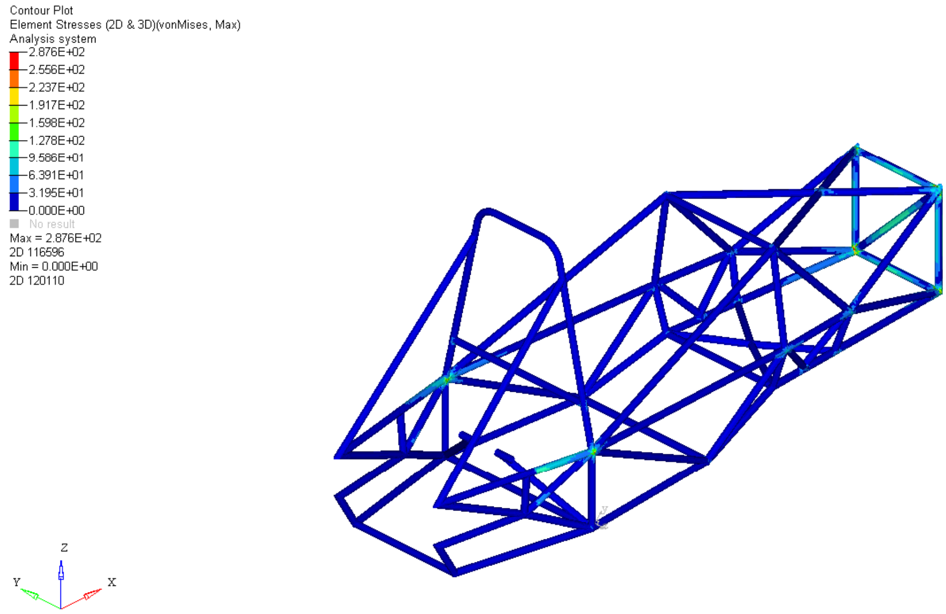


Fig. 6.1.1 (a) Front Impact test

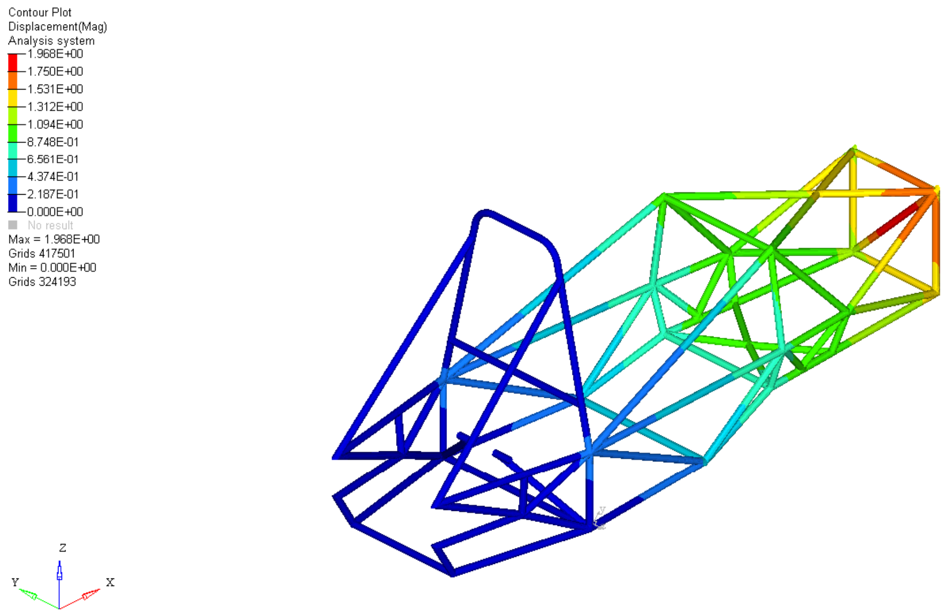


Fig. 6.1.1 (b) Front Impact Displacement

2) Rear Impact Analysis-

The chassis experiences a force of 4G at rear end during impact. For the rear impact test, the front end of the chassis is constrained.

$$Rear\ Impact\ = 4 \times Mass\ of\ the\ Vehicle$$

Total rear impact force = 10000 N

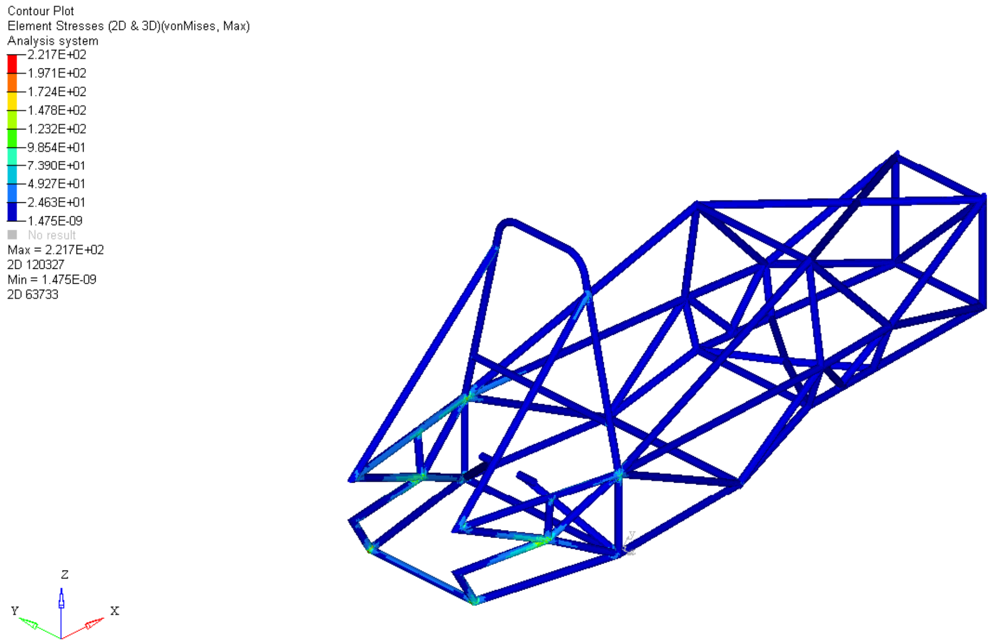


Fig. 6.1.2 (a) Rear Impact test

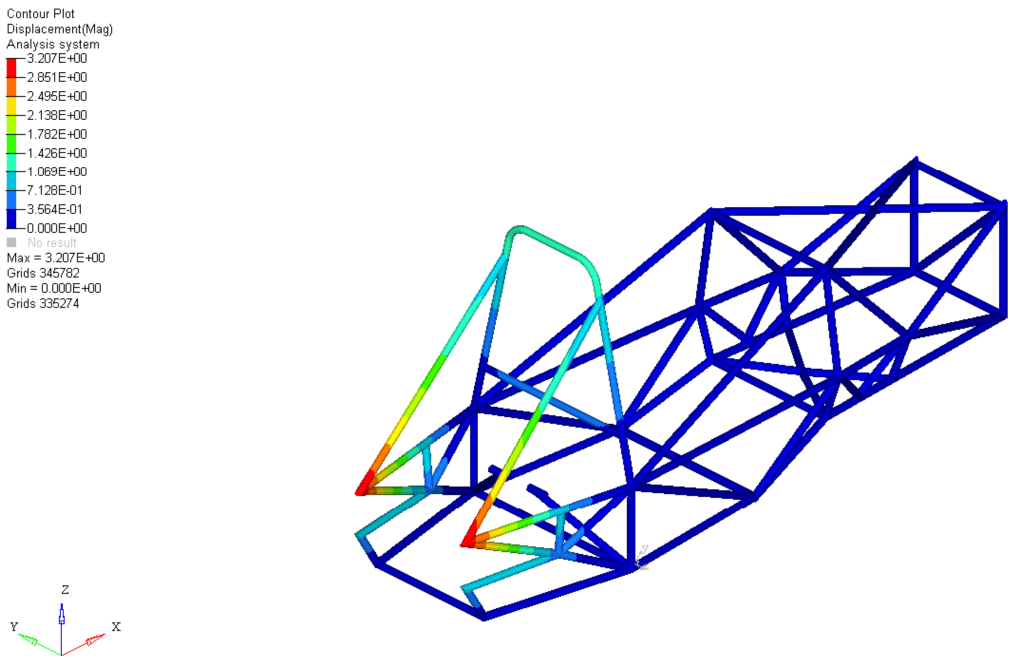


Fig. 6.1.2 (b) Front Impact Displacement

3) Side Impact Analysis-

Considering the chassis experiences 3G load during side impact. The Exact opposite side of applied load is constrained.

$$Side\ Impact\ = 3 \times Mass\ of\ the\ Vehicle$$

Total force = 7500 N

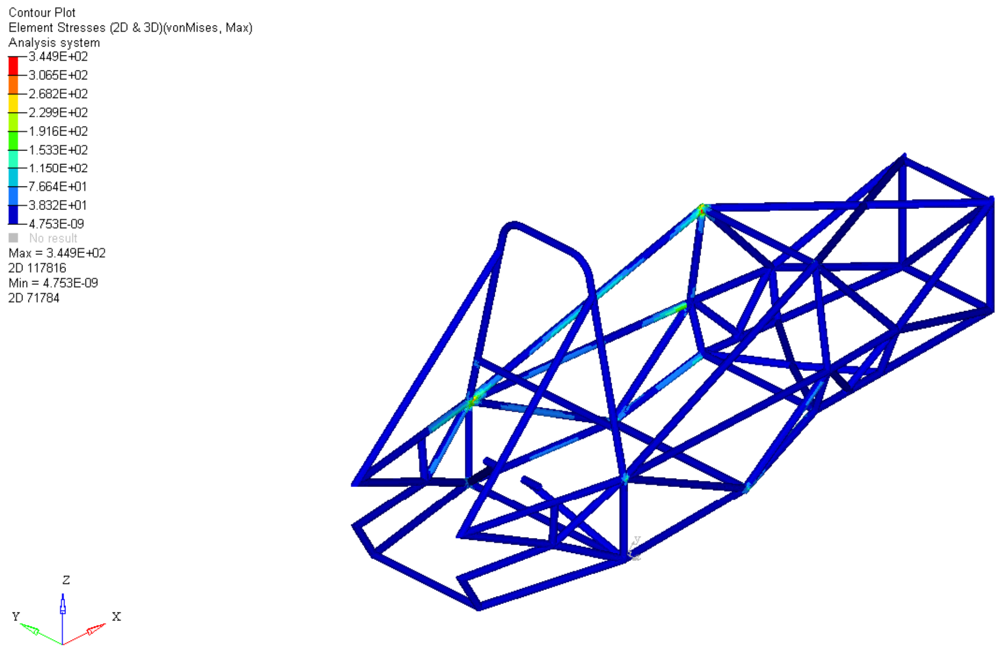


Fig. 6.1.3 (a) Side Impact Test

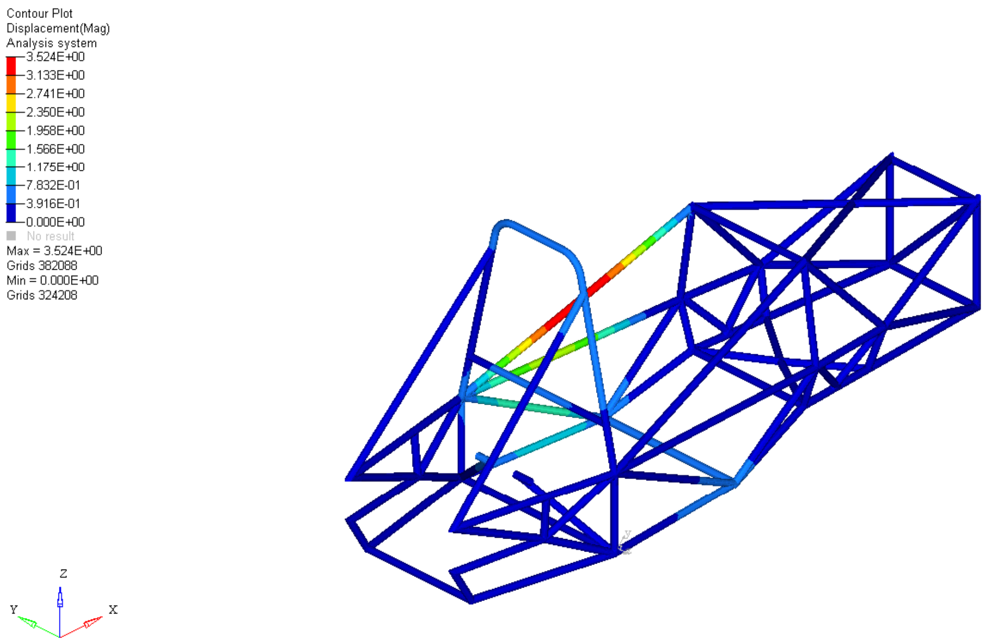


Fig. 6.1.3 (b) Side Impact Displacement

4) Rollover Test

This test is carried out considering there are possibilities of vehicle roll over when Driver takes sudden turn & sharp turn. Driver applies a sudden brake at high speeds. If the vehicle is rollover over its main hoop,it should sustain 1.7G force.

Force = 1.7*10*250

Force = 4250N

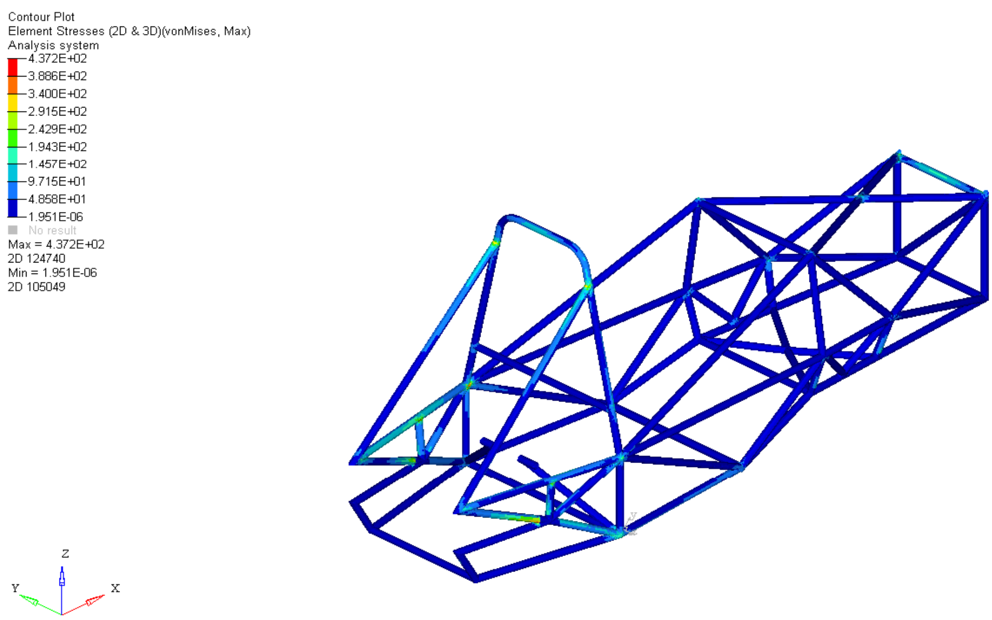


Fig. 6.1.4 (a) Rollover test

Fig. 6.1.4 (b) Rollover test Displacement

5) Torsional Analysis

In the Torsional Impact Test the chassis is assumed to be influenced by the racing environment when the suspension are active and the theoretically calculated values of forces are applied on the suspension mounting points and A-arm mounting points. Analysis was carried out by fixing the front of the chassis and forces of magnitude 2000N were applied.

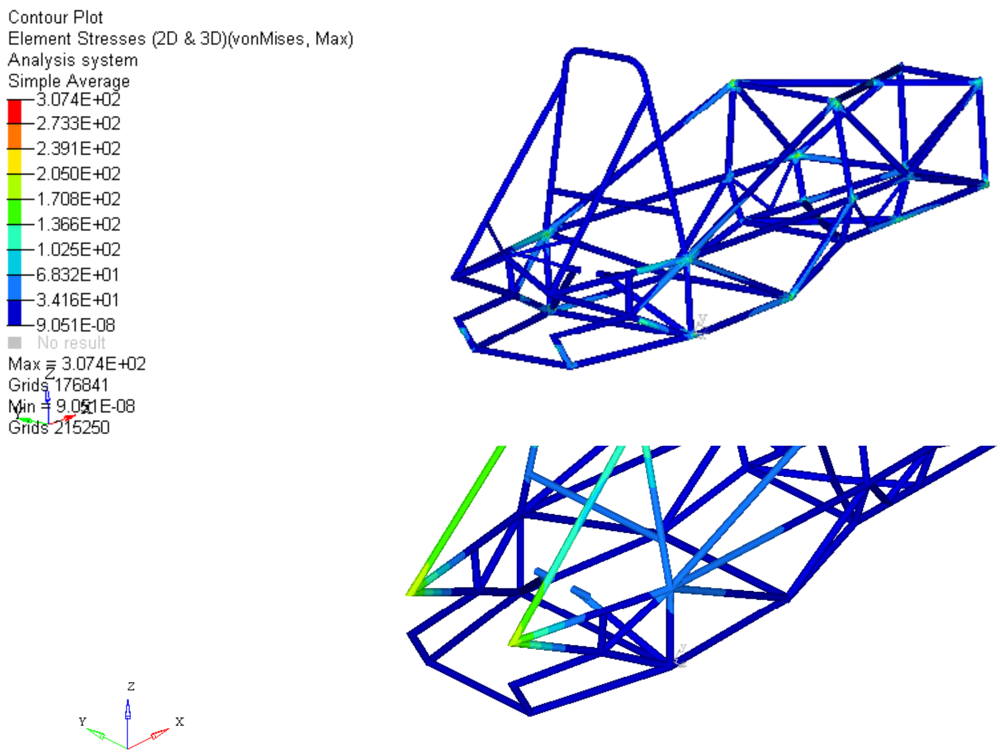
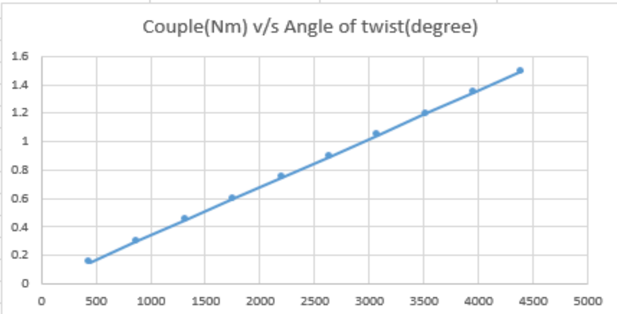


Fig. 6.5.1 Torsional test

6.2 Modal analysis on roll cage for frequency:

The main aim of chassis design is to make it stiff and strong i.e. to achieve high stiffness to weight ratio. Higher stiffness increases responsiveness and driver feedback while lower weight enhances handling and overall performance. Therefore higher stiffness to weight ratio means your frame will perform well. Traditional method to find stiffness to weight ratio is to measure weight and the torsional rigidity of chassis experimentally. There is another way to calculate this is to do modal frequency analysis.

Force(N)	Torque(Nm)	Displacement(mm)	Radian	Angle	Stiffness(Nm/degree)
800	440	0.7175	0.002609091	0.149429752	2944.527404
1600	880	1.434	0.005214545	0.29865124	2946.580771
2400	1320	2.1515	0.007823636	0.448080992	2945.895997
3200	1760	2.869	0.010432727	0.597510744	2945.55373
4000	2200	3.5865	0.013041818	0.746940496	2945.348407
4800	2640	4.2995	0.015634545	0.895433058	2948.294098
5600	3080	5.0205	0.018256364	1.045591736	2945.700406
6400	3520	5.738	0.020865455	1.195021488	2945.55373
7200	3960	6.4555	0.023474545	1.34445124	2945.439658
8000	4400	7.172	0.02608	1.493672727	2945.759081
					2945.865328



When excited, any object vibrates with its natural frequency given as,

$$\omega_n = \sqrt{\frac{k}{m}}$$

Where ω_n represents its natural frequency, k is stiffness of the object and m is mass, therefore higher natural frequency of vibration means higher stiffness to weight ratio. Another advantage of knowing the natural frequency of vibration is Resonance. In our vehicle the main source of vibration is engine and vibration due to road irregularities. If these frequencies correspond to the natural frequency of vibration of the chassis the resonance will occur. To avoid this we need to know the natural frequency of vibration of the engine and avoid this frequency of vibration to match with the natural frequency of vibration of chassis to avoid chassis failure due fatigue.

For the first six modes corresponding frequencies are approximately zero. This is because it has unconstrained motion in all six DOF. In order to increase the performance of the chassis the most significant mode is seventh and eighth mode because it causes twisting in the chassis.

6.3 Chassis to chassis impact

This test is an advanced one considering the utmost possibilities of chassis failure.In this test it is assumed that two chessis of same speed impact head on with each other. This rarely happens in races.

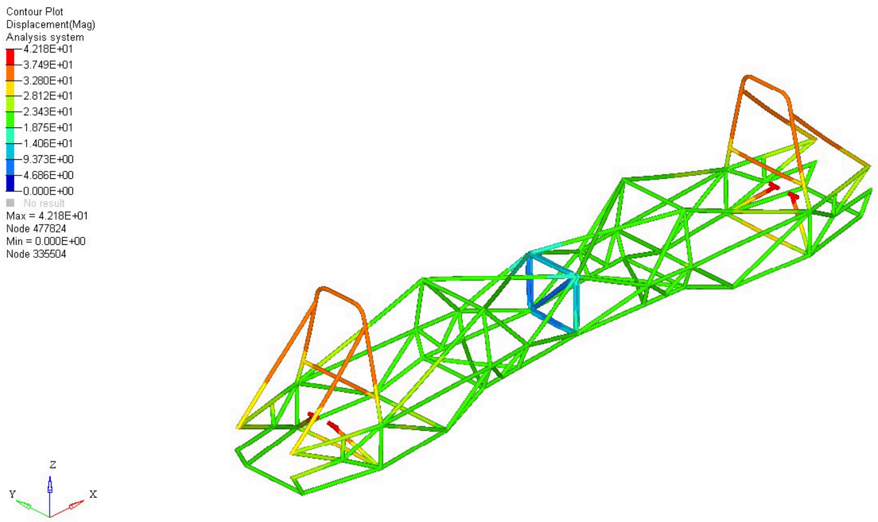


Fig. 6.3.1 Chassis to Chassis Impact test

6.4 Dynamic impact test on roll cage

Dynamic tests are carried out considering the vehicle is dynamic condition. (i.e. at a certain speed).

1) Front impact - For front impact analysis the velocity considered is max velocity of vehicle which is 90 km/hr. The results obtained are as follows

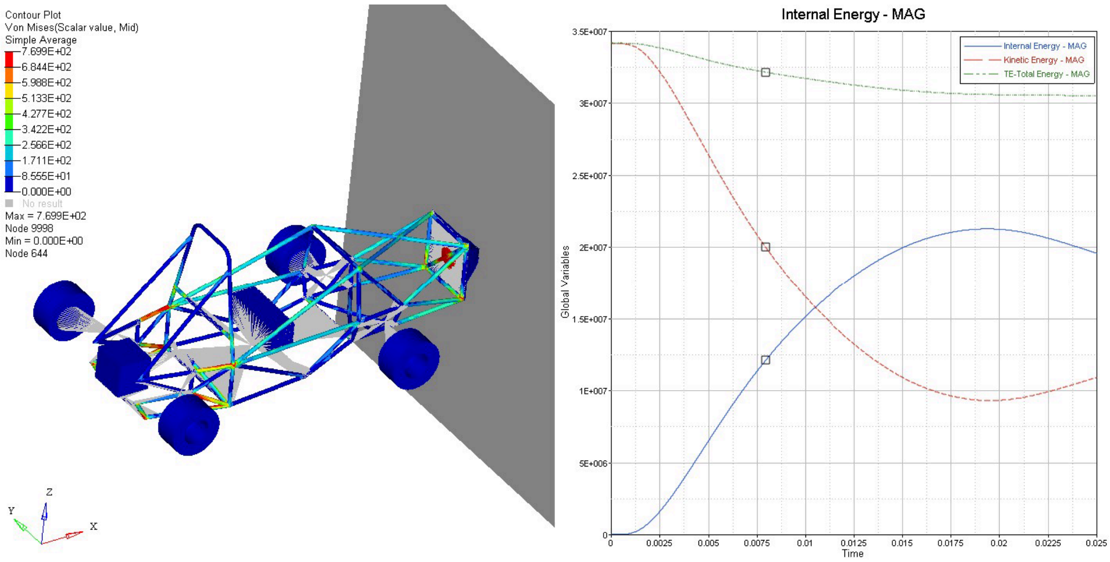
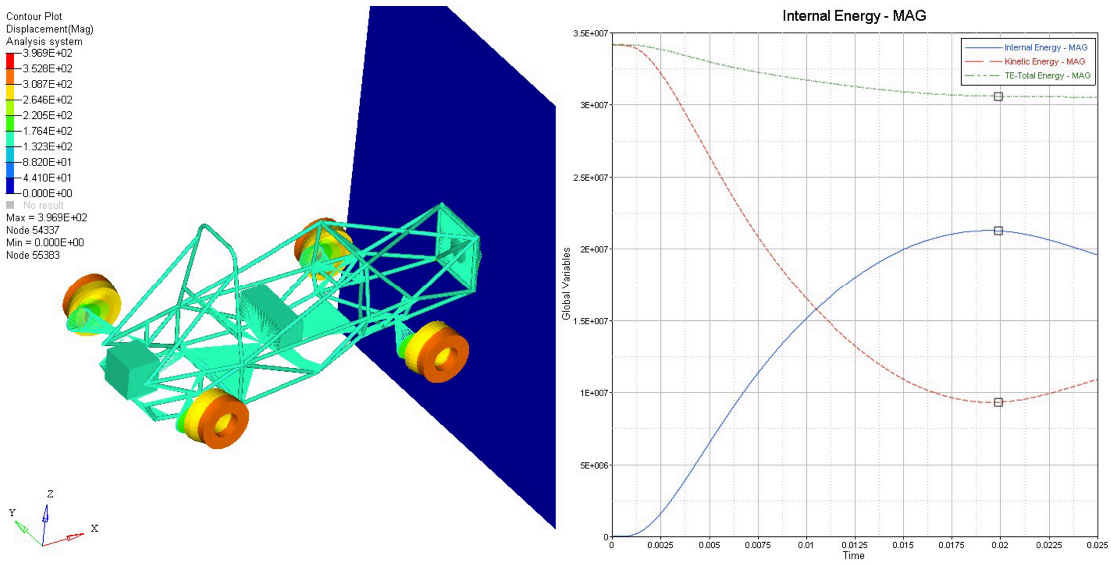


Fig. 6.4.1 Dynamic Front Impact Test

Fig. 6.4.1 Dynamic Front Impact Displacement



2) Side impact analysis- This test is carried out considering our vehicle in dynamic (i.e. running at certain speed) condition & another car of same mass hits our vehicle from right or left side.

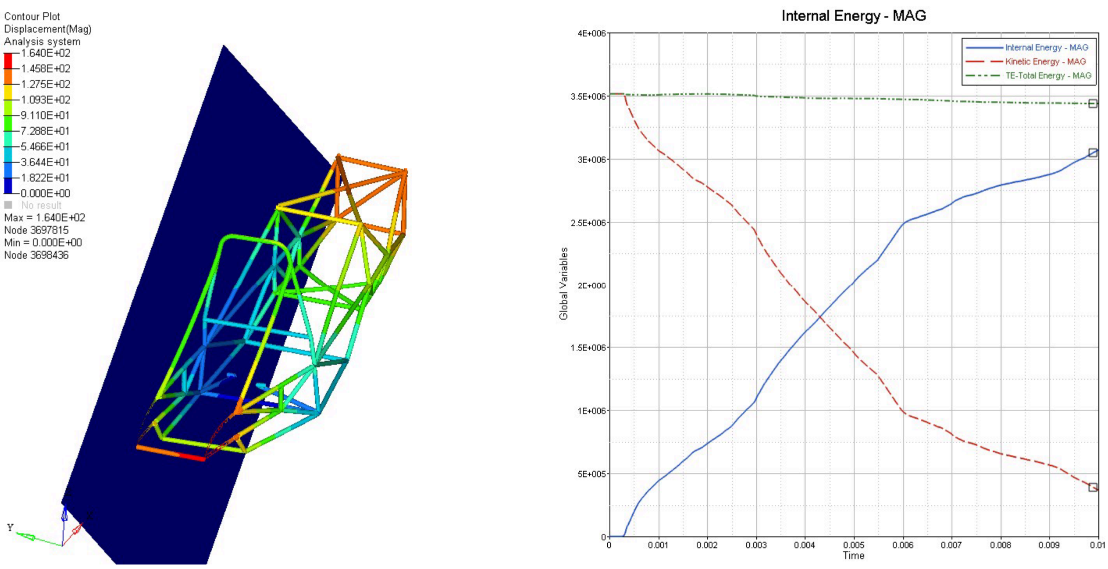


Fig. 6.4.1 Dynamic Side Impact Displacement

CHAPTER 7.0

RESULTS

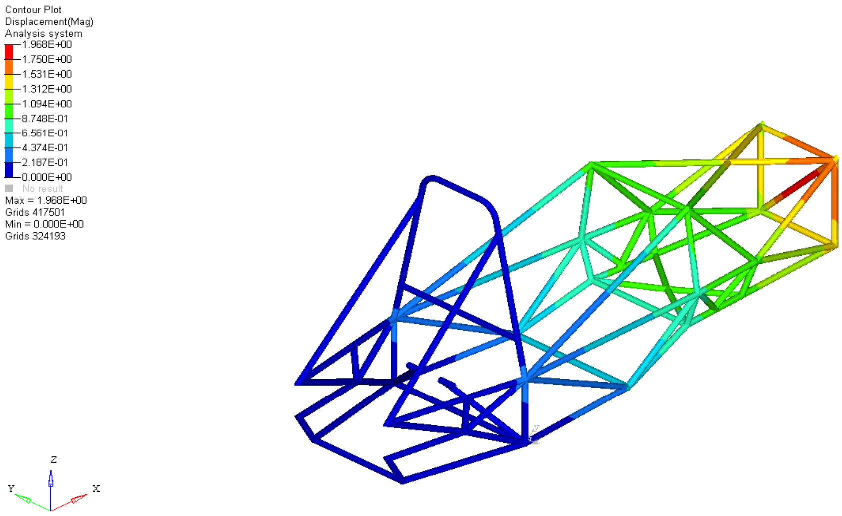


Fig. 7.1 Displacement generation Chassis

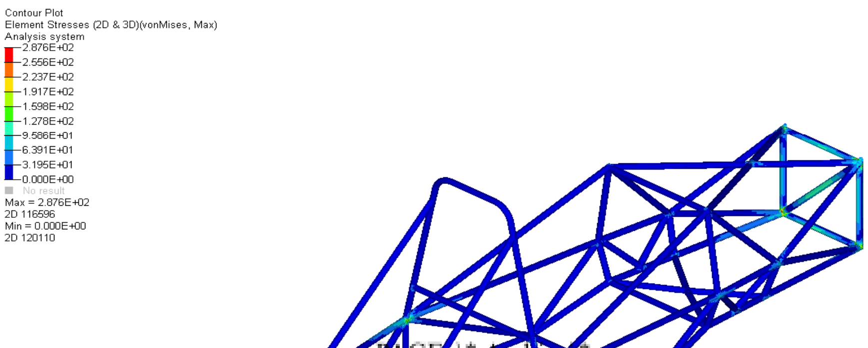


Fig.7.2 Stress generation in Chassis

Parameters	Last Year	This Year
Max Stress	259.2 Mpa	287.6 Mpa
Max Deflection	1.911 mm	1.968 mm
Weight with all brackets	35 kg	33 kg
Torsional Stiffness	1800.22 Nm/degree	2945.86 Nm/degree

Table No. 7.1

CHAPTER 8.0

MANUFACTURING

8.1 General procedure

1. Drafting

Drafting, Technical drawing or drawing, is the act and discipline of composing drawings that visually communicates how something functions or is constructed.

2. Fixtures

A fixture is a work-holding or support device used to locate (position in a specific location or orientation) and support the work.

3. Hydraulic Bending

Bending is a manufacturing process that produces a V-shape, U-shape, or channel shape along a straight axis in ductile materials, most commonly sheet metal.

4. Cutting

Cutting performed by means of a hand cutter machine. In this each member is cut into the desired length.

5. Profiling

Profile cutting or pipe profiling, is a mechanized industrial process that removes material from pipe or tube to create a desired profile.

6. Welding

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering.

8.2 Fabrication of chassis

Fabrication is obviously the most important part of completing a Formula SAE chassis. Merlin 3 is constructed of Steel 4130 tubing TIG welded. Steel 4130 is chosen for its weldability and strength. Tubes are fitted together through manual notching on a bench grinder. There are other methods of tube fitment including CNC laser cutting the end of each tube so that the chassis fits together like a puzzle. The chassis must be built in steps so that it is made accurate to the design.

8.3 Jig and Fixtures

The first step is to have a jig designed and built to locate the critical members of the chassis, or the fixed elements as referred to earlier. A jig consists of a table that is drilled and tapped at certain points to locate a fixture that holds a fixed element in place. In this case, a table made up of plywood is drilled and tapped to locate fixtures for the bulkhead, roll hoops, engine, and all suspension points. These fixtures are also made of aluminum and steel and are machined precisely to locate these critical points in space. The fixtures also act as a restraint for the tubes when being welded. If there was no jig, the chassis would be warped and unusable.

Fig. 8.3.1 Fixtures

8.4 Roll Hoops

The first tubes to be made are the roll hoops and the front bulkhead. These are the only parts of the chassis made off of the jig table. A large-scale drawing of these features is printed (or sketched precisely) and used as a guide when making bends and welding these tubes. Once these features are completed, they are bolted to the jig table in their respective locations. The bottom of the main roll hoop is used as a height reference for other parts of the chassis because it is bolted directly to the table with no spacer.

8.5 Cockpit

The cockpit is the first section to be built on the frame. This section is built first so that it can be used as a template for seat construction. The side impact structure of the cockpit must be built from the bottom toward the top so that during tube notching and fitment, a tight fit may be achieved for each tube.

Fig. 8.5.1 Cockpit Welding

8.6 Front Section

After the cockpit is built and welded, the team moves to the front of the car to build the front suspension mounting locations and front impact structure. The first tubes to be made are the lowest tubes. On the frame, these tubes stretch from the front roll hoop to the front bulkhead. The next tubing to be notched and welded is the box tubing for the upper suspension mounts. It is critical to keep this tube jigged during all welding so that these points are not warped. If these points move in space from where they have been designed, the upper a-arms will not fit correctly and suspension geometry will be compromised. The front impact structure must form a triangle according to the FSAE rules. The two tubes that form the triangle connect to the upper suspension tube to form a node.

The final pieces to be welded to the front part of the chassis are the bell crank and shock mounts. These mounts must be jigged so that the bell crank and shock can rotate in the same plane to produce the desired motion ratio. The bell crank mount is a short length of tubing that is welded to the lower suspension tube. This small tube carries a bung that incorporates the races for needle and thrust bearings that allow rotation of the bell crank.

The rest of the front section of the frame is made up of miscellaneous bracing tubes that constrain nodes and distribute loading to other parts of the chassis. These tubes are thin since most of the time, they do not carry any significant load. Weight savings can be made by designing this bracing effectively and using small tubing sizes.

8.7 Rear Section

After the front section of the frame is complete, the team works toward the rear. The first major tube to be put in place is the shoulder belt tube. This tube is located by a jig attached to the table. Once this tube is on the jig, all of the tubes that connect to it can be notched and fit up. At the same time, tubes that connect to the engine mount are fit to the main hoop and the engine mount. This mount is then bolted to one of the stock mounting holes on the engine block with a 0.5” aluminum spacer. This aluminum will reduce vibration slightly and will permit easier installation of the engine into the frame.

The rear suspension tubes are the next to be constructed. The lower points are located inside the box tubing as mentioned before. Another jig is used to locate the upper suspension tube. This jig holds a set of tabs that determine the position of this tube in space.

Fig. 8.7 Rear Section

The upper suspension tube will stay in the jig as long as possible while other welding is being performed so that warping can be kept to a minimum. Perhaps the most critical tube of the rear chassis is the shock mounting tube that runs across the rear of the engine. Not only does this tube carry the shocks but it also contains the rearmost engine mounting tabs. This tube must have a small bend in the centre to accommodate the shocks and this bend must be perfectly in line with the centreline of the car. Once this tube is in place, the tabs that the shocks mount to must be located on the tube. These tabs must also be perfectly centered on the car.

The rear section of the chassis also contains bracing tubing that connects the left and right sides and also the upper points to the lower points. These tubes must be carefully placed so that the half shafts that drive the wheels clear the frame. There is also bracing in the large open space above the engine. Small, thin tubing is used to create an X and stiffen the rear section of the frame.

8.8 Final Preparation

Once the rear section of the frame is completed, the chassis may be taken out of the jig for final welding. During construction, most welds on tubes can only be half or three quarters of the way done due to space constraints. With the chassis off of the table, welders can easily reach these places that were neglected earlier. Welding out of the jig is not normally done due to potential warping but by skipping from one location to another and spreading out the heat of welding, the chassis will remain mostly as it was in the jig with minimal warp.

Fig. 8.8 Completed Chassis

CHAPTER 9.0

COST EVALUATION

9.1 Cost of the Material

Material	**Unit Cost/Meter**	**Length**	**weight**	**Sub Total**
Steel Alloy Tube (25.4*2.40)	₹ 550	6m	8.17kg	₹ 3300.0
Steel, Alloy Tube (25.4*1.65)	₹ 500	9m	8.7kg	₹ 4500.0
Steel, Alloy Tube (25.4*1.20)	₹ 450	21m	15.63kg	₹ 9450.0
			Total	₹ 17,250

Table No. 9.1

9.2 Processing Cost

Process	**Unit Cost**	**Quantity**	**Sub Total**
Tube Bending (Hydraulic)	₹ 100	8	₹ 800
Welding of Tube Joints (TIG)	₹ 50	100	₹ 5000
Miscellaneous			₹ 1000
	Processing Cost Total		₹ 6800
	Material Cost Total		₹ 17,250
	Total		₹ 24,050

Table No. 9.2

CHAPTER 10.0

CONCLUSION

10.1 Future scope in chassis

Day by day trends in automobiles are changing. As the compactness of the vehicle technology is increasing the chassis designing will have a bright future. Use of recent technologies like CFD analysis, hybrid chassis will become more popular in future. Use of composites to reduce weight will also be a goal for researchers. Vehicle aerodynamics is also a recent trend in the automobile field.

10.2 Conclusion

The function of the chassis is to protect the driver and support front and rear suspension systems, engine, drive train, steering system and other systems in the vehicle. The objective of the chassis design was to satisfy these functions while meeting the formula student regulations with special considerations given to safety of the driver, quality, weight, ergonomics and aesthetics.

The complexity of design and the arrangement of the components contribute to waste space which does not make the car more compact and improvement in the chassis to overcome problems faced in assembly and maintenance.

The purpose of this project is not only to design the roll cage for the fsae competition, but also to provide an in-depth study in the process taken to arrive at the final design. During the design process, we must achieve a compromise between cost, manufacturing, performance, and design time so that the car will be competitive in all aspects of the fs competition. However, we should understand that it will take several iterations to converge on a satisfactory design.

CHAPTER 11.0
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