The Computational Analysis & Design Optimisation of Roll Cage for a Sae Standard based Small Segment Car

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Abstract— The primary objective of this paper is to optimize the design of a roll cage frame structure for SAE standard based small segment car. A small segment vehicle is a small, off road vehicle powered by a four stroke engine, thus large part of vehicle performance depends on acceleration which is proportional to the weight of the roll cage and hence chassis. To achieve greater performance of the vehicle, a balance must be found between strength and weight of the roll cage to ensure safety of the driver. So roll cage part of the chassis is the primary protection for the driver. The design optimization of roll cage is based on position, location and orientation of link. Hence a multi-body dynamic analysis is carried out to study performance of the roll cage. Modelling was done to distribute the mass of the vehicle over its frame members to simulate the real world problem for dynamic analysis. The finite element analysis software program used for solving the problem was LS-DYNA. the main criteria for selection of material of roll cage was safety, cost and durability.LS-DYNA is a general purpose explicit and implicit finite element program used to analyze the non-linear dynamic response of the three dimension structure. Due to the advances in computational techniques with the advent of higher end software, the computing capacity has been enhanced. Also computing capacity helps in reducing the design cycle time and saves the graphic and relative costs. In the present work, a Roll-cage for small car is analysed using implicit and explicit algorithms for stress conditions. The roll-cage is built using CATIA software for the standard dimensions. Modal analysis is carried out to find resonant frequencies to ease selection of the engine speed. Modal analysis results show improved natural frequency for the modified design. LSDYNA explicit analysis is carried out for 90KMPH speed for crash testing. This work is done to find the usage of crash solvers in the role-cage design and understanding the weak regions in the SAE structures.

Key words: DYNA, CATIA, SAE, FIA

I. INTRODUCTION

The Formula One regulations specify that cars must be constructed by the racing teams themselves, though the design and manufacture can be outsourced.

A. *Chassis Design*

The modern day Formula One cars are constructed from composites of carbon fibre and similar ultra-lightweight materials. The minimum weight permissible is 642 kg (1,415 lb) including the driver but not fuel. Cars are weighed with dry-weather tyres fitted. However, all F1 cars weigh significantly less than this (some as little as 440 kg (970 lb)) so teams add ballast to the cars to bring them up to the minimum legal weight. The advantage of using ballast is that it can be placed anywhere in the car to provide ideal weight distribution. This can help lower the car's centre of gravity to improve stability and also allows the team to fine tune the weight distribution of the car to suit individual circuits.

B. *Engine*

The 2006 Formula One season saw the Federation International de l'Automobile (FIA) introduce the current engine formula, which mandated cars to be powered by 2.4-litre naturally aspirated engines in the V8 engine configuration, with no more than four valves per cylinder. Further technical restrictions, such as a ban on variable intake trumpets, have also been introduced with the new 2.4 L V8 formula to prevent the teams from achieving higher RPM and horsepower too quickly. The 2009 season limited engines to 18,000 rpm, in order to improve engine reliability and cut costs. The engines consume around 450 l (15.9 ft3) of air per second. Race fuel consumption rate is normally around 75l/100 km travelled (3.1 US mpg, 3.8 UK mpg, 1.3 km/l). A modern F1 clutch is a multi-plate carbon design with a diameter of less than 100 mm (3.9 in), weighing less than 1 kg and handling around 540 kW As of the 2009[update] race season, all teams are using seamless shift transmissions, which allow almost instantaneous changing of gears with minimum loss of drive.

C. *Aero Dynamics*

The aerodynamic designer has two primary concerns: the creation of down-force, to help push the car's tyres onto the track and improve cornering forces; and minimising the drag that gets caused by turbulence and acts to slow the car down. The changes were designed to promote overtaking by making it easier for a car to closely follow another. The new rules took the cars into another new era, with lower and wider front wings, taller and narrower rear wings, and generally much ‘cleaner’ bodywork. Perhaps the most interesting change, however, was the introduction of ‘moveable aerodynamics’, with the driver able to make limited adjustments to the front wing from the cockpit during a race.

D. *Roll cage designs*

Fig. 1.1: Roll Cage

Fig. 1.2: Auto Power Bolt in Cage

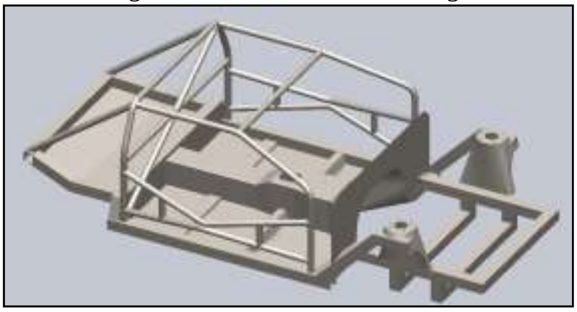

Fig. 1.3: Typical Roll-Cage

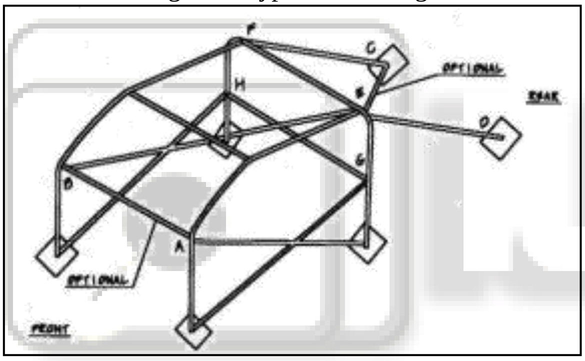

Fig. 1.4: Basic Roll-Cage in 3D View

Fig. 1.5: Roll Cage with Maximum Number of Tubes

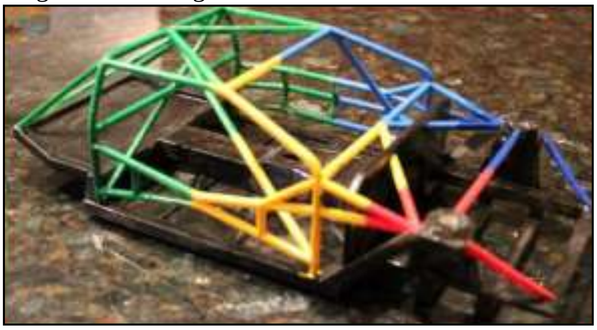

Fig. 1.6: ABS Rapid Prototype Roll Cage

E. Wings

Early designs linked wings directly to the suspension, but several accidents led to rules stating that wings must be fixed rigidly to the chassis. The cars' aerodynamics are designed to provide maximum down-force with a minimum of drag; every part of the bodywork is designed with this aim in mind. Like most open-wheel cars they feature large front and rear aero-foils, but they are far more developed than American open-wheel racers, which depend more on suspension tuning; for instance, the nose is raised above the centre of the front aerofoil, allowing its entire width to provide down-force. The front and rear wings are highly sculpted and extremely fine 'tuned', along with the rest of the body such as the turning vanes beneath the nose, bargeboards, side-pods, under body, and the rear diffuser. They also feature aerodynamic appendages that direct the airflow. Such an extreme level of aerodynamic development means that an F1 car produces much more down force than any other open-wheel formula; Indy cars, for example, produce down force equal to their weight (that is, a down force :weight ratio of 1:1) at 190 km/h, while an F1 car achieves the same at 125 to 130 km/h, and at 190 km/h the ratio is roughly 2The bargeboards in particular are designed, shaped, configured, adjusted and positioned not to create down force directly, as with a conventional wing or under body venture, but to create vortices from the air spillage at their edges. The use of vortices is a significant feature of the latest breeds of F1 cars. Since a vortex is a rotating fluid that creates a low pressure zone at its centre, creating vortices lowers the overall local pressure of the air. Since low pressure is what is desired under the car, as it allows normal atmospheric pressure to press the car down from the top, by creating vortices down-force can be augmented while still staying within the rules prohibiting ground effects.

The F1 cars for the 2009 season came under much questioning due to the design of the rear diffusers of the Williams, Toyota and the Brawn GP cars raced by Jenson Button and Rubens Barrichello, dubbed double diffusers. Appeals from many of the teams were heard by the FIA, which met in Paris, before the 2009 Chinese Grand Prix and the use of such diffusers was declared as legal. Brawn GP boss Ross Brawn claimed the double diffuser design as "an innovative approach of an existing idea". These were subsequently banned for the 2011 season. Another controversy of the 2010 and '11 seasons was the front wing of the Red Bull cars. Several teams protested claiming the wing was breaking regulations. Footage from high speed sections of circuits showed the Red Bull front wing bending on the outsides subsequently creating greater down force. Tests were held on the Red Bull front wing however the FIA could find no way that the wing was breaking any regulation.

II. LITERATURE REVIEW

A. Introduction

Analysis of roll-cage structure of SAE small segment car and optimization of model is an area on which different researches have been carried out. Different people at institutional and individual level involved in the area produced findings which are relevant in the automotive industry. In nearly all the literature reviewed it is observed that most of the researches constitute development of virtual or prototype models and all the analyses are performed on these models. Verification of the results is accomplished by comparison made with experimental or analytical results. Listed below are some of the literatures surveyed that are deemed to be significant to this study that is conducted on analysis of chassis structure of the truck vehicles.

B. A Broad based review of Crash Analysis

DVExperts International (DVE) Shane Richardson [3] has developed requirements for vehicle rollover protection systems for military, mining and civilian use. The world's major resource companies have identified rollover crashes of light vehicles (Pickups and SUV's) as a serious problem for both their own and contractor vehicles operated on their sites. The structural roll over protective systems were being developed and manufactured locally for vehicles operating sites to no specific requirement(s)and resulted in a range of outcomes. Following a commercial tender process DVE structural requirements have been adopted for fleets of 4x4 vehicles (Pickups and SUV's). The rollover structural requirements are based on DVE research into roll over protective systems and define loading, intrusion and robustness criterion. The analysis and testing processes used to develop and validate the rollover protective structural systems. Structural solutions have been manufactured by DUYS Engineering (South Africa), Largo Tank & Equipment (USA) and Industrias Metalicas Miller (Colombia). The design criteria, analysis and testing processes used to develop and validate the rollover protective structural systems are presented, and provide a basis for roof strength design for all light vehicles.

E. Nassiopoulos and J. Njuguna [4], Side impact accidents against a tree or pole remain the most dangerous accident scenarios in rally cars. Statistical data shows that 52% of the fatalities between 2004 and 2009 concern crashes against a rigid pole by the track sides, whilst among those more than 60% were side impacts. Despite the present scientific efforts, rallying cars side impacts are still among the least understood primarily due to limited space between the occupant and door sill, evolving safety regulations and vehicle dynamics. In this study, finite element dynamic characteristics of the whole car were studied. The finite element model consisted of the whole car structure and 241 parts including the engines, tyres and the suspension members with 4 different element types and 7 material models. All structural parts were modelled as low-carbon steel with the piecewise-linear-plasticity material model (mat24). The tyres were modelled with the Blatz-Ko rubber material (mat 07) whilst also rigid and other materials (mat 020, 01, 09, S01 and S02) were used to represent different parts of the model, as the suspension members, suspension links and the engine. A roll cage and two racing seats were modelled with four-node shell elements and the use of piecewise-linear-plasticity and composite-damage materials respectively. A semi-cylindrical pole of 200mm diameter was also designed and modelled as a rigid body. The model was used to first investigate the dynamics of the crash, and later run a wide range of simulations and parametric studies in the cage, the car.

Njju, C.D. , Annamali K [5]This study is aimed at carrying out a finite element analysis on a roll cage of a vehicle used for student competitions around the world. The design process was carried out using a CAD package and analysis was done using finite element analysis software Ansys. Impact test was carried out on the roll cage under different conditions and the effect on the structural members are studied and discussed. The results are very much helpful and assure that the car is in safe condition in case of a crash or accident. Finite element analysis (FEA) is also carried out with the frame against torsional loading. Two different materials were considered for the analysis. The results of displacement of frame, nodal solution and element solutions are obtained.

Vikas Sharma,Divyanshu Purohit [6] A frame of a vehicle is of vital important, for the passenger and mass safety the passenger cabin must of great strength to resist crimple. The front and the rear can be failed during the various testing but the passenger cabin must be safe to withstand load. It could be achieved either by using the material of high strength or of better cross section against the applied load. The SAE BAJA vehicle development manual restricts us about the vehicle weight, shape and size, and dimensions .Material is also a limitation, increment in dimension raising overall weight, thereby lowering the fuel efficiency, so in order to overcome all this, circular cross-section is employed for the roll cage development. And circular section is always a perfect one to resist the twisting and the rolling effects. Circular section is preferred for torsional rigidity.

C. Finite Element Method

To understanding the behavior of a structure of a machine component, the analyst at his disposal two standard tools:

- Analytical methods.
- Numerical methods.

1) Analytical Methods

Analytical methods provide quick close form solutions, but they treat only small geometries and capture only the idealized structural theory. Analytical methods are classified into two ways.

a) Exact method

This method provides exact solution to the problems, but the limitation of this method is that all practical problems cannot be solved and even if they can be solved, they may have very complex solution.

b) Approximate analytical methods

This method is alternative to the exact methods, in which certain functions are assumed to satisfy the geometric boundary conditions, but not necessary the governing equilibrium equations. These assumed functions, which are simpler, are then solved by any conventional method available. The solutions obtained from these methods have limited range of values of variables for which the approximate solution is nearer to the exact solution.

2) Numerical Methods

Numerical methods require very few restrictive assumptions and can treat complex geometries. Numerical method has been developed to solve almost all types of practical problems. The two common numerical methods used to solve the governing equations of practical problems are numerical integration and finite element technique.

a) Numerical Integration Methods (NIM)
Runge-Kutta, Miline's method etc adopt averaging of slopes of given function at the given initial values. These methods yield better solutions over the entire field width but sometimes laborious.
b) Finite Difference Method (FDM)
In this method the differential equations are approximated by finite difference equation. Thus the given governing equation is converted to a set of algebraic equations. These simultaneous equations can be solved by any simple method such as Gauss Elimination, gauss-Seidel iteration method, Crout's method etc. The method of finite difference yield fairly good results and are relatively easy to program. Hence, they are popular in solving heat transfer and fluid flow problems. However, it is not suitable for problems with awkward irregular geometry and not suitable for problems of rapidly changing variables such as stress concentration problems.

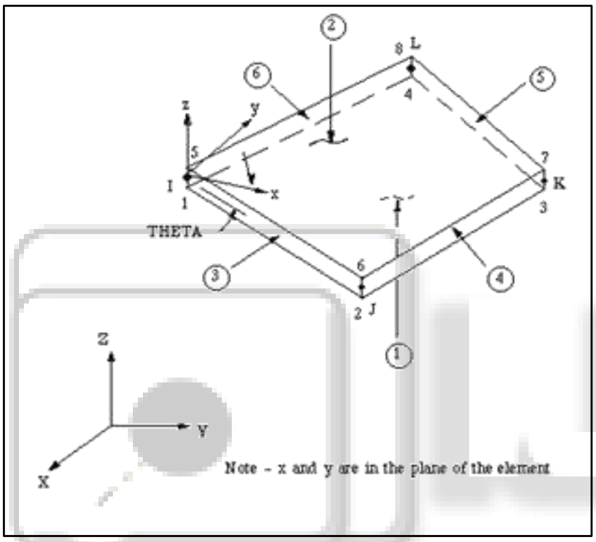

Fig. 2.1: Shell 63 Geometry

III. MODELLING

A. Problem Definition

Dynamic analysis of Cage structure using LS-DYNA for finding the structural properties under impact condition is the main definition of the problem. The cage is the main body to take the impact loads as the structure is subjected to dynamic loads continuously. The structural body should take all possible loads and should have good capacity absorbing the impact energy without failure. Generally LS-DYNA is the main software to test the ability of bodies under impact conditions. Since LS-DYNA is explicit solver, it can be used for transient loads without much problem. LS-DYNA has better options of defining the contact conditions. It has the advantage of applying the dynamic loads like velocity, acceleration etc.
The objectives include

– Cad modelling of the Cage structure.
– Meshing of the cage structure.
– Dynamic equivalent static load analysis for frontal, side and rollover.
– Modal behaviour of the structure.
– Impact analysis of the cage structure for 90 Km/ Hr.
– Finding the structural properties of the cage structure under this impact.

B. Design Considerations for Roll Cage

The basic purpose of the roll cage is to protect the driver if the car turns over, runs into an obstacle such as a guardrail or catch fence, or is struck by another car. It shall be designed to withstand compression forces from the weight of the car coming down on the rollover structure and to take fore/aft and lateral loads resulting from the car skidding along on its rollover structure. A system of head restraint to prevent whiplash and rebound, and also to prevent the driver's head from striking the underside of the main hoop shall be installed on all vehicles. Roll cage or chassis design shall prevent engine intrusion into the driver compartment. No portion of the safety roll cage shall have an aerodynamic effect by creating a vertical thrust.

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C. Roll Cage Size Optimization

Sl. No	Property	Value
1.	Material	Steel AISI -42
2.	Outer diameter(mm)	25.4 mm
3.	Inner diameter(mm)	19.2 mm
4.	Young modulus(GPa)	200
5.	Yield strength(MPa)	420
6.	Poisson ratio	0.3
7.	Density(Kg/m^3)	7800

Table 3.1: Material Properties used for the Roll Cage Structure

D. Dimensional Details of Roll Cage

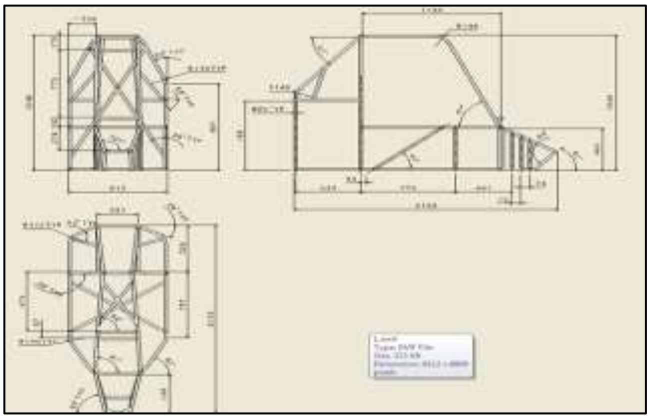

Fig. 3.1: Orthographic Dimensions of Roll Cage

The present roll cage under investigation has been referenced from SAE BAJA rules 2009 and same structure has been considered for our investigation. The figure4.1 shows dimensional details of the Roll Cage. The dimensions are represented in mm. The cage is made of rigid hallow tubes. The Tubular section has been considered due to its torsion strength. The cross members are added to increase the axial and torsional stiffness to the structure.

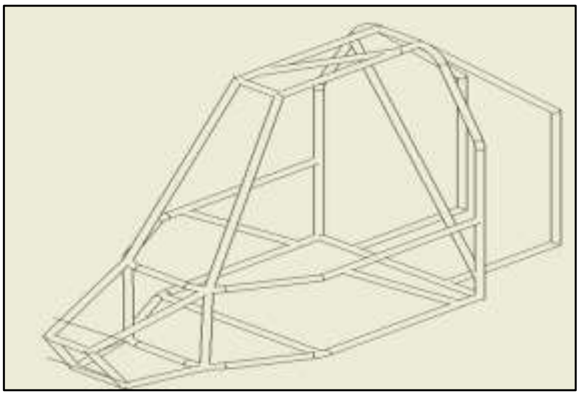

Fig. 3.2: Isometric view of the roll-cage

Figure3.2 shows isometric view of the problem. The isometric gives full view of the problem. So the structure can be visualized and by general engineering sense the drawbacks can be identified. Front portion is made strong by closer beam additions. Side members are also not much present as the lateral load extent is smaller compared to the frontal impact and motion loads. This view also shows top side member connections. These members are useful for lateral loads. At the joint region, the structure is bent to join with other members. Generally these are the potential source of stress generation. Also the members are joined by welds. So this forms the permanent joints and increases the stresses. Any weld configuration is the source of higher bending moment and along with this higher stresses.

E. Stages of Analysis

1) Solid modelling using CATIA software

CATIA is a three dimensional modelling software. It is having options to create and draft the models. Initially the geometry to be created will be created in the sketcher. Later it is extruded to form three dimensional tubes. These tubes are assembled to form the cage structure using Assembler module in CATIA.

2) Meshing using HYPER MESH

Two types of meshing options are considered for analysis. Since it is having constant cross section, one dimensional beam modelling is considered for implicit analysis using ANSYS. But to capture explicit deformations using LSDYNA, shell meshing is adopted. Since it is difficult to define contact zones for one dimensional modelling, two dimensional modelling is considered for LSDYNA. HYPERMESH has the options to create the mesh with good quality satisfying parameters like aspect ratio, war page, skew angle and jacobian. Also it has the advantage of dynamic control to change the quality parameters.

3) Solver packages

a) ANSYS 5.0

The meshed geometry in 'inp' file format is imported to Ansys solver for execution. The appropriate boundary conditions are applied and problem is executed for the given loads. The results are represented for Vonmises stress consideration. Most of the ductile material failure is decided by Vonmises stress theory due to which, these criteria is selected for showing the results.

b) Solver package used LS-DYNA

The meshed geometry in the shell form is exported to LS-DYNA and loading options are applied. The part geometries are applied with automatic contact definitions with the rigid body and velocity and accelerations are applied on the deformable body. Convergence controls are set and executed using explicit solver.

IV. RESULTS & DISCUSSIONS

A. Introduction

Issues related to roll cage of a SAE (Small segment car) has been discussed, the frame has been designed by incorporating continuous lengths of tubing, which reduces welding zones and hence improves strength. By adopting this design it has been possible optimize strength, weight, durability and facilitate easy fabrication, the use of geometric modelling and Finite Element Analysis (FEA) techniques are extremely useful in addition to conventional analysis.

B. Design Optimisation Approach

The following assumptions have been made for the analysis of roll cage.

1) The candidate material considered for the roll cage analysis is AISI 42 grade steel due to its homogeneity and isotropic.
2) The work revolves around Linear and Non- linear Analysis in the elasto-plastic region of the structure.
3) 4 Nodded shell element and beam188 elements are used for meshing the geometry.

ANSYS implicit solver is used for frontal, side and rollover analysis under impact conditions and LS-DYNA explicit solver is used for dynamic analysis.

C. Solid Modelling of Roll cage

CATIA V5 is parametric solid modelling software which can used to generate 2-Dimensional model of the roll cage using surface work bench or part modelling option available in the software

By selecting surface work bench option, an appropriate geometric set is chosen in order to sequence the operations in order to achieve the dimensions as stipulated by SAE BAJA rules2009 for Roll Cages. The 3-D model of the roll cage is achieved using part option.

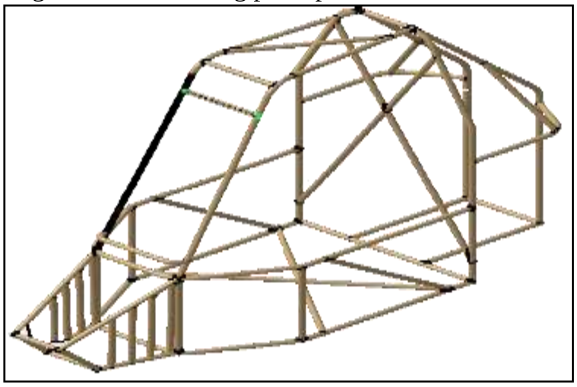

Fig. 4.1: Frame of the Roll Cage

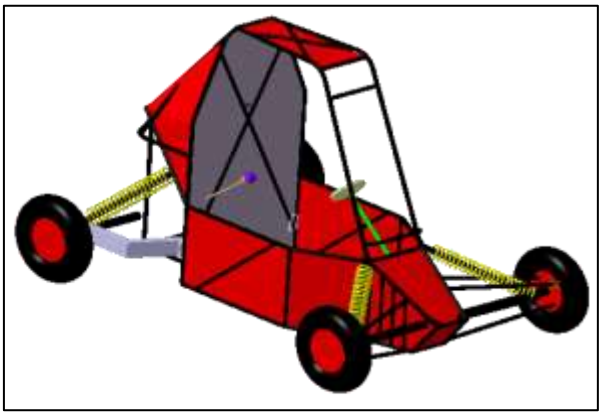

Fig. 4.2: Complete View of Roll-Cage

The Figure 4.2 shows the 3D modelled roll cage using CATIA. The structure is covered with sheet metal, engine mounted, dampers and wheels. But for analysis only frame structure has been considered. Wishbone, hub, spacer and wheel connections are shown in the figure.

D. Hypermesh model

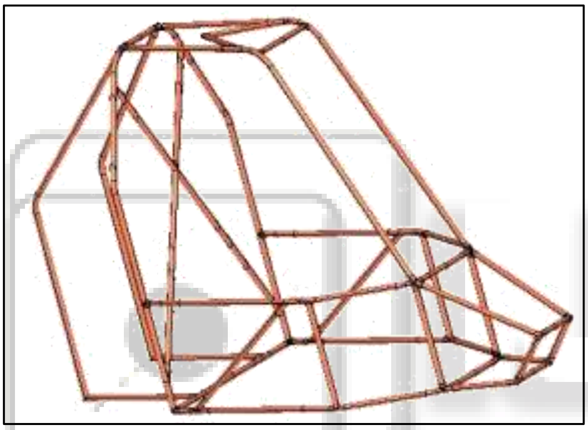

Fig. 4.3: Mid Surface of the Geometry

The figure 4.3 shows extracted mid surface of the geometry. The mid surface is extracted by auto mid surface option in HYPERMESH. Later the improperly generated areas are stitch worked to make a single body for connections. HYPERMESH has greater options for Boolean options. Also simple tools are available for stitching of the unconnected geometries.

E. Shell Mesh of the Model

The shell mesh is carried out on all the members. The minimum size maintained is 10mm for the problem. A total of 23230 elements and 23719 nodes are used for the meshing of the geometry. Generally shell mesh is the best mesh for dynamic applications as it takes minimum number of elements along with reduction in solution time. Generally three dimensional mesh is closer to the physical object, but three dimensional mesh is difficult. Especially weld regions, sharp curve regions are difficult to mesh. Also shell mesh has the advantage of reducing approximation in one dimension.

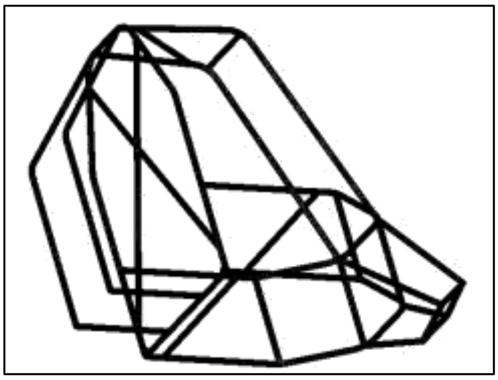

Fig. 4.4: Shell Mesh of Roll Cage Structure

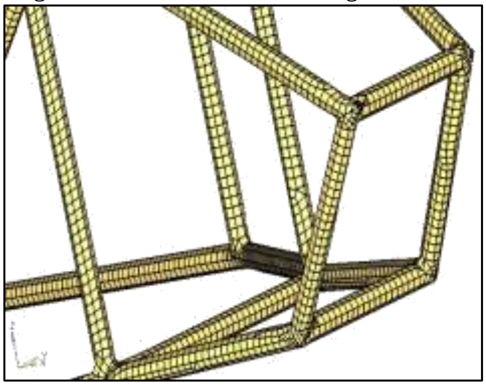

Fig. 4.5: Meshed View1

F. Loads applied on Roll Cage

Analysis has been carried out in two stages. In the first stage dynamic equivalent static loads are applied and the resultant effect on front, side and rollover of roll cage. These loads are given as design inputs for dynamic analysis using ANSYSIS. In the second stage an explicit solver LSDYNA has been used for crash analysis with the original structure. This analysis is done only for frontal impact.

1) Implicit Analysis using ANSYS

In this particular chapter implicit analysis is carried out on the structure for dynamic equivalent loads. The analysis is done for front, side and rollover loads. The result pictures are as follows.

The major data inputs are as follows

– Loads for Frontal Impact= 24315N.
– Load for roll over =2600 N
– Load for Side Impact=2598 N.

All the above data are used as major inputs to analyse Dynamic Static Load conditions using implicit solver of ANSYS.

a) Resultant analysis for frontal impact (Basic Structure)

The impact analysis on the roll cage is carried on the front structure. the analysis is carried out to evaluate the strength of frame structure.imapact analysis is carried out by loading the four points at the frontal structure, while the rear portion of the roll cage structure is constrained. The Loads for Frontal Impact is 24315N.

(1) Boundary Conditions Plot

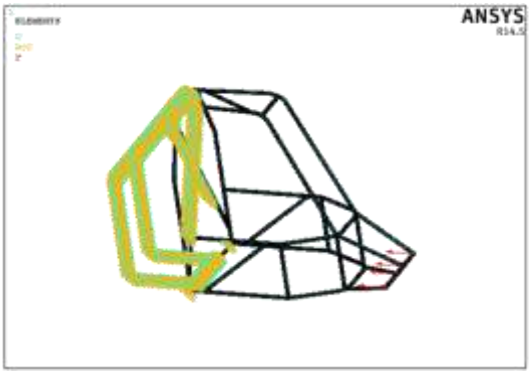

Fig. 4.6: Meshed View1

The front impact load distribution is shown in the Figure 4.6 The frontal impact load is applied at the front 4 corner nodes. The displacement boundary conditions are shown in the above figure. The rear portion of the structure is constrained.

(2) Displacement Plot

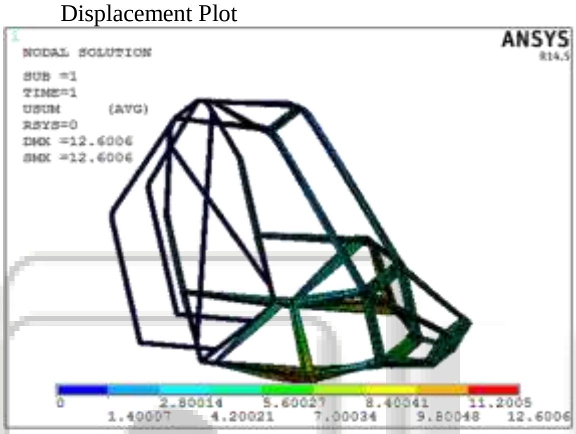

Fig. 4.7: Displacement Plot

The Figure 4.7 shows displacement in the structure. For the given front loading, the structure is deforming to 12.6mm. So deformation is not within the allowable deformation for the structure. Displacement generally represents stiffness of the structure. Since higher deformation is observed in the problem, the stiffness of the structure is less in the design. So region of deformation should be made rigid to reduce the deformation and stress.

(3) Vonmises Stress Plot

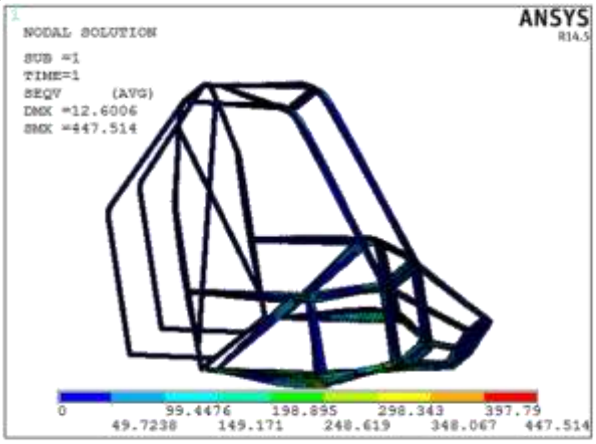

Fig. 4.8: Vonmises Stress Plot

The figure 4.8 shows vonmises stress in the structure. The developed stress is more than the allowable stress of the structure. So structure can't take this load. So a modified design is required to reduce the deformation.

b) Modified Frame Roll Cage Structure

The roll cage structure needs modification for improvement. So a modified design is considered with additional ribs to take the loads within the allowable range of deformation and stress. Vonmises stress theory is considered for failure of the structure as the vonmises stress represents equivalent stress condition in the problem. Vonmises stress is the resultant of all stresses in the system subjected to loading. Also Vonmises stress is the most popular theory in the application of finding failure in the ductile materials. In addition, Tresca's criteria also can be applied to find the failure of the structure. But Tresca is mainly based on principal stresses where shear stress is zero. So Tresca's stresses may not cover all the stresses generated in the structure.

(1) Deformation Plot (Modified Roll Cage)

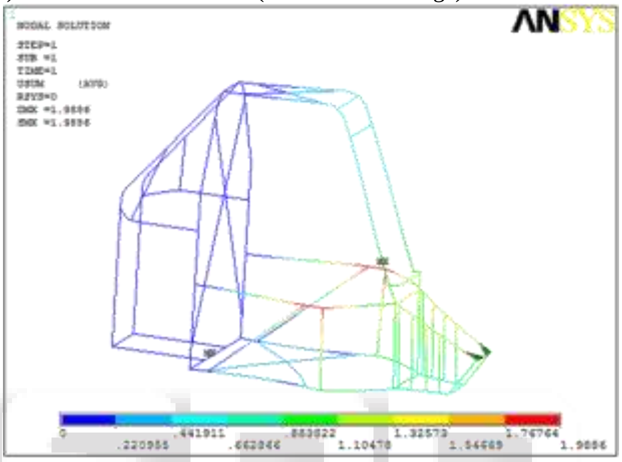

Fig. 4.9: Deformation with Modified Design

Figure 4.9 shows Maximum deformation is only 1.98mm which is within the allowable range of the material. So structure is safe for the given loading conditions. Hence the modified roll cage structure can take the load.

(2) Vonmisses stress plot

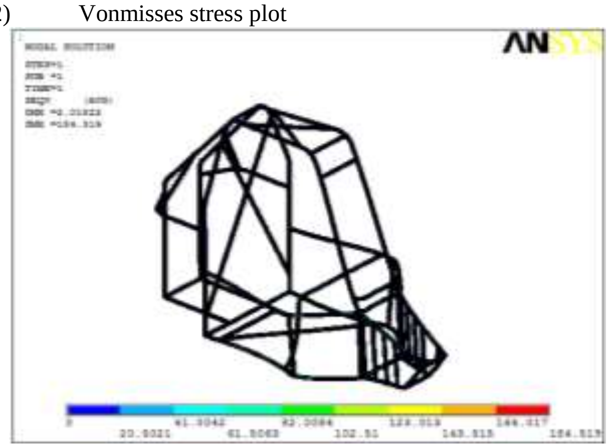

Fig. 4.10: Vonmises Stress Plot

The figure 5.10 shows vonmises stress in the structure. Maximum vonmises stress is around 184Mpa. This stress is within the allowable range of the material for impact. So rib addition helps to reduce the stress in the structure.

(3) Stress Concentration Zone

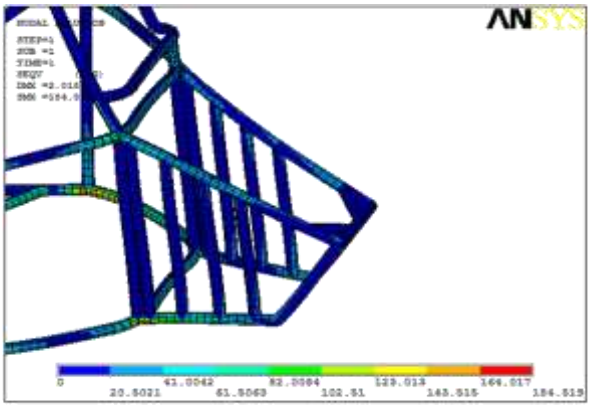

Fig. 4.11: Stress concentration zone

The figure 4.11shows stress concentrations region. The stress is maximum as shown in the picture by red colour. The added members are reducing the overall stress generated in the structure. The stress value has been reduced from 447Mpa to 184.519Mpa. So greater reduction of stress is observed by the addition of vertical ribs. This can be attributed to increased load sharing area in the problem. The status bar at the bottom shows variation of stress in the structure. 9 coloured status bar at the bottom shows the variation of stress in the structure.

c) Resultant Analysis for Side Impact

In this particular chapter implicit analysis is carried out on the structure for dynamic equivalent loads. The loads are applied on the one side of the roll cage section at six corner nodes, while the other half of the section is constrained. a load of 2598N is applied on the roll cage structure for side impact analysis. This load is based on the structural weight.

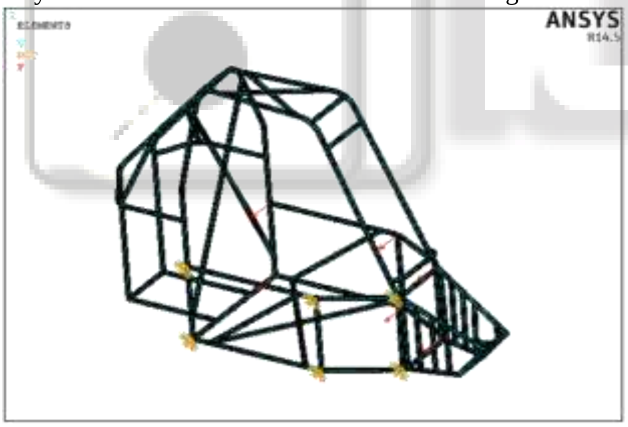

Fig. 4.12: Boundary Conditions for Side Impact (Modified Configuration)

The Figure 4.12 shows applied boundary conditions for the problem. The side loads as shown by red colour arrow marks.

(1) Displacement Plot

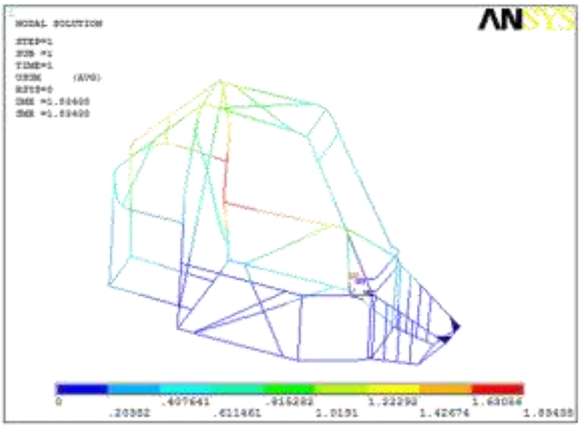

Fig. 4.13: Displacement Plot for Side Impact

The figure 4.13 shows displacement in the structure. For the given side loading, the structure is deforming to 1.63056mm. So deformation is within the allowable deformation for the structure. So structure can take this load. Displacement generally represents stiffness of the structure.

(2) Von Misses Stress Plot

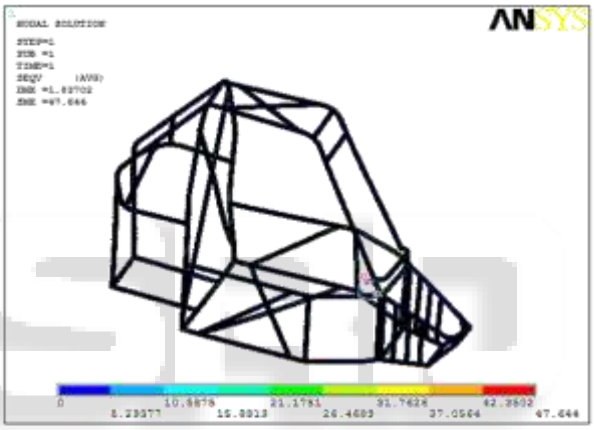

Fig. 4.14: Vonmises Stress Development In The Roll-Cage (Side Impact)

The figure 4.14 shows vonmises stress in the structure. Maximum vonmises stress is around 47Mpa. This stress is within the allowable range of the material for impact. So rib addition helps to reduce the stress in the structure.

(3) Stress Concentration Region

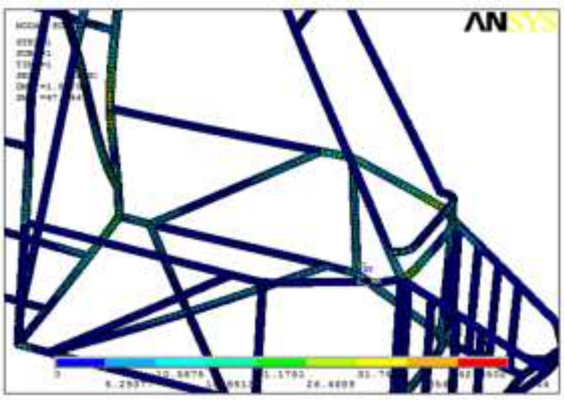

Fig. 4.15: Stress Concentration Region in The Side Impact In The Object (Stress Condition)

The figure4.32 shows stress view at the time of impact. The obstruction and the cage can be seen at the impact condition. Almost zero stress can be observed in the problem from the fringe plot at the right. Since the member is not having complete contact, the stresses are zero.

The figure 4.7 shows stress generation at the joints after 10 seconds. Almost the stresses are localized at the joints. The fringe value shows a stress development of 21Mpa. The stresses at various members of roll cage structure are zero when compared to joints location.

d) Displacement V/S Time Plot

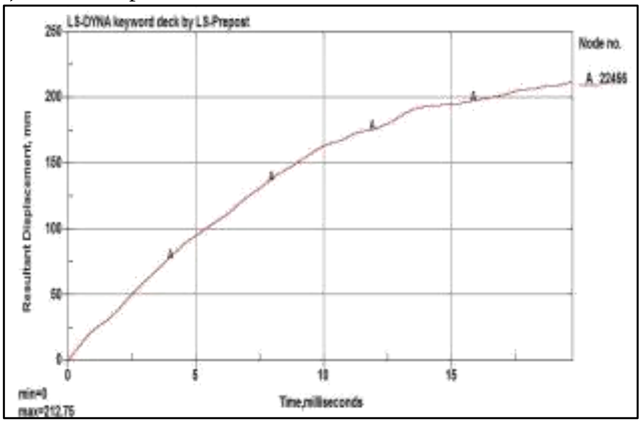

Fig. 4.34: Displacement Vs Time of Impact

The figure4.34 shows displacement development with the time. The displacement is semi-parbolically increasing from zero position to more than 200mm displacement. The nodal location of graphical plot is also given. This high displacement is corresponding to rear size of the structure.

e) Kinetic Energy and Internal Energy Plot

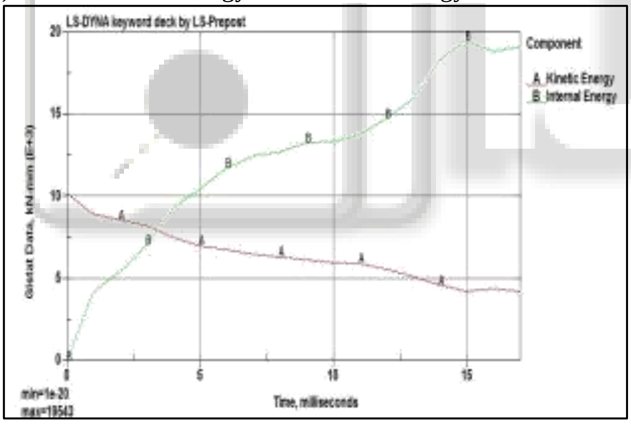

Fig. 4.35: Kinetic Energy and Internal Energy Plot

The figure4.35 shows energy plots in the problem. In the problem, kinetic energy is slowly reducing and internal energy is increasing in the problem. This can be attributed to transfer kinetic energy body to the static internal energy. Kinetic energy is due to its motion. As the motion is reduced, automatically the kinetic energy will reduce. The internal energy which is at zero position in the beginning is increasing to the higher value where kinetic energy has minimum value.

f) Resultant Velocity v/s Time Plot

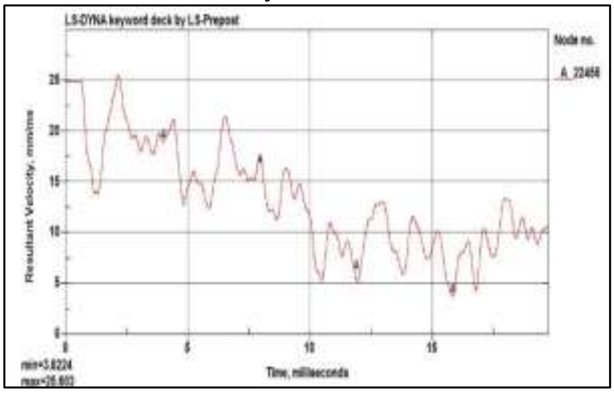

Fig. 4.36: Resultant Velocity with Time

The figure 4.36 shows drop of velocity of the member from 25m/sec to almost 10m/sec after 20milliseconds. This shows stopping of the vehicle by the front abstraction. The velocity drop is affecting the drop of kinetic energy.

g) Effective Stress Vs Time Plot

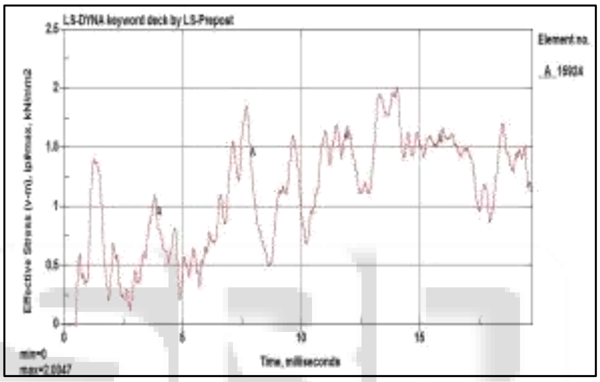

Fig. 4.37: Effective Stress with Time

The Figure 4.37 shows effective stress in the problem. The stress value is increasing from zero value to the 2KN/mm2 at the peak response time. So LSDYNA simulation helps to estimate the structural behaviour like absorption capacity of the structure and peak response times etc. Also it can be used to estimate time of stopping the member. LSDYNA is useful tool for analysis of the dynamic structures and to predict the nature of behaviour of the members. The response curves gives dynamic responses like, maximum peak time, rise time, settling time etc. LSDYNA with explicit algorithm helps in large deformation effect along with minimum convergence problems.

V. SCOPE OF PRESENT INVESTIGATION

The objective of this present design optimisation is to simulate real-world engineering design projects and their related challenges. The major part of vehicle performance depends on the drive train and the manoeuvrability of the vehicle. The total weight of the vehicle has significant impact on performance. Overall, a light vehicle should perform better since the engine capacity is fixed. Driver safety is an important concern in the design of such vehicles. The roll cage part of the chassis is the primary protection for the driver. So as to ensure driver safety, the roll cage must be structurally rigid. The chassis design becomes very important in the vehicle performance. The roll cage frame design discussed in this report is in compliance with the 2009 Baja SAE Rules.

The present investigations have been carried out with following main objectives.

- The frame design discussed in this report is in compliance with the 2009 Baja SAE Rules.
- The objective of this present design analysis was to develop guidelines linear and Non-Linear analysis for SAE small segment cars.
- Modifications to the frame for the improved strength and safety have been defined. The analysis from this work would provide guidelines that will help to design a more optimized roll cage which a critical aspect of the vehicle frame.
- Modelling the roll cage based on specifications given by SAE using the modelling software package CATIAV5.
- Perform a linear static analysis that simulates the frontal impact on the roll cage adopting FEA techniques using commercially available ANSYS software. The results obtained would reveal fault lines in the existing design and appropriate design modification would be incorporated to obtain a stable structure under static loading conditions during the frontal, side and rollover impact.
- Perform the multi body dynamic analysis for the frontal impact for the same roll cage subjected crash loading using LS-DYNA which would determine acceleration response, energy dissipation during the impact and reaction force on the frame structure.

VI. CONCLUSIONS & FURTHER SCOPE

A. *Conclusions*

1) The cage used for Formulae 1 cars has been analysed using ANSYS for frontal, side and roleover loads and LS-DYNA for 90KMPH crash impact. The overall summary of analysis is as follows.
2) Initially the cage structure has been modelled using CATIA, modelling software.
3) The structural dimensions are represented using CATIA drafting module.
4) The CATIA model in step file format is ported to HYPERMESH for meshing
5) In HYPERMESH, mid surfaces were extracted from the geometry for quad meshing with good quality elements
6) Check's for quality criteria like aspect ratio, skew angle, war page, max and minimum angle quad, and jacobian matrix has been carried out. But to reduce the solution time, the mesh is done specifically for its use in LSDYNA.
7) Using ANSYS, Beam188 element was subjected to analysis for frontal, side and rollover loads the front impact analysis for the initial configuration shows higher deformations and stresses above the critical values. So the design has been modified by including ribs in the frontal section. The modified design shows safety of the structure for the given loading conditions. Similarly, side and rollover analysis is carried out on initial configuration.
8) The modified shows improved structural dimensional stability when subjected the implicit dynamic loads.
9) Further Modal analysis has been carried out to find the resonant frequencies. This helps in preventing resonance and selection of engine speed. The modified design shows a natural frequency of 16Hz compare to the initial configuration fundamental frequency of 15.1Hz. Further explicit analysis is carried out on the shell structure using LSDYNA solver for initial configuration for 90Km/hr
10) The meshed geometry after application of boundary conditions is ported to LSDYNA for finding the dynamic stability of the structure. Analysis is done for 20milli seconds solution time.
11) The results shows maximum deformation at the rear structure and higher stresses are experienced by the frontal members. The total energy absorbed by the structure is uniform. The VONMISSES or effective stress plot reveal even under crash load condition the deformation is comparatively less
12) Results so obtained conclude displacements at different time intervals, velocity, acceleration and energy storage shows gradual increase in internal stresses with time. The velocity plot shows reduction of velocity with time of impact.
13) Using LSDYNA, the structural parameters like stress, displacement, velocity and energy can be obtained at different intervals of time using explicit algorithm.

B. *Future Scope*

1) The analysis can be extended with composite material usage
2) Topology optimisation can be carried out for further improvement
3) Thermal effects can be considered
4) Aerodynamic effects can be considered.
5) Size optimization can be carried out on the structure
6) Spectrum analysis can be carried out. These spectrum loads may be either road vibrations or air borne vibration.

