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STRESS AND DEFORMATION RESPONSE OF A CAR SAFETY FRAME ON STATIC IMPACT LOADING FOR MILD STEEL AND OTHER COMPOSITE MATERIALS

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1. ABSTRACT

The safety frame is the main element of passive safety for most racing cars. Till now the frames stiffness is investigated only on the basis of static loading tests, which are not able to take into account the dynamic effect of the high speed impact due to the car collision. For more correct frame safety analysis, the dynamic impact loading simulation is necessary. The influence of the impact velocity on the frame stiffness, stress and deformation has been studied and comparison with results obtained for the static loading has been performed. The static and dynamic loadings exhibit very different stiffness, deformation and stress time courses in the time just after impact. Later the differences are not so big. Furthermore, the car rollover has been modelled as a dynamic impact problem for the impact velocity 20 km/hour. A relative good agreement with corresponding prescribed static test has been achieved with exception of the time period close to impact. The impact is considered as a transient response function which can give more clarity over the impact load and the load transformation. MSC Nastran and patran is used for the analysis. Static analysis is carried out with all the dead loads.

***Index Terms*— car safety frame, impact loading, Static analysis, stress and deformation analysis, finite element method, Transient response analysis.**

2.Literature Review

Before commencing any design work it is useful to see what is already being done by others in the same field. As mentioned in the introduction the 2011 REV FSAE car will be powered by a unique drive-train and as such requires a unique chassis, however the basic principles of chassis design still apply. For a background into chassis design a relevant text was discovered and reviewed. The book published by Penguin Books is entitled “The Race Car Chassis” and is written by Forbes Arid. The book discusses different types of chassis’ and the history of chassis evolution. It focuses primarily on space-frames and stressed skin type chassis’ which is highly relevant to this project due to the low cost, readily available materials used and relatively simple manufacturing processes. “The Race Car Chassis” is somewhat of a review of different chassis designs used by different race cars, discussing chassis from all manner of classes such as drag, circle track and even passenger cars. The book also covers the different materials commonly used to construct chassis’ and lists each material’s advantages and disadvantages. Arid includes information regarding suspension and other loads on the chassis and how these should be supported. Significantly the book covers the design process for space-frame chassis’ including material selection, tube sizing and member arrangement. “The Race Car Chassis” was originally written in 1997 which means it is not up to date with the latest and most advanced technology however space-frames have not changed significantly in recent years so the book is still highly relevant. The main advancements that have been made in chassis technology since 1997 are in composite monocoque frames which are not relevant to this project due to their relatively high cost and the REV team’s limited budget. Overall this is a very useful book for the project covering much relevant information without any significant bias. Another text that was analysed for this project was “Chassis Engineering” written by Herb Adams and published by Penguin Books. The book was first published in 1992 making it slightly older than “The Race Car Chassis” described above. Contrary to Aird and this project, Adams considers the chassis to include suspension and bodywork components so the book contains a large amount of information about suspension setup and tuning as well as tyre characteristics which is not relevant for this project as the suspension for the car has already been designed by another student. Much of the frame11 design information covered in this book is the same as found in “The Race Car Chassis” which serves to validate and confirm the information already found rather than actually providing any new information. This does not make the book useless though as it is useful to have a second source back up the information already gathered. “Chassis Engineering” does include some useful pictures of various chassis design models being tested in

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torsion which serve to give a good idea of what designs work well and which ones don't. This information is not quantitative and cannot be directly applied in the design process, but it is likely to be useful in that the design will have a better starting point. The University of Western Australia has a history of competing at the FSAE event successfully. UWA Motorsport (UWAM) has been competing at the event since 2001, winning the Australian competition in 2005 and 2007 and even winning the international competition in 2008. UWAM has been using carbon fibre monocoque chassis since 2003, as discussed earlier the 2011 UWA REV team would not be using a carbon monocoque due to the cost associated.

2.1 SAE Rules and Regulations

All SAE rules and regulations can be found in Appendix A. The Frame rules are specifically, in "SECTION 3 ROLL CAGE, SYSTEMS & DRIVER'S EQUIPMENT." Some highlights of that section are:

- "The driver's helmet to be 15.24 cm (6 in) away from the straightedge applied to any two points on the cockpit of the car, excluding the driver's seat and the rear
  driver safety supports."
- "The driver's torso, knees, shoulders, elbows, hands, and arms must have a minimum of 7.62 cm (3 in) of clearance from the envelope created by the structure of the car."
- Fit a 95% Male driver, while maintaining all constraints above.
- The LBD, LFS, SIM, FAB, and FLC must be at minimum 0.035 wall thickness tubing with a minimum outside diameter (O.D.) of 1 inch.
- The RRH, RHO, FBM, and LC must be "(A) Circular steel tubing with an outside diameter of 2.5 cm (1 inch) and a wall thickness of 3.05 mm (.120 inch) and a carbon content of at least 0.18%", or "(B) Steel members with at least equal bending stiffness and bending strength to 1018 steel having a circular cross section with a 2.5 cm (1 inch) outer diameter and a wall thickness of 3.05 mm (.120 inch)."
- Figure 2 below displays the location of each frame member referred to above.

2.2 Process methodology

This gives us how we can use the size optimization, shape optimization, topology optimization. Below block diagram
shows how we can use these techniques to improve the design and its shape. Let's see these one by one.

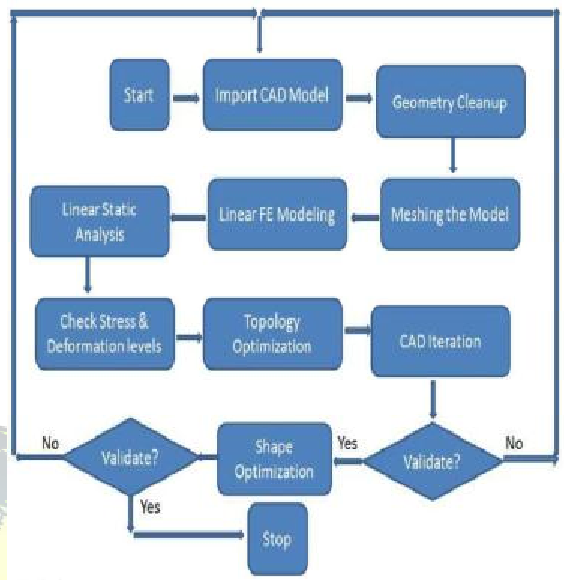

Fig 1. Process Methodology

2.3 General Information

Automotive chassis can be considered as the backbone of any vehicle. Chassis is tasked at holding all the essential components of the vehicle like engine, suspension, gearbox, braking system, propeller shaft, differential etc. To sustain various loads under different working conditions it should be robust in design. Moreover, chassis should be stiff and strong enough to resist severe twisting and bending moments to which it is subjected to. This Project presents the dynamic loading due to impact transient load analysis (including damping and inertia effects) of the Car safety frame of high speed car.

2. CHASIS TYPE AND FRAME

3.1 Sports car chassis

Chassis frames can also be considered as the structures. A carefully weighed arrangement of material that is intended to resist loads is called as structures. Automotive chassis space frame is a skeleton material on which most of the mechanical parts that include the tires, brakes, engines, and etc. are bolted. The chassis usually includes longitudinal channels placed in a pair and multiple transverse cross members that intersect the channels. The space frame in a vehicle includes running gear and the basic structure such as the drive shaft, suspension, transmission and engine. Even the body of a vehicle is entirely supported by a chassis (to let the vehicle get completed). The space frames are basically manufactured with steel or

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aluminium. The increasing use of aluminium for manufacturing the space frames in present world is what can be observed.

3.2 Different Types of Chassis Frames

The different types of chassis that are available in the market are:

- Ladder chassis.
- Back bone chassis.
- Monocoque chassis.

3.2.1 Ladder Chassis

This is the earliest kind of chassis. It looks like a ladder, so for that sake it is called a ladder chassis. The construction of this chassis is two longitudinal rail interconnected by many lateral braces. The rigidity to the structure is provided by the cross members and lateral. Most SUV's are still built up on them, though these types of space frames are not much used in the present day.

3.2.2 Back Bone Chassis

It is simple in structure with a study tubular backbone which joins the front and rear axle and is responsible for most of the mechanical strength of the frame work. At the end of the chassis, the suspension and the drive train are connected. From inside, it resembles the drive shaft tunnel or more conventional front engine vehicles, but the difference is that it was closed in the bottom surface to provide a true tubular section. Still when the torsional stiffness of a chassis is derived from one large central tube running the length of the car, the resistance to twist depends mostly on the cross sectional area of that tube, and it is clearly possible from that cross section to be much larger than that of a typical drive shaft tunnel.

3.2.2 Monocoque chassis

Today, 99% cars produced in this planet are made of steel Monocoque chassis, thanks to its low production cost and suitability to robotised production.

Monocoque is a one-piece structure which defines the overall shape of the car. While ladder, tubular space frame and backbone chassis provides only the stress members and need to build the body around them, Monocoque chassis is already incorporated with the body in a single piece, as you can see in the above picture showing a Volvo V70.

In fact, the "one-piece" chassis is actually made by welding several pieces together. The floorplan, which is the largest piece, and other pieces are press-made by big stamping machines. They are spot welded together by robot arms (some even use laser welding) in a stream production line. The whole process just takes minutes. After that, some accessories like doors, bonnet, boot lid, side panels and roof are added.

Monocoque chassis also benefit crash protection. Because it uses a lot of metal, crumple zone can be built into the structure.

Another advantage is space efficiency. The whole structure is actually an outer shell, unlike other kinds of chassis, therefore there is no large transmission tunnel, high door sills, large roll over bar etc. Obviously, this is very attractive to mass production cars.

There are many disadvantages as well. It's very heavy, thanks to the amount of metal used. As the shell is shaped to benefit space efficiency rather than strength, and the pressed sheet metal is not as strong as metal tubes or extruded metal, the rigidity-to-weight ratio is also the lowest among all kinds of chassis bar the ancient ladder chassis. Moreover, as the whole Monocoque is made of steel, unlike some other chassis which combine steel chassis and a body made of aluminium or glass-fibre, Monocoque is hopelessly heavier than Although Monocoque is suitable for mass production by robots, it is nearly impossible for small-scale production. The setup cost for the tooling is too expensive - big stamping machines and expensive mouldings. I believe Porsche is the only sports car specialist has the production volume to afford that.

in dimensions leads to bigger assembly gaps can be seen. This is usually perceived as lower visual quality compare with steel Monocoque. 2) Image problem. Many people don't like "plastic cars".

Glass-fibre has become a must for British sports car specialists because it is the only way to make small quantity of cars economically. In 1957, Lotus pioneered Glass-fibre Monocoque chassis in Elite (see picture). The whole mechanical stressed structure was made of glass-fibre, which had the advantage of lightweight and rigidity like today's carbon-fibre Monocoque. Engine, transmission and suspensions were bolted onto the glass-fibre body. As a result, the whole car weighed as light as 660 kg.

However, this radical attempt caused too many problems to Colin Chapman. Since the connecting points between the glass-fibre body and suspensions / engine required very small tolerances, which was difficult for glass-fiber, Lotus actually scrapped many out-of-specification body. Others had to be corrected with intensive care. As a result, every Elite was built in loss. Since then, no any other car tried this idea again. Today, no matter Lotus, TVR, Marcos, GM's Corvette / Camaro / Firebird, Ventura and more, employ glass-fiber in non-stressed upper body. In other words, they just act as a beautiful closure and provide aerodynamic efficiency. The stressed chasses are usually backbone, tubular space-frame, aluminium space-frame or even Monocoque.

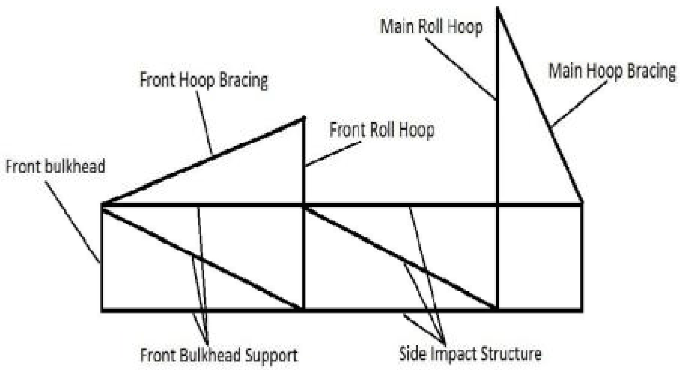


Figure 2. Pictorial representation of the members required by the FSAE rules

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

Figure 3 2011 Formula SAE Rules for Member size. Adapted from 2011 Formula Student rules (SAE, 2010)

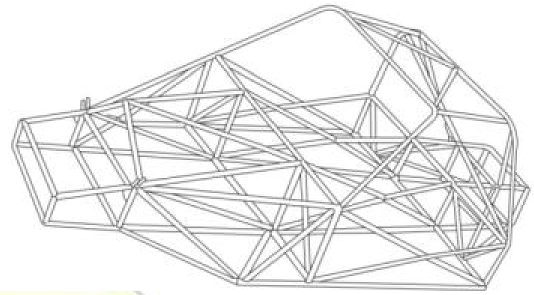
3.2.6 Space frames

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

- Increasing depth increases bending strength
- Used in race cars
- All planes are fully triangulated
- Beam elements carry either tension or compressive loads.
- Ring frames depends on bending of elements

A) Windscreen, back light
B) Engine compartment, doors
C) Lower shear stiffness

- In diagonal braced frame s stiffness provided by diagonal element



3.2.7 Integral structures

Modern cars are mass produced

• Sheet steel pressings and spot welds used to form an integral structure
• Components have structural and other functions
• Side frames + depth + roof gives good bending and torsional stiffness
• Geometrically very complicated
• Stress distribution by FEM only
• Stress distribution is function of applied loads and relative stiffness between components
• Advantages:

A) Stiffer in bending and torsion
B) Lower weight
C) Less cost
D) Quiet operation

3.3 Purpose of Chassis Frames in a Vehicle

i. The main purpose of the chassis frame is that, it carries all the mechanical parts of a vehicle like tires, engine, axle assemblies, steering and brakes and all these mechanical parts are bolted to this skeletal frame.

ii. Under any conditions, the strength, and stability is provided to the vehicle by these chassis frames.

iii. One of the basic purposes of the chassis frame is to rigidly connect the front and rear suspension while providing attachment points for different systems of a car.

iv. Throughout the automobile, low levels of noise, harshness and vibrations are ensured by the frames.

v. The weight efficiency of the vehicle is improved by the space frame chassis only.

vi. A proper and structured built frame improves the crash worthiness and also the safety of a passenger while driving.

3.4 Idealization of a Chassis Frame

The main aim of this project is to design a chassis space frame and determine its stresses, torsional stiffness, bending stiffness, cross sectional area and the moment of inertia of the frame by using finite element analysis and thus the final procedure of modal analysis follows at the end. A specific load is to be applied at the centre where the entire weight of the chassis space frame can be suspended. Firstly, and very firmly a space frame from ALMA building was selected. The model of the space frame is a Class 1 type racing vehicle. The weight, height and the dimensions of the space frame were measured using ruler, weighting gauges. These instruments were used from the metrology lab. It is a steel space frame. The overall length of the chassis is 2650mm, the wheelbase is 2000mm and its weight is 35 kilograms. The measurements obtained were implemented in the computer using the software CATIA V5. After the design was prepared it was imported into ANSYS Classic 11.0 for analysing. Static analysis and modal analysis was done to find out the stresses of the space frame and all the 6 Degrees of freedom. The model was first developed using CATIA V5 software. The procedure in brief for this is as follows: -Firstly 4 points were located on a surface and then denoted as point 1, 2 3 and point 4. Next 4 lines were allowed to join these 4 points and then sweep was used to sweep all the 4 joined points and in this way the entire procedure was carried out and finally the chassis space frame was designed using this software of Catia V5.

3.5 Production process

Carbon-fibre panels are made by growing carbon-fiber sheets (something look like textile) in either side of an aluminium foil. The foil, which defines the shape of the panel, is sticked with several layers of carbon fiber sheets impregnated with resin, then cooked in a big oven for 3 hours at 120°C and 90 psi pressure. After that, the carbon fiber layers will be melted and form a unformal, rigid body panel.

<u>4.0 ASSUMPTIONS</u>

Any problem becomes complex if the real situation is considered. It becomes very difficult to analyze the problem with such complexities. In order to simplify the problem, some assumptions are made. In the present analysis the following assumptions are made

- The tyres are considered as linear springs.
- The mass of the engine gearbox and the other components are lumped at exactly placed at centre of gravity location of nodes.

4.1 Boundary Condition

Following displacement constraints are applied in the present modelling.

- Three times of gravity load is applied to the weight of the chassis body (3G beaming load), tyre contact patch location (i.e. A, B, C and E) nodes were constrained all degree of freedoms to carry out the applications of static analysis.
- In modal analysis the bottom points of tyres are fully arrested in all degrees of freedom

<u>5.0 CATIA V5</u>

Initially, CATIA name is an abbreviation for “Computer Aided Three-dimensional Interactive Application”.

We had already said in the introduction of historical, that the French Dassault Systems is the parent company and IBM participates in the software’s and marketing, and Catia is invades broad industrial sectors, and has been explained in the previous post position of CATIA between 3d modelling software programs.

Now we will speak about another point which is whether there is a drawing program better than the other?... we must know, that drawing programs provides us drawing tools while not any of them can provide you the ability to design, you should, thinking and looking and imagine then building a design in your mind, either drawing program will help you to transform these designs graphics on papers, for that, we prefer CATIA because it provides us with all the tools that we need.

Before we come to learning any 3d modelling software's, you must know their classification as a drawing program, Where CATIA classified under the following software packages:

CAD (Computer Aided Design)

CAM (Computer Aided Manufacturing)

In general, “CAE (Computer Aided Engineering)” Version that most of the people works on it now is CATIA V5 or fifth version, which is a rewriting and revision the code of the fourth edition.

For the fifth version, there are versions from 1 to 20, for example, CATIA V5 R17, it Means CATIA fifth edition

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version seventeenth, while years system was adoption in the sixth edition, for example, CATIA V6 2011 means CATIA sixth edition version of Year 2011.

5.1 3-d view of catia model of SUV frame

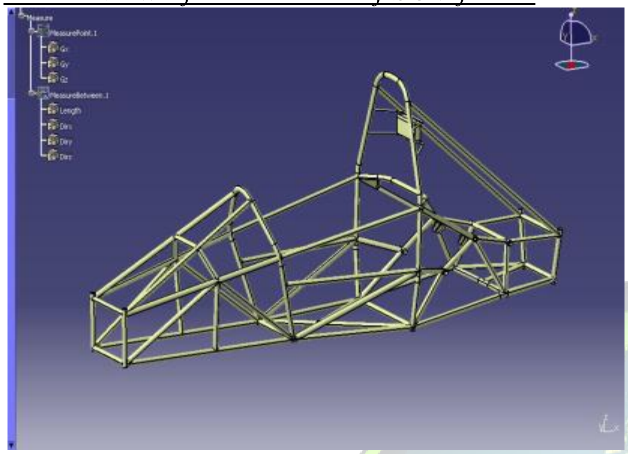


Fig -5.1A - 3-d view of Catia model of SUV frame

5.2 FEM model of suv frame

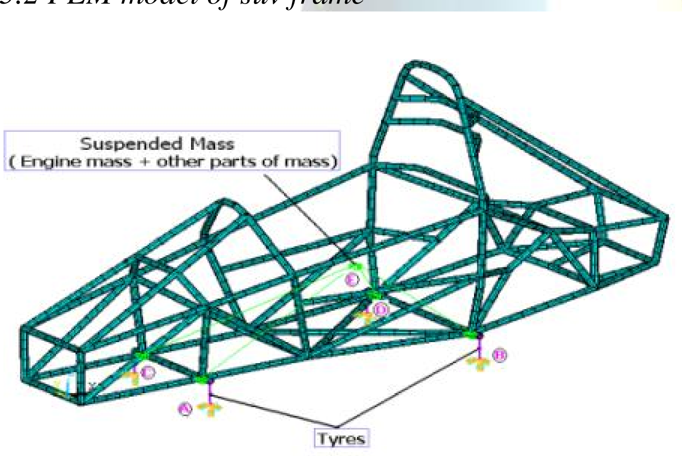


Fig -5.2A -_FEM model of SUV frame

5.3 Tubular Cross Section Properties

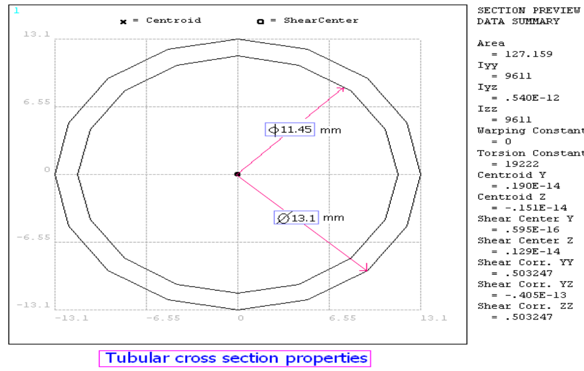


Fig -5.3A - Tubular Cross Section Properties

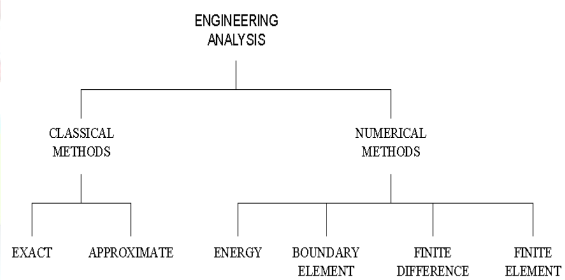
Material selection where done according to the stress induced in chassis & AISI 1018

Material specification as follows

- Outer Diameter. Pipe1 =25.4mm
- Thickness on pipe1 =2.88 mm
- Outer Diameter. Pipe 2 =50.8mm
- Thickness of pipe 2 = 3.9mm

6.0 ANALYSIS

As a start, it is useful to see where the finite element method fits in with other methods of engineering analysis. Engineering analysis can be broadly divided into two categories: classical methods and numerical methods.



6.1 CLASSICAL METHODS

Classical methods attempt to solve field problems directly by forming governing differential equations based on fundamental principles of physics. Exact solutions--those having closed forms--are possible only for the simplest cases of geometry, loading, and boundary conditions. A somewhat wider variety of classical problems can be solved using approximate solutions to the governing differential equations. These solutions take the form of series expansions that are truncated after a reasonable degree of convergence. In the structural world, many of Timoshenko's works and Roark's

Formulas for Stress and Strain are essentially catalogs of these types of solutions. Like exact solutions, approximate solutions require regular geometric shapes, simple boundary conditions, and well behaved loads. Consequently, these solutions bear little resemblance to most practical engineering problems. The principal advantage of classical methods is the high degree of problem insight provided by solutions of this type.

6.2 NUMERICAL METHODS

Numerical methods address a broad range of problems. The energy method seeks to minimize an expression for the potential energy of a structure over its entire domain. This approach works extremely well for certain problems, but it is not broadly applicable. The boundary element method approximates functions satisfying the governing differential equations, but not the boundary conditions. Problem size is reduced because elements represent only the boundary of the domain. However, the application of this method relies on knowing the fundamental solution to the governing equations, which can be difficult to obtain. The finite difference method replaces governing differential equations and boundary conditions with corresponding algebraic equations. This permits the representation of somewhat irregular problems, but complex geometry, boundary conditions, or loads become difficult to handle.

6.3 THE FINITE ELEMENT METHOD

The finite element method offers virtually unlimited problem generality by permitting the use of elements of various regular shapes. These elements can be combined to approximate any irregular boundary. In similar fashion, loads and constraints of any type can be applied. Problem generality comes at the expense of insight--a finite element solution is essentially a stack of numbers that applies only to the particular problem posed by the finite element model. Changing any significant aspect of the model generally requires a complete reanalysis of the problem. Analysts consider this a small price to pay, however, since the finite element method is often the only possible method of analysis. The finite element method is applicable to all classes of field problems, including structural analysis, heat transfer, fluid flow, and electromagnetics. In this book, we will concentrate on linear static structural analysis. Two various analysis is carried out in this projects. Static loading and dynamic impact test in unsymmetrical manner. Finite element model has generated. All the parts are assumed to be bar elements.

Finite element analysis seeks to approximate the behaviour of an arbitrarily shaped structure under general loading and constraint conditions with an assembly of discrete finite elements. Finite elements have regular (or nearly regular) geometric shapes and known solutions. The behaviour of the structure is obtained by analysing the collective behaviour of the elements.

6.4 Final 3-D model of SUV Chassis

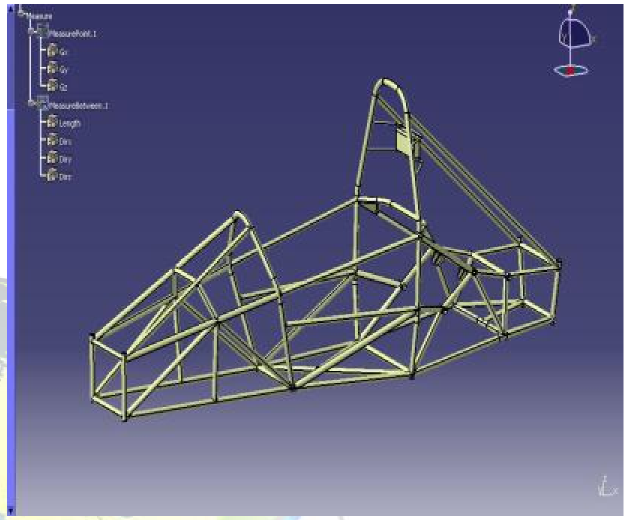


Fig 6.4A - 3D- View of SUV chassis modelled in Catia-v5

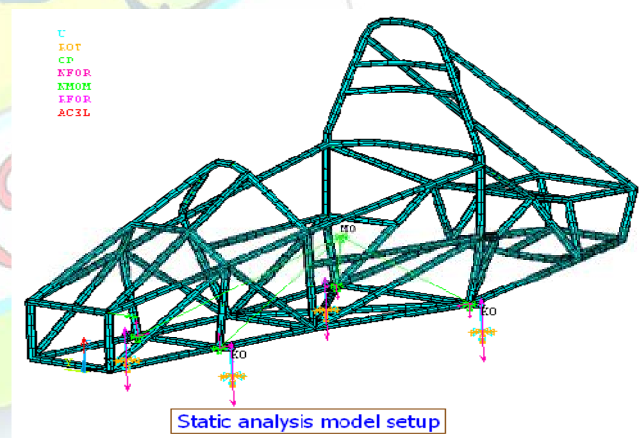


Fig 6.4B Static Analysis Setup Model

6.5 -3D View of FEM

Above showing figure defines the FEM of car safety frame. These elements are first order elements having two nodes on both side. Element identification numbers should be unique with respect to all other element identification numbers.

Bar element geometry shows below.

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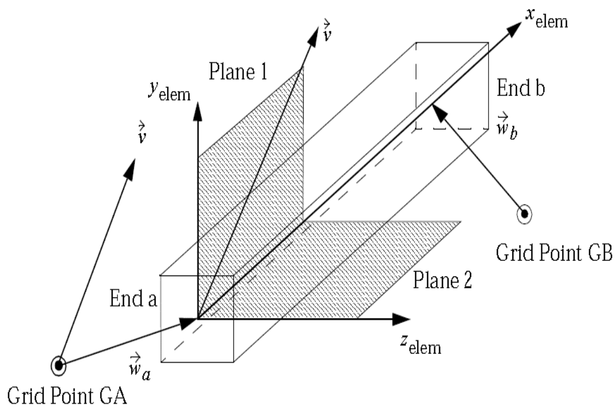

6.6 BAR ELEMENT

Two various materials used in the formation of car safety frame, Steel and aluminium. The inner frame contains steel and remaining portion made of aluminium.

Length = mm
Force = N
Mass = Ton

6.7 STATIC ANALYSIS

Static test is carried out to find out the static strength of the Car safety frame. A number of important assumptions and limitations are inherent in linear static analysis. As a finite element analyst, you are responsible for ensuring that these restrictions are understood and accounted for. Failure to do so will result in an analysis that on the surface appears credible, but in reality is not faithful to the structure's physical behavior. Restrictions on linear static analysis are summarized as follows:

LINEAR ELASTIC MATERIAL –

Our material is assumed to be homogeneous and isotropic. We are restricted to material in which stress is directly proportional to strain (linear) and to loads that do not take the material beyond its permanent yield point (the material remains elastic). In addition, we assume that the unloaded structure is free of initial or residual stress.

SMALL DISPLACEMENTS –

We are restricted to the small displacement assumptions used in the formulation of governing equations for linear beam, plate, shell, and solid behaviour and in MSC Nastran element development. In practice, these assumptions mean lateral plate deflections substantially smaller than the thickness of the plate and beam deflections substantially less than the smallest dimension of the beam's cross section. Violating linear analysis restrictions on small displacements quickly leads to grossly inaccurate displacement results-large displacements require nonlinear analysis methods

SLOWLY APPLIED LOADS –

In linear static analysis our structure is in static equilibrium. Loads must be "slowly applied," which means that they induce no dynamic effects. Some types of loads, such as impact loads, violate this restriction in an obvious way. Some loads are not as obvious. Suppose that you place a brick on the surface of a cantilever beam and then release the brick quickly. The resulting maximum deflection will be greater than the final static equilibrium position. Although impact is not involved, dynamic effects occur. Therefore, "slowly applied" can, for our purposes, be taken to mean a load that does not result in significant dynamic behaviour.

6.7.1 Procedure for Static Analysis

- The model using linear elements by using tapered beam44, combination14, structural mass21 was created and coupled with mass to the structure by couple-couple equations.
- The material properties of linear isotropic such as young's modulus= 206900 MPa and density of steel and poisons ratio= 0.27 have been defined.
- The lumped mass like engine, gear box, propeller shaft, including the lumped mass, passengers and driver's mass placed on the chassis at appropriate centre of gravity nodes locations.
- The nodal degrees of freedom at the bottom nodes of the tyre in all directions have been arrested.
- Enter the ANSYS solution Pre-processor in which analysis type is modal analysis, and by selecting static method, solution method is continued by using linear static method.
- The problem is solved by using current LS command from the solution menu bar

6.8 Modal Analysis

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. The main aim of modal analysis is to obtain the Eigen

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frequencies, eigenvectors and different mode shapes of the model at different frequencies. Block Lanczo's method was used for modal analysis with the help of ANSYS. Block Lanczo's method is used to find out the closed spaced eigenvectors of large symmetric matrix. This method was used for trigonalization only. The frequency response function is displayed between any two-measurement points on the vehicle independent of the exciter locations chosen for the actual test data collection. Display the response the vehicle at any single point to any type of specified input force at any other point. Display in animated form, the natural mode shapes of the vehicle.

6.8.1 Procedure for Modal Analysis

- A model using linear elements is created because only linear behaviour is valid in the modal analysis
- The material property of linear isotropic such as young's modulus= 206900 MPa and density are defined.
- The lumped mass like engine, gear box, propeller shaft, including above lumped mass, passengers and drivers mass placed on the chassis at appropriate nodes locations.
- The nodal degrees of freedom at the bottom nodes of the tyre in all directions are arrested.
- Enter the ANSYS solution processor in which analysis type is taking as modal analysis, and by taking mode extraction method, by defying number of modes to be extracted.
- Solution method is chosen as block Lanczo's method.
- The problem is solved using current LS command from the solution menu bar.

6.9 TRANSIENT RESPONSE ASNALYSIS

Transient response analysis is the most general method for computing forced dynamic response. The purpose of a transient response analysis is to compute the behavior of a structure subjected to time varying excitation. The transient excitation is explicitly defined in the time domain. All of the forces applied to the structure are known at each instant in time. Forces can be in the form of applied forces and/or enforced motions. The results obtained from a transient analysis are typically displacements and accelerations of grid points, and forces and stresses in elements. Depending upon the structure and the nature of the loading, two different numerical methods can be used
for a transient response analysis: direct or modal. Direct transient response analysis performs a numerical integration of the complete coupled equations of motion. Modal transient response analysis uses them normal modes of the structure to uncouple the equations of motion with the solution obtained through the summation of the individual modal responses.

7. CALCULATIONS

[1] Front impact – In this case, the front of the car, disregarding the impact attenuator is considered to collide with a stationary object in a head-on collision at maximum speed with an impact time of 0.4 sec.

[2] Rear impact – In this case, another car is considered to collide head-on with the rear of the car at maximum speed with an impact time of 0.8 sec.
[3] Side impact – In this case, a sideways impact into an obstruction is considered at the maximum speed with an impact time of 0.6 sec.

[4] Rollover impact – In this case, overturning or rollover of the chassis is considered and the effect of self-weight is considered as an impact load.

[5] Torsional rigidity - The torsional rigidity of the frame is determined by applying an equal and opposite bending moment on the chassis and quantifying the angular displacement.

7.1 Centre of Gravity

Centre of mass location X =1179.2 mm
Y =-0.34809 mm
Z =323.89 mm
Moment of inertia about centre of mass= Ixx= 3876.0 mm^4
Iyy= 0.1848e+5 mm^4
Izz= 0.1768e+5 mm^4
Ixy= -4.664 mm^4
Iyz= 3.594 mm^4
Izx= -1066 mm^4
Stiffness calculation race car chassis frame.
For stiffness calculation we have applied unit load (i.e. 1 N force) on the chassis, due to this load maximum deformation on chassis is 0.633e-3 mm obtained.

Structural Stiffness of Member Formula
[K]* [X] = [F]
Where K is called the stiffness matrix,
X is called the displacement matrix and
F is the load matrix so,
K=F/X=1/0.633e-3
=1579.03 N/mm
Chassis stiffness is 1579.03 N/mm

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7.2 Front Impact Test Assumptions made-

- Car travelling at 27.77m/s rams into stationary mass longitudinally.
- Crash impulse of 0.4 s
- Force distribution ratio = 70-30
  - 70% on bulkhead members and 30% on frontal cross members

Such distribution is assumed keeping in mind that that the cross members are—

[1] Welded to support the impact attenuator and

[2] Prevent the longitudinal penetration of impact attenuator and of any broken part from the front.

[3] Form triangulated structure to increase the stiffness of the frame members of front bulkhead.

[4] The cross members are not bonded to any other member in the longitudinal direction and hence tend to form

cantilever type structure when load is applied. The total force acting on the front bulkhead was calculated using following relations-

[1] Final velocity(v) = initial velocity(u) + acceleration(a)*time(t)

[2] Total force(f)1 = mass(m)*acceleration(a)

[3] Force [f2] = stiffness[k]*deformation[x] (at node level)

[4] Stress = force/area

[5] Acceleration = 69.44 m/s2 (retarding)

Total force acting on the body = 400*69.44 N = 27776.47 N by doing the time independent static analysis of structure for frontal impact, we are able to observe the result for-

1. Total deformation in the body
2. Stress induced

7.3 Rear Impact Test Assumptions made

- Vehicle travelling at 27.77m/s crashes into a stationary vehicle
- Crash impulse = 0.8
- Acceleration=-34.71m/s2(retardation)
- Force applied =400 x 34.71= 13444.44 N

The entire energy transfer will be in the form of kinetic energy and potential energy.

7.4 Side Impact Test- Assumptions made

- Car travelling at 27.77m/s rams into a stationary vehicle
- Crash Impulse- 0.6

In case of any side or lateral collision the maximum amount of forces are transferred to the between them. The entire energy transmitted is stored in the form of
1] Potential energy, which causes the deformation and induces the stresses in body and 2] Kinetic energy, which causes the body to have some lateral motion after collision.

Due to kinetic energy of the body, the body motion ceases after comparatively larger duration. This increases the stopping time of the vehicle thus reducing the effects of impact up to some level.

The formulae used for the force calculation are same as above.

Acceleration = -46.283m/s2 (retarding)
Force = 400*46.283 N
= 18512.56N

By doing the time independent static analysis of structure for frontal impact, we are able to observe the result for
[1] Total deformation in the body
[2] Stress induced

7.5 Material Properties

Anisotropy and Isotropy material properties.
In a single crystal, the physical and mechanical properties often differ with orientation. It can be seen from looking at our models of crystalline structure that atoms should be able to slip over one another or distort in relation to one another easier in some directions than others.
When the properties of a material vary with different crystallographic orientations, the material is said to be anisotropic. Alternately, when the properties of a material are the same in all directions, the material is said to be isotropic. For many polycrystalline materials the grain orientations are random before any working (deformation) of the material is done.
Therefore, even if the individual grains are anisotropic, the property differences tend to average out and, overall, the material is isotropic. When a material is formed, the grains are usually distorted and elongated in one or more directions which make the material anisotropic. Material forming will be

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discussed later but let us continue discussing crystalline structure at the atomic level. forming will be discussed later but let us continue discussing crystalline structure at the atomic level.

7.6 Material Selection

As per the material survey the best suited material is the aluminum alloy. The mentioned material was chosen as the material for bicycle frame due to its low density and compatible yield strength. This material was chosen for designing
frame and comparing its results with different materials as mild steel, EN8 etc.

Table1 and table2 indicates the material properties considered.
Optional Material

1. Al-6061-magnesiam and Silicon Major Alloying Element-density 2.70g/Cm^3.
2. Al-7005-Zinc-density-2.78g/cm^3- depending on the temper, may be slightly stronger.

Bamboo fiber based composite material. [BF (30%) + PP]

7.6.2Comparison of properties

Material	Density (g/m3)	Young's Modulus (GPA)	Yeild Strength (MPA)
Mild steel	7.83	210	280-310
Al6061	2.70	69	64-350
Al7075	2.78	71	95-345

Table7.6.2A Comparison of mechanical properties

Material selection where done according to the stress induced in chassis & AISI 1018
Material specification as follows

- Outer Diameter. Pipe1 =25.4mm
- Thickness on pipe1 =2.88 mm
- Outer Diameter. Pipe 2 =50.8mm
- Thickness of pipe 2 = 3.9mm

8.0 ANALYSIS OF MILD STEEL FRAME

Once the CATIA modelling of mild steel frame is completed, material grade will be assigned as mild steel and the analysis will be done. The results of the analysis will be as follows.

8.1 Front Impact Test of mild steel Frame
8.1.1 Displacement vector sum

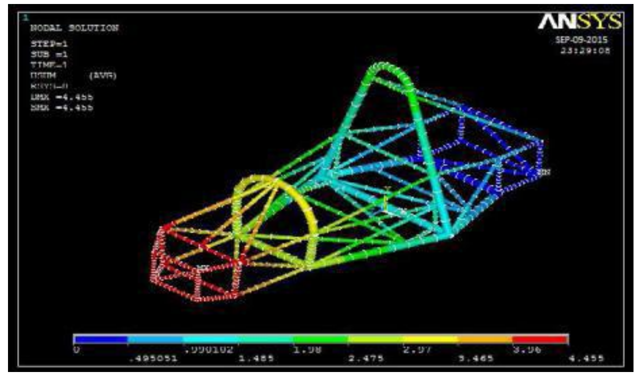

Fig – 8.1.1A Front Impact Test Displacement vector of mild steel Frame

8.1.2 Stress Intensity

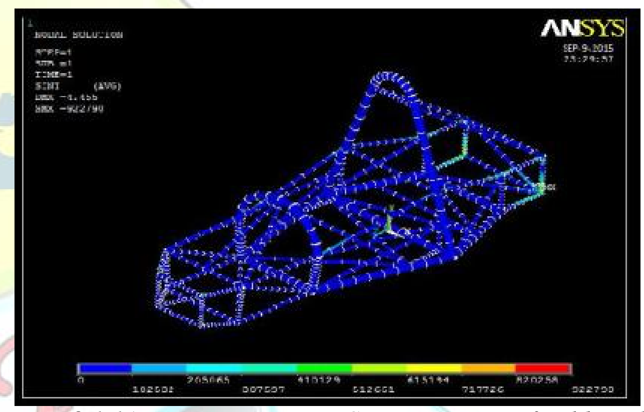

Fig – 8.1.1A Front Impact Test Stress Intensity of mild steel Frame

8.2 Rear Impact Test of mild steel Frame
8.2.1 Displacement vector sum

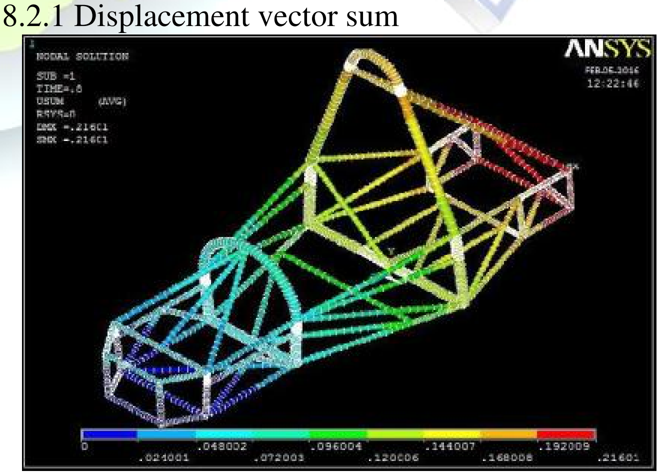

Fig - 8.2.1A Rear Impact Test Displacement vector of mild steel Frame

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8.2.2 Stress Intensity

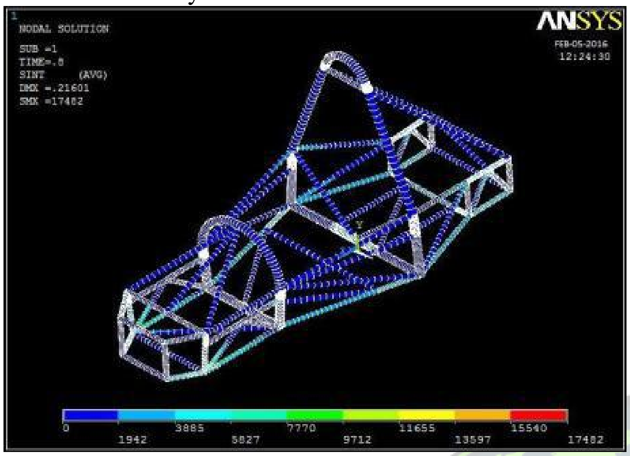

Fig - 8.2.2A Rear Impact Test Stress Intensity of mild steel Frame

8.3 Side Impact Test of mild steel Frame

8.3.1 Displacement vector sum

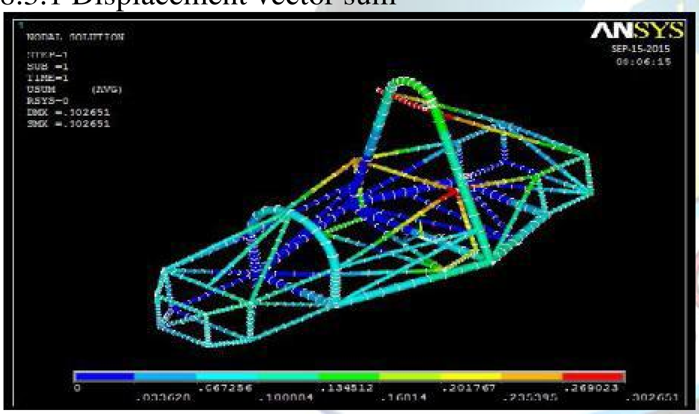

Fig - 8.3.1A Side Impact Test Displacement vector of mild steel Frame

8.3.2 Stress Intensity

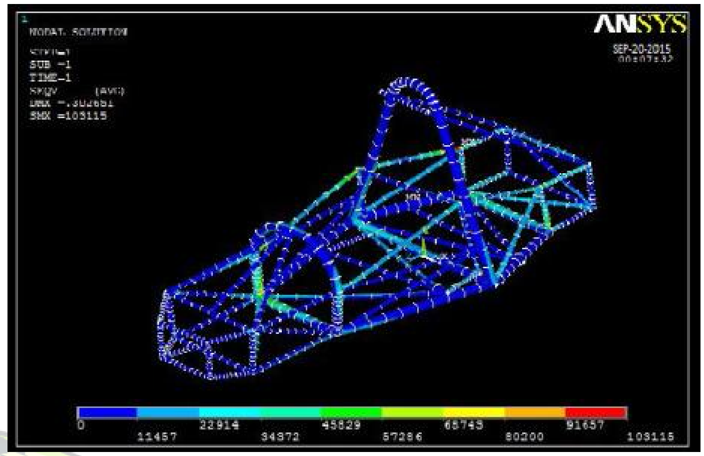

Fig - 8.3.2A Side Impact Test Stress Intensity of mild steel Frame

9.0 ANALYSIS OF Al7075 FRAME

Once the analysis of mild steel frame is completed, Modifications were done to the frame by changing the material grade to AL6061 and the same procedure of analysis has to be repeated and it shows following result as shown below

9.1 Front Impact Test of Al6061 Frame

9.1.1 Displacement vector sum

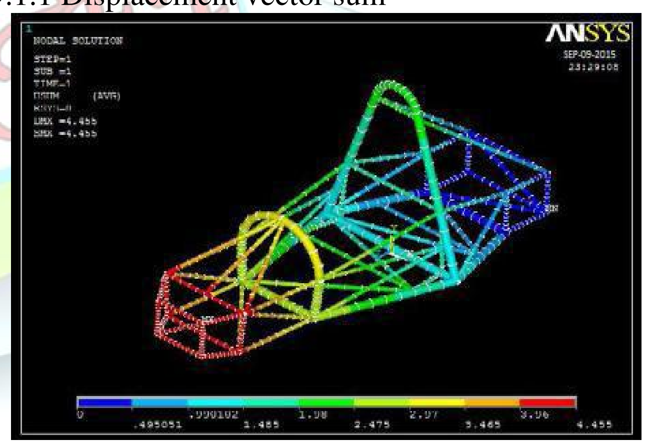

Fig 9.1.1A Front Impact Test Displacement vector of Al6061 Frame

9.1.2 Stress Intensity

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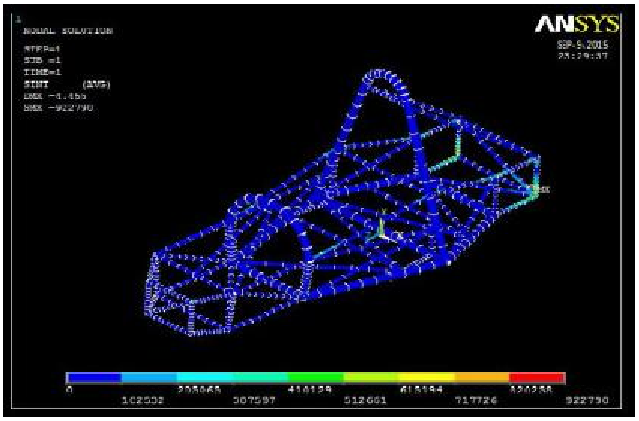

Fig – 9.1.2A Front Impact Test Stress Intensity of Al6061 Frame

9.2 Rear Impact Test of Al6061 Frame

9.2.1 Displacement vector sum

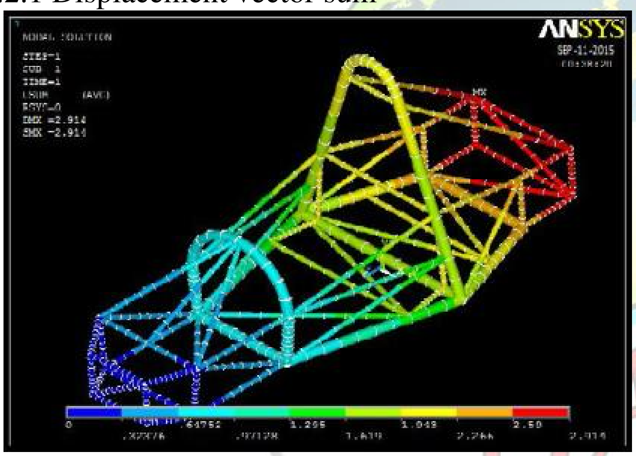

Fig – 9.2.1 Rear Impact Test Displacement vector of Al6061 Frame

9.2.2 Stress Intensity

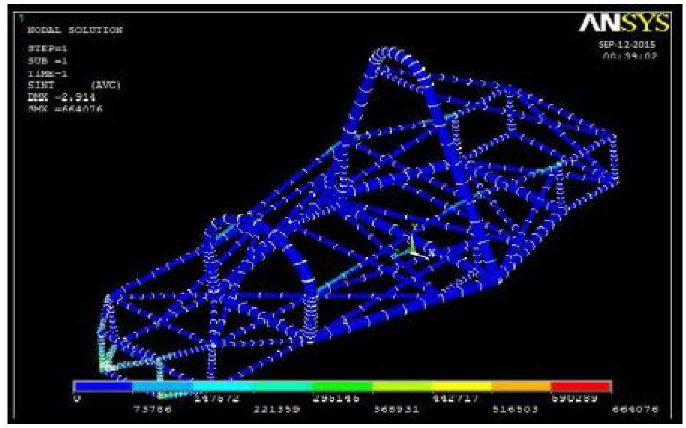

Fig – 9.2.2A Rear Impact Test Stress Intensity of Al6061 Frame

9.3. Side Impact Test of Al6061 Frame

9.3.1 Displacement vector sum

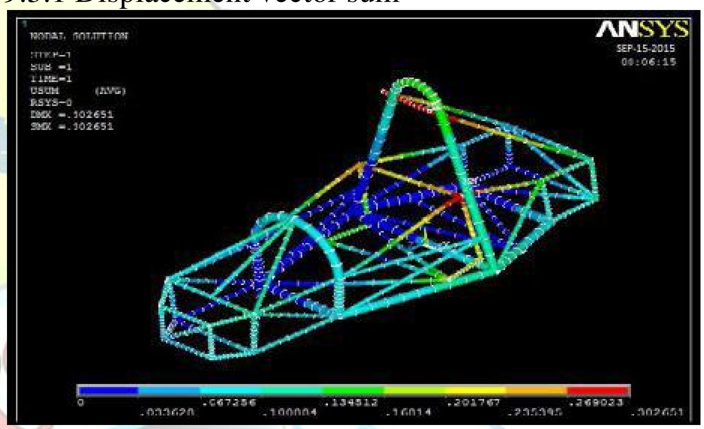

Fig - 9.3.1A Side Impact Test Displacement vector of Al6061 Frame

9.3.2 Stress Intensity

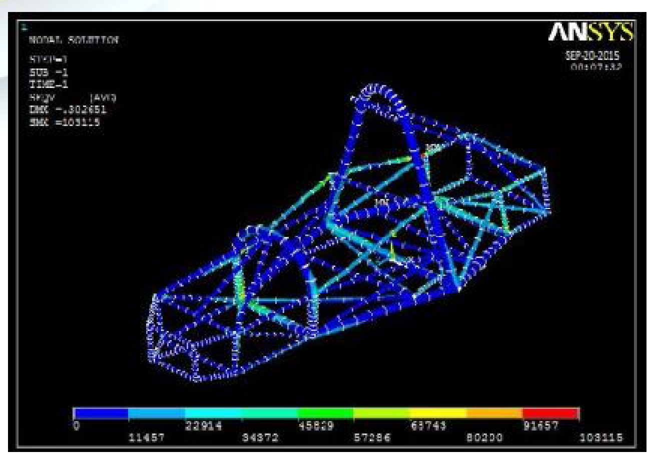

Fig - 9.3.2A Side Impact Test Stress Intensity of Al6061 Frame

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10.0 ANALYSIS OF Al7075 FRAME

Once the analysis of Al6061 frame is completed, Modifications were done to the frame by changing the material grade to AL7075is and analysis shows following result as shown below

10.1 Front Impact Test of Al7075 Frame

10.1.1 Displacement vector sum

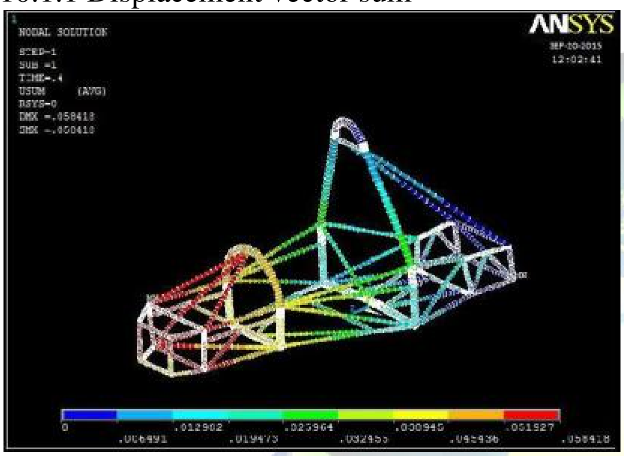

Fig – 10.1.1A Front Impact Test Displacement vector of Al7075 Frame

10.1.2 Stress Intensity-

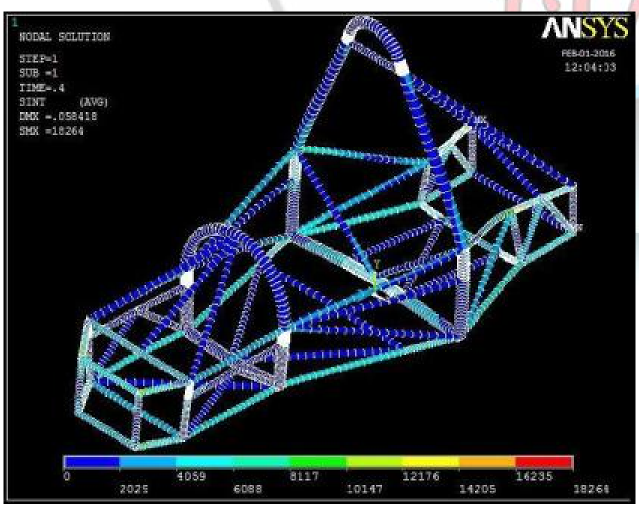

Fig – 10.1.2A Front Impact Test Stress Intensity of Al7075 Frame

10.2 Rear Impact Test of Al7075 Frame

10.2.1 Displacement vector sum

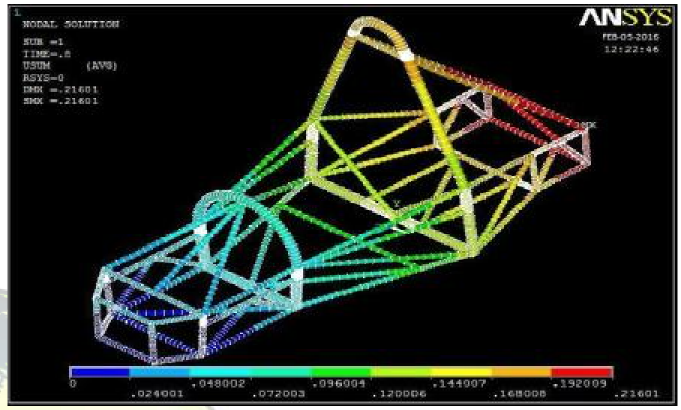

Fig – 10.2.1A Rear Impact Test Displacement vector of Al7075 Frame

10.2.2 Stress Intensity

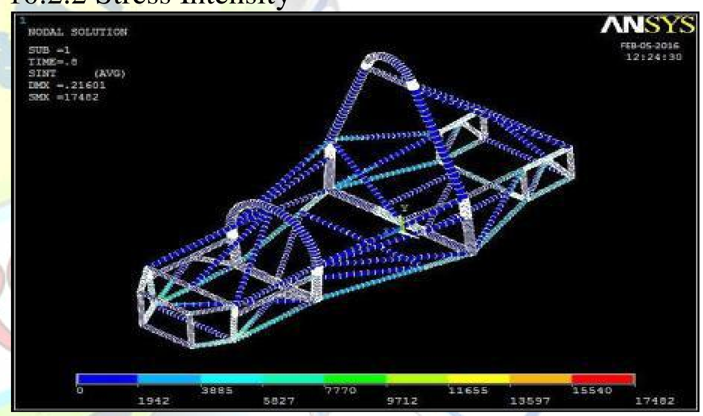

Fig – 10.2.2A Rear Impact Test Stress Intensity of Al7075 Frame

10.3 Side Impact Test of Al7075 Frame

10.3.1 Displacement Vector Sum

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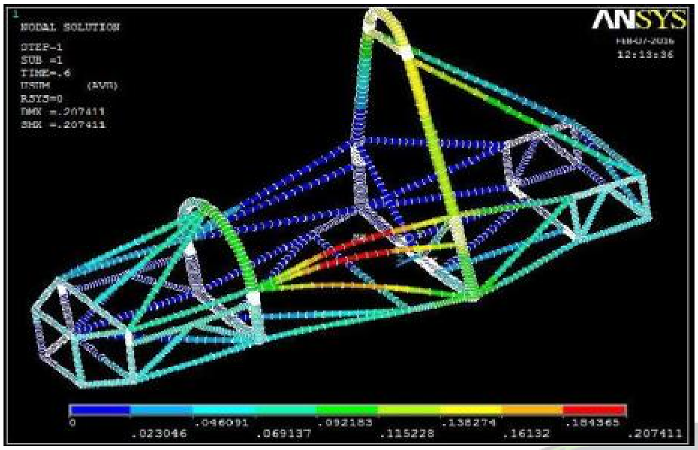

Fig – 10.3.1A Side Impact Test Displacement vector of Al7075 Frame

10.3.2 Stress Intensity

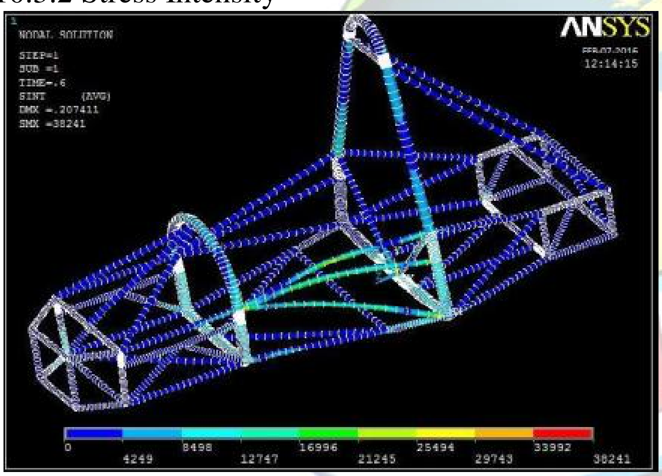

Fig – 10.3.1A Side Impact Test Stress Intensity of Al7075 Frame

11.0 Roll over test

This test is done to check the strength of main roll hoop when the vehicle overturn, when any vehicle overturn the total weight of vehicle fall on the top most point of chassis in the direction positive x or negative x.

Thus we have applied force in positive x direction at the top most point of chassis (i.e. at top point of main roll hoop).

11.1 Roll over test of Mild steel frame

11.1.1 Displacement vector sum

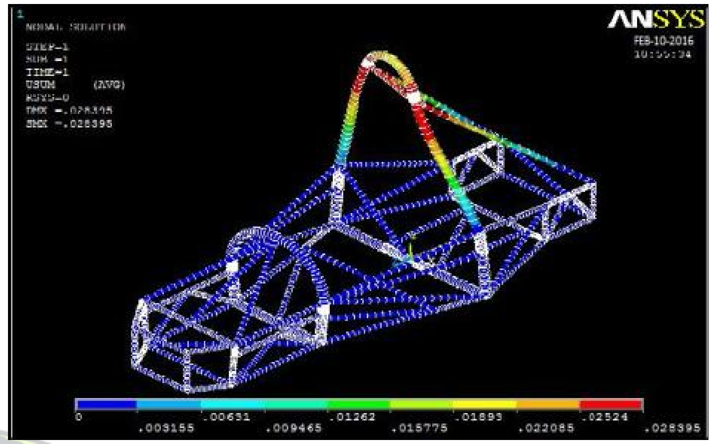

Fig – 11.1.1A Roll Over Test Displacement vector sum of mild steel Frame

11.1.2 Stress intensity

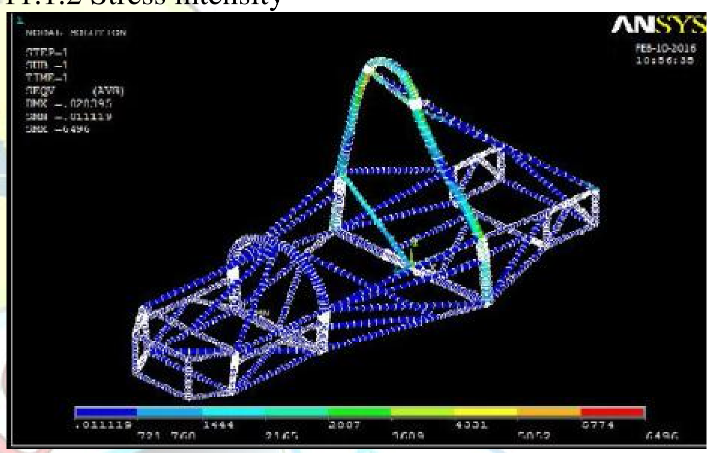

Fig – 11.1.2A Roll Over Test Stress intensity of mild steel Frame

11.2 Roll over test of Al6061 frame

11.2.1 Displacement vector sum

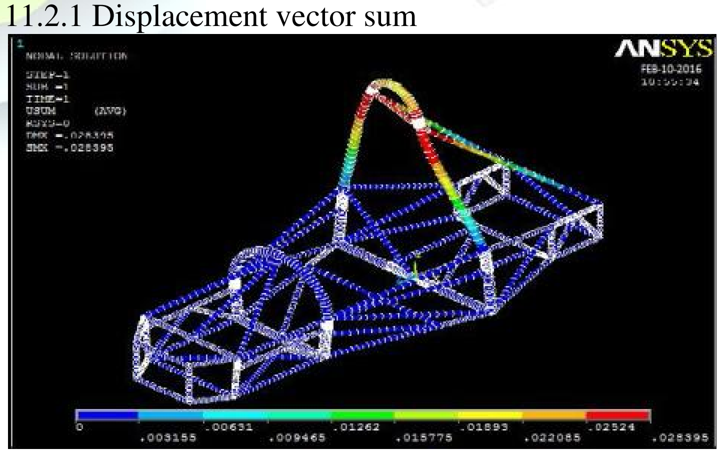

Fig – 11.1.1A Roll Over Test Displacement vector sum of Al6061 Frame

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11.2.2 Stress intensity

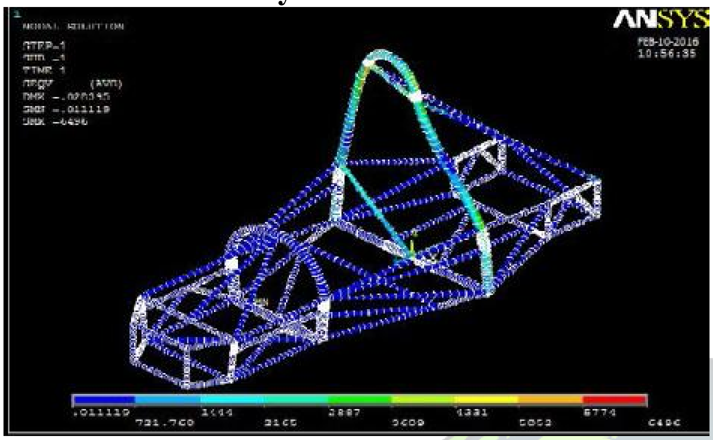

Fig – 11.1.2A Roll Over Test Stress intensity of Al6061 Frame

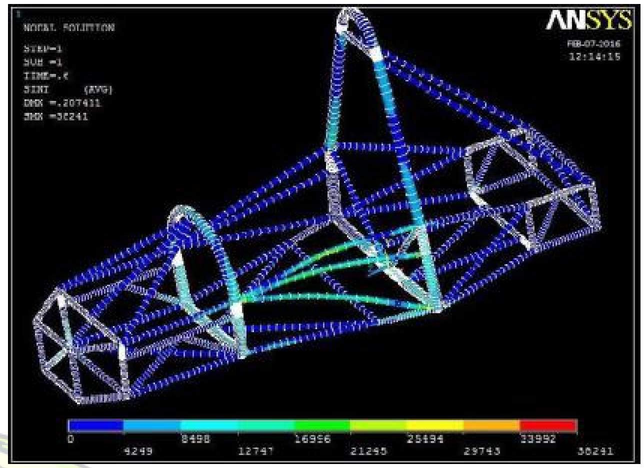

Fig – 10.3.2A Side Impact Test Stress Intensity of Al7075 Frame

11.3 Roll over test of Al7075 frame

11.3.1 Displacement Vector Sum

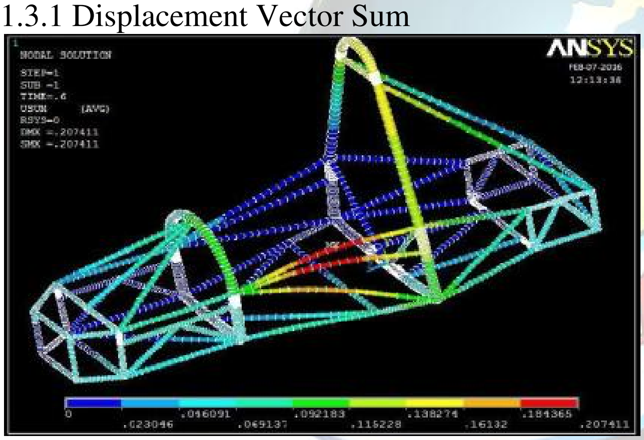

Fig – 11.3.1A Side Impact Test Displacement vector of Al7075 Frame

10.3.2 Stress Intensity

12.0 Torsional test

Rear suspension mounting points of the frame were fixed and loads were applied in the front suspension spring mounting as shown in the figure X. Maximum displacement obtained from the results and torsional rigidity was found using the following formula

K=FL/tan^-1(dy1+dy2)/2L

A couple force of 2000N is calculated value for torsional rigidity analysis.

12.1 Torsional test of Mild Steel frame

12.1.1 Displacement vector sum

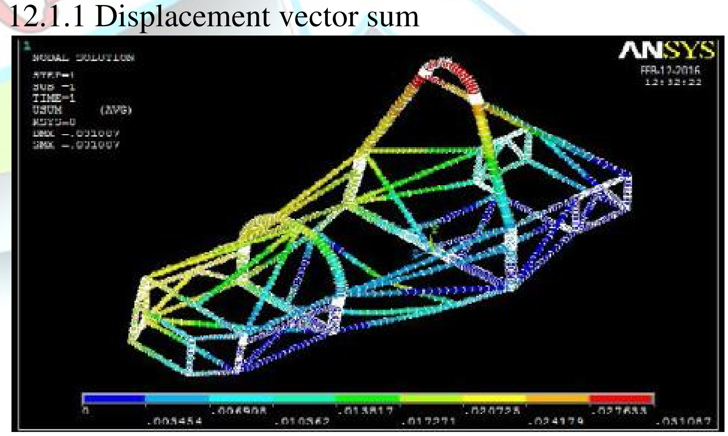

Fig – 12.1.1A Torsional Test Displacement vector sum of mild steel Frame

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12.1.2 Stress intensity

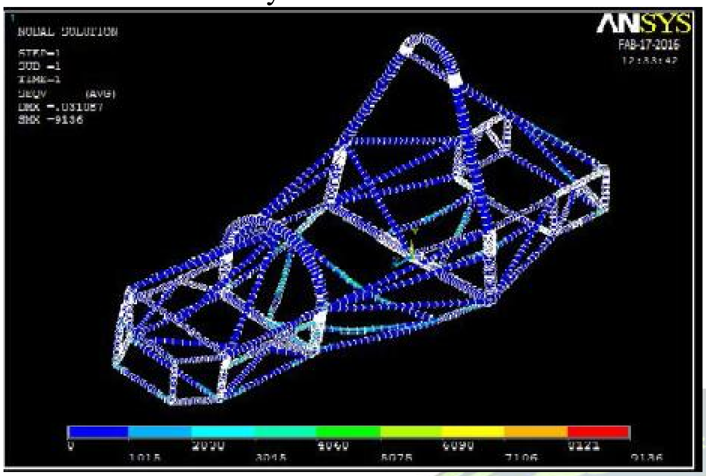

Fig – 12.1.2A Torsional Test Stress intensity of mild steel Frame

12.2 Torsional test of Al6061 Frame

12.2.1 Displacement vector sum

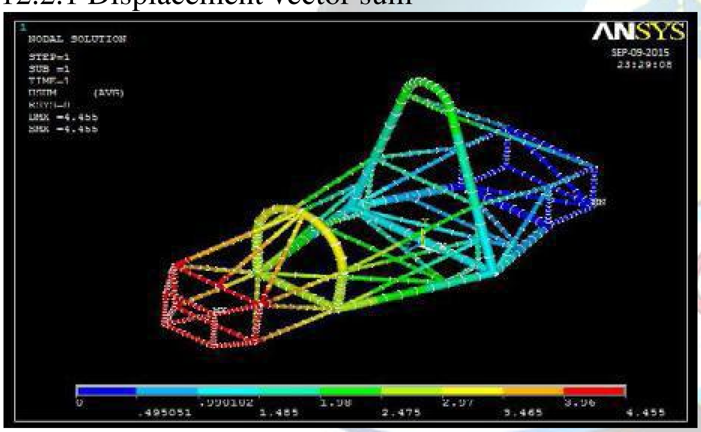

Fig – 12.2.1A Front Impact Test Displacement vector of Al6061 Frame

12.2.2 Stress Intensity

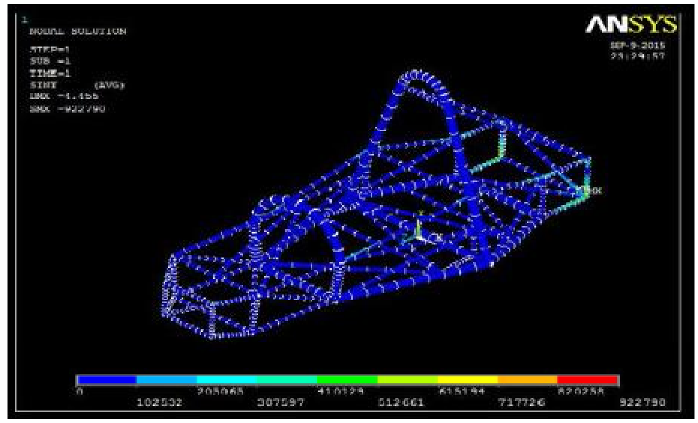

Fig – 12.2.2A Front Impact Test Stress Intensity of Al6061Frame

12.3 Torsional test of Al7075 frame

12.3.1 Displacement vector sum

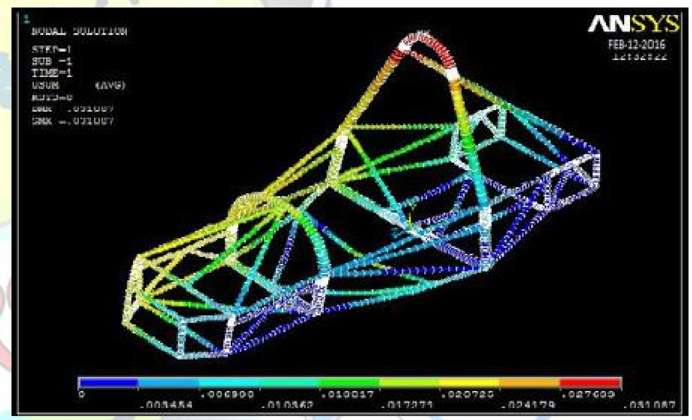

Fig – 12.3.1A Torsional Test Displacement vector sum of Al7075 Frame

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12.3.2 Stress intensity

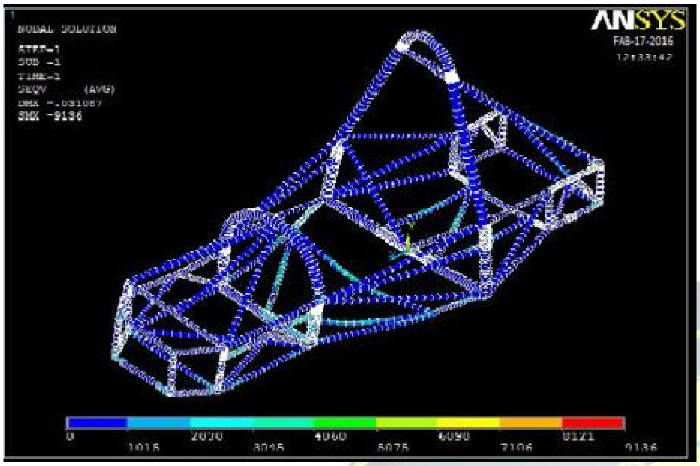
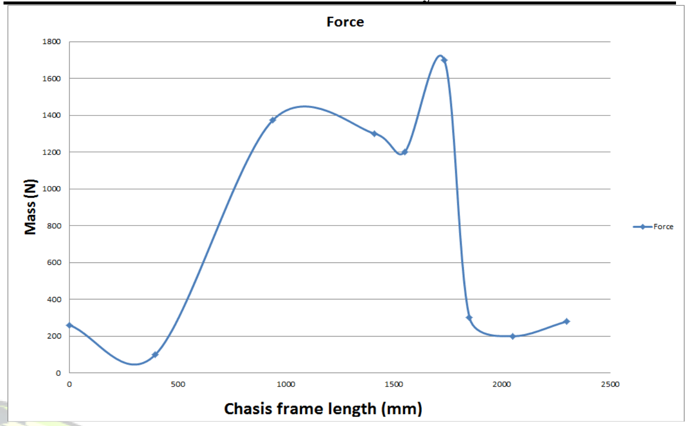


Fig – 12.3.2A Torsional Test Stress intensity of Al7075 Frame

Force distribution over car safety frame for Al6061



The above figure shows the axial stress distribution along entire frame due to static loading. Yield point of aluminium and steel is considered to analyse the failure of the material. Vonmises failure method is considered as failure criteria. Yield value of aluminium is 440 Mpa and Steel is 1100 Mpa and all the values are below the yield.

FINAL RESULT VALIDATION

SI No	Analysis type	Condition	MS Frame	Al6061 Frame	Al7075 Frame
1	Front impact test	Displacement (mm)	2.640	3.13	3.45
2		Stress	12.509	14.95	16.45
3	Side impact test	Displacement (mm)	1.640	1.982	2.222
4		Stress	10.603	11.555	12.229
5	Rear impact test	Displacement (mm)	3.465	4.778	5.123
6		Stress	11.29	13.45	15.78
7	Roll over test	Displacement (mm)	13. 5	14. 8	15.23
8		Stress	18.23	22.13	26.32
9	Torsional test	Displacement (mm)	13. 23	15.36	17.25
10		Stress	20.22	26.32	28.74

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CONCLUSION

Impact, Rollover and Torsional analysis proves that the structure is so tough enough to take all the loads under both conditions. From the analysis it is clear that the structure is much safer, this leads to an optimisation process if required in future.

The design which was done in CATIA V5 and then imported to ANSYS classic 11.0 to find the finite element analysis and its degrees of freedom has been made from the studies. Thus I would conclude by observing the above results and analyzation that the chassis space frame structure depends on the stiffness and stresses in that particular frame.

The stresses obtained above are the well-deserved in order to manufacture a chassis space frame as the stresses are very much lower as compared to that of the yield point of the material.

The analysis is done using three materials Mild steel, Al6061 and Al7075. By using composites instead of mild steel, Al6061 and Al7075 weight is reduced up to 25% and quality is improved by 17% than by using steel because density of steel is more than the composites.

The various test taken on the frame are front impact test, side impact test, etc. The selection of the material is an important factor in the design of the frame. After comparison between the three materials (Steel IS grade 3074, Aluminum Al6061 and Al7075)
we can conclude that Steel IS grade 3074 is better for design a roll cage to provide a driver safety in front and side crash than the other two materials.

So using composites for chassis is safe. By using composites instead of steel, the weight of the chassis reduces 4 times than by using steel because density of steel is more than the composites. By using layers for same thickness of the chassis, the displacement and stress values are Not effective as Mild steel frame but it is still in the safer side to use Al6061 and Al7075 frames

So it is better to take Al6061 and Al7075 chassis while compared with Mild steel

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