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ROLL CAGE DESIGN AND ANALYSIS FOR FORMULA STUDENT RACE CAR

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ABSTRACT

This paper deals with the Design and Analysis of Roll Cage for the Formula Student Car. In a Formula Student Car the roll cage is one of the main components. It form the structure or the main frame of the vehicle on which other parts like Engine, Steering, and Transmission are mounted. Roll Cage comes under the sprung mass of the Vehicle. There are a lot of forces acting on vehicle in the running condition. These forces are responsible for causing crack initiation and deformation in the vehicle. Deformation results in Stress Generation in the Roll Cage. Hence it is important to find out these areas of maximum Stresses. In this paper an attempt is made to find out these areas by carrying out FEA of the Roll Cage. We have carried out Crash Analysis (Front and Side Impact), Torsional Analysis, Bump Analysis, and Modal Analysis. In running condition, there are vibrations generated in the vehicle. Here in this paper the Vibration analysis is also done known as Direct Frequency Response Analysis. All these Analysis have been carried out in HyperWorks 13.0. The design procedure follows all the rules laid down by FSAE Rule Book for Formula Type Cars.

KEYWORDS: - Roll Cage, Material, Finite Element Analysis, Strength, Factor of Safety, modes, damping.

INTRODUCTION

For a proper working of a formula student car it is important that all the components work in the desired manner. As roll cage/chassis being the important system, which absorbs all the static and dynamic loads, the structure must be such that it will sustain the stresses generate without deformation.

There are a lot of forces acting on the vehicle when the vehicle is in static as well as in the dynamic condition. These forces can cause deformation resulting into stress generation in various parts of the roll cage. These forces are generally occurring during braking, acceleration, cornering or combination of above. The stiffness of the roll cage must be such that it must be able to resist these forces.

An Ideal Roll cage is one which absorbs all the loads from the suspension without any deformation. This is also one of the basic requirement of the roll cage. The second basic requirement is that it should act as a support or mounting for all the other components on the vehicle. The third requirement is that it must have high longitudinal as well as high torsional stiffness to sustain the forces during braking and cornering.

There are 2 types of masses inside the car – Sprung and the Un-sprung mass. All the mass that is damped by the spring is called as the sprung mass. Generally the sprung mass must be greater than that of the unsprung mass. Roll cage comes under the category of the sprung mass of the car.

Moreover, the roll cage is made by welding pipes together. First a proper design of the frame or the roll cage is carried out. The pipes are cut in the required lengths. If required, bending of the pipes are also done. Then notching is done of these pipes. These pipes are then joined or connected by welding them together.

MATERIALS AND METHODS

Selection of a proper material is necessary to maintain the stress level in the roll cage up to a desired limit. Here the strength of the material especially the ultimate yield strength (Syt) plays a very important role. There are a lot of factors which affect the selection of the material which are

1. The Stress Generated and in the Factor of Safety of the roll cage.
2. The Condition in which the car is required to operate.
3. The way in which the other components will be mounted on the roll cage.

Here the factor of safety (fos) comes into picture. The Factor of Safety is defined as the ratio of the ultimate yield strength to that of the stress generated in the roll cage. This value for roll cage of a formula student car is always required to be within 1-3. If the value is less than 1 then the roll cage will get deformed even before the maximum value of stress is reached. If the value is greater than 3, then the roll cage will be too heavy.

The vehicle is required to be operated in sunny, rainy and non-toxic environment. Besides the parts which will be mounted on the vehicle will be either nut bolted to the brackets or welded to the roll cage. Thus a weldable metal must be selected.

Hence we require a material which has high strength, is durable and also which is weldable. In order to fulfil these requirements we have selected the following material.
AISI 1018

Table:

Table 1. Material Properties

Property	Metric
Hardness, Brinell	126
Tensile Strength, Ultimate	440 MPa
Tensile Strength, Yield	360 MPa
Elongation at Break (50 mm)	15.0 %
Modulus of Elasticity	205 GPa
Bulk Modulus	140 GPa
Poisson's Ratio	0.290
Shear Modulus	80.0 GPa
Density	7.87g/cc

FRAME DESIGN

The frame is designed considering many factors such as cross sectional area, the front impact force, the side impact force, the endurance, the vibrations generated by the engine and the wheel while running, and also the damping capacity.

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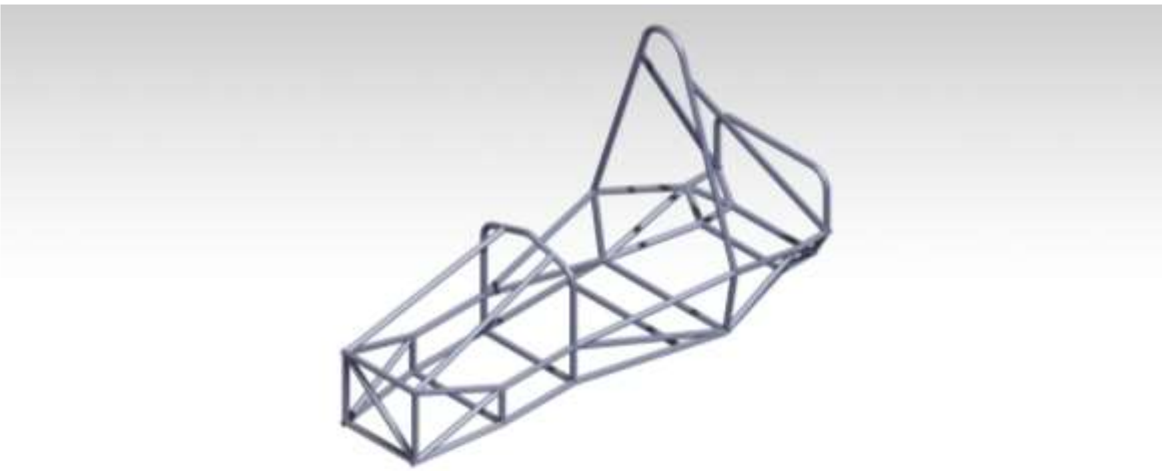
The structure of the frame must be such that when the vehicle is hit from the front, the stress must be absorbed by the pipes and must also allow this impact to flow from the front to the rear, not allowing the stress to get concentrated in that particular part only.

The frame is designed in CAD Software- Catia and the notching is done in Solid Works. The Designed roll cage is as shown in the figure.

Figure:



Roll Cage Design CAD Model

FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. Here we divide the roll cage into small sizes known as element and collective elements on the model form a mesh .The computer analyses the elements and shows us a collective result. The computer solves by the computational method provided.

The material and structure of roll cage was finalized and then FEA was performed on it. It is tested whether the roll cage will be able to withstand torsion, impact, bump and vibrations.

The analysis was done in HyperWorks 13.0 .We choose to do 2D shell analysis as it gives appropriate result. Elements selected were 2D QUADS and 2D R-TRIAS. We also inserted dead mass (CONM2) to account for the inertia of the mass of engine.

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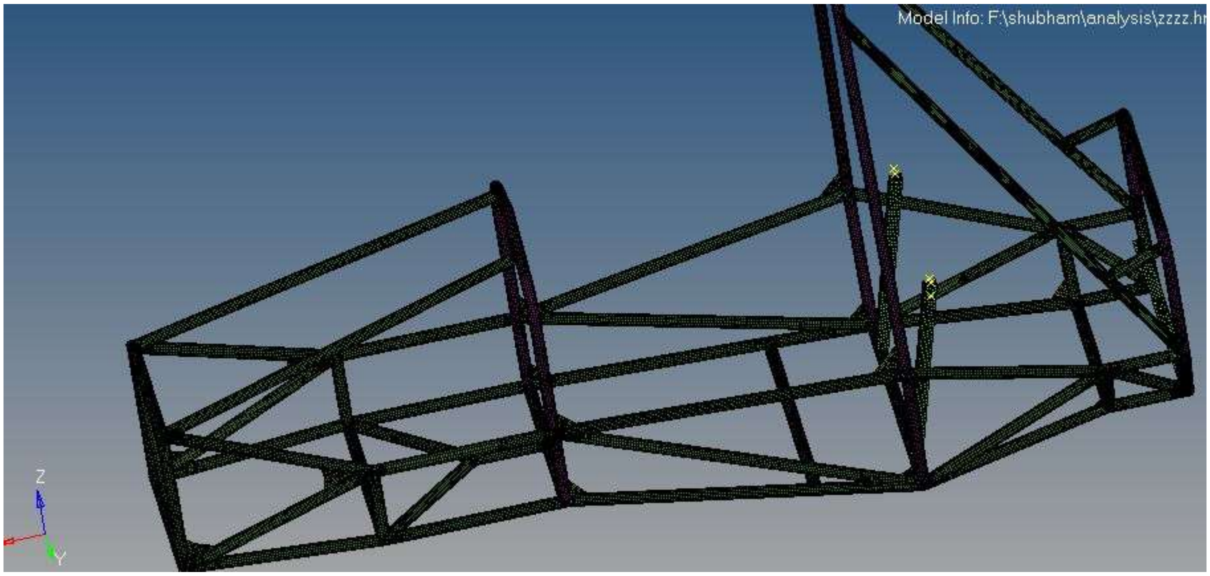
Figure:



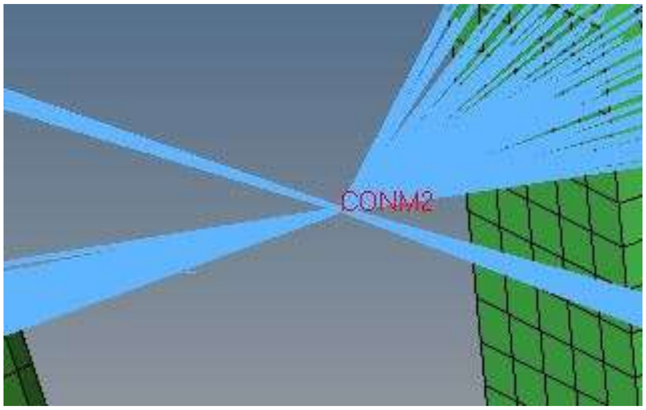
Roll Cage Meshed Model

Table:

Table 2. Mesh Parameters

Sr. Num.	Parameter	Value
1	Warpage	5mm
2	Aspect	5mm
3	Skew	60
4	Chord Dev.	0.1mm
5	Cell Squish	0.5mm
6	Length	3mm
7	Jacobian	0.7
8	Equia Skew	0.6
9	Area Skew	0.6
10	Taper	0.5^0
11	Trias Min. Angle	20^0
12	Trias Max Angle	120^0
13	Quads Min Angle	45^0
14	Quads Max Angle	135^0

Figure:



Dead Mass

Table:

Table 3. Optistruct Solver Elements

Sr. Num.	Parameter	Value
1	Tria 3	CTRIA 3
2	Quad 4	CQUAD 4
3	Tria 6	CTRIA 6
4	Quad 8	CQUAD 8

Table:

Table 4. Radios Solver Elements

Sr. Num.	Parameter	Value
1	Tria 3	SHELL 3N
2	Quad 4	SHELL 4N

Following tests were performed on the Vehicle

1. Front Impact.
2. Side Impact.
3. Bump analysis.
4. Modal Analysis.
5. Direct frequency Analysis.

Front Impact

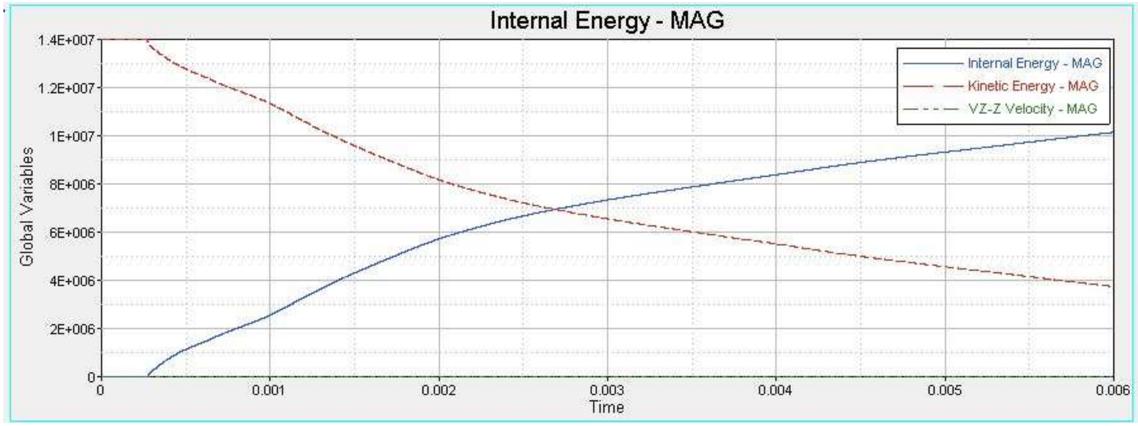
The Front Impact Analysis is done in order to find out the amount of stress generated in the roll cage if the car hits a solid body from the front. The dynamic crash analysis has been performed in HyperWorks 13.0 using RADIOSS Block 120 solver. Impact analysis is used to verify the safety of the driver.

Boundary Conditions

1. The roll cage mass is 27Kg and a dead mass of 75Kg for engine and transmission was applied to consider its inertia.
2. Roll cage o speed is taken as 120kmph along +eve X-Direction.
3. Symmetry along (Plane Z-X.)

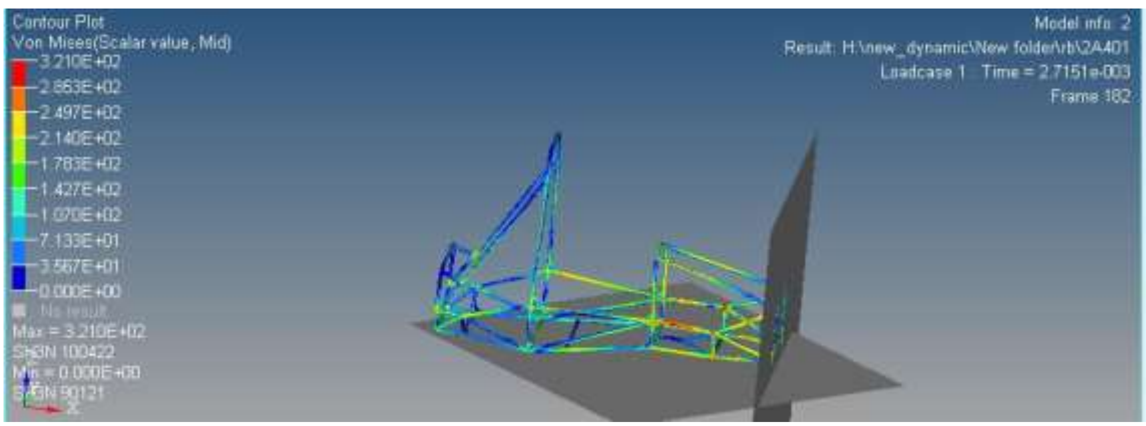
The material type is visco-elastic i.e. the material shows a visco- elastic behavior

Figure:



Internal Energy

Figure:



Von-Mises Stress Distribution

Results

1. As the impact happens the internal energy goes on increasing and kinetic energy goes on decreasing advancing impact time. The kinetic energy is absorbed in the structure. The roll cage starts to bounce back after the intersection point i.e. the penetration stops and impact is said to be complete.
2. Impact time is 0.0026 sec
3. Maximum Von-Mises Stress = 321MPa
4. Factor of Safety = 360/321
   = 1.12

   (Factor of safety above 1 in dynamic crash is good).
5. Penetration in roll cage is 10.6cm

Here the design and driver is safe.

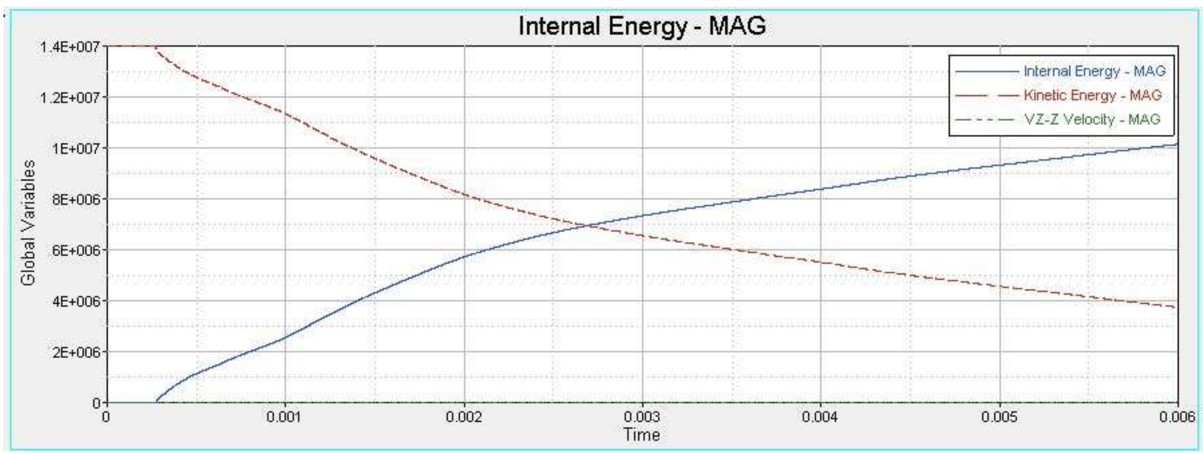
Side Impact Analysis

The Side Impact Analysis is done in order to find out the amount of stress generated in the roll cage if the car hits a solid body from the side. The dynamic crash analysis has been performed in HyperWorks 13.0 using RADIOSS Block 120 solver.

Initial Conditions

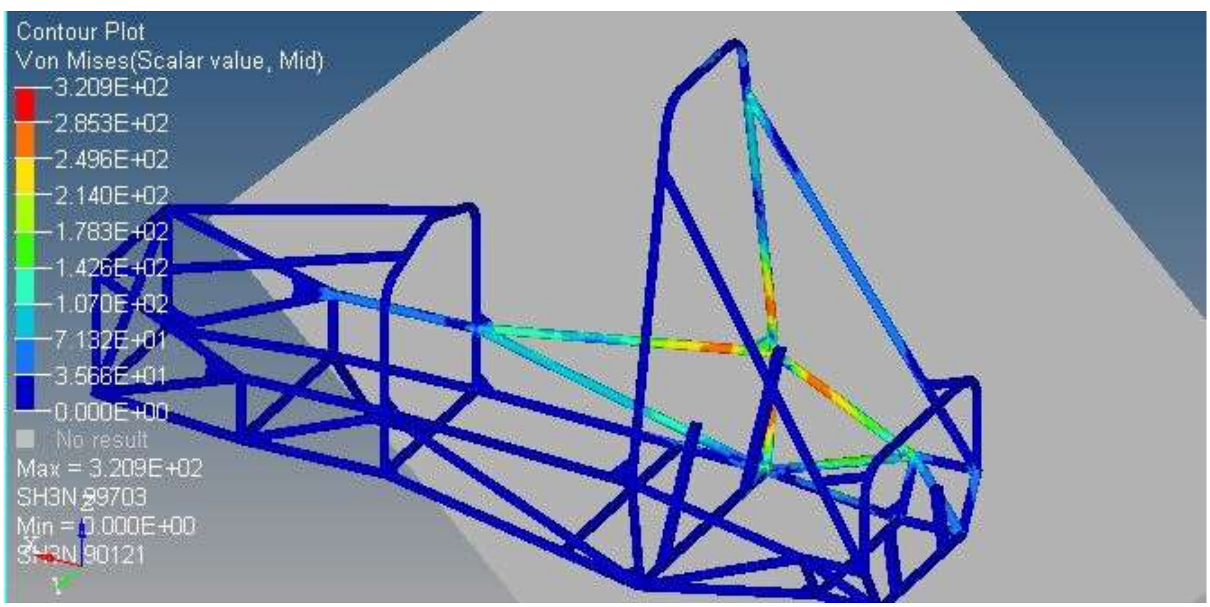
1. The roll cage mass is 27Kg and a dead mass of 75Kg for engine and transmission was applied to consider its inertia.
2. Velocity of roll cage is taken as 60kmph in –eve Y-Direction.
3. The wall is a rigid wall.

Figure:



Internal Energy

Figure:



Von-Mises Stress Distribution

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Results

1. As the impact happens the internal energy goes on increasing and kinetic energy goes on decreasing advancing impact time. The kinetic energy is absorbed in the structure. The roll cage starts to bounce back after the intersection point i.e. the penetration stops and impact is said to be complete.
2. Impact time is
3. Max Von-Mises stress is 321MPa
4. Penetration is 9cm
5. Factor of safety is 1.12

Here the design is safe.

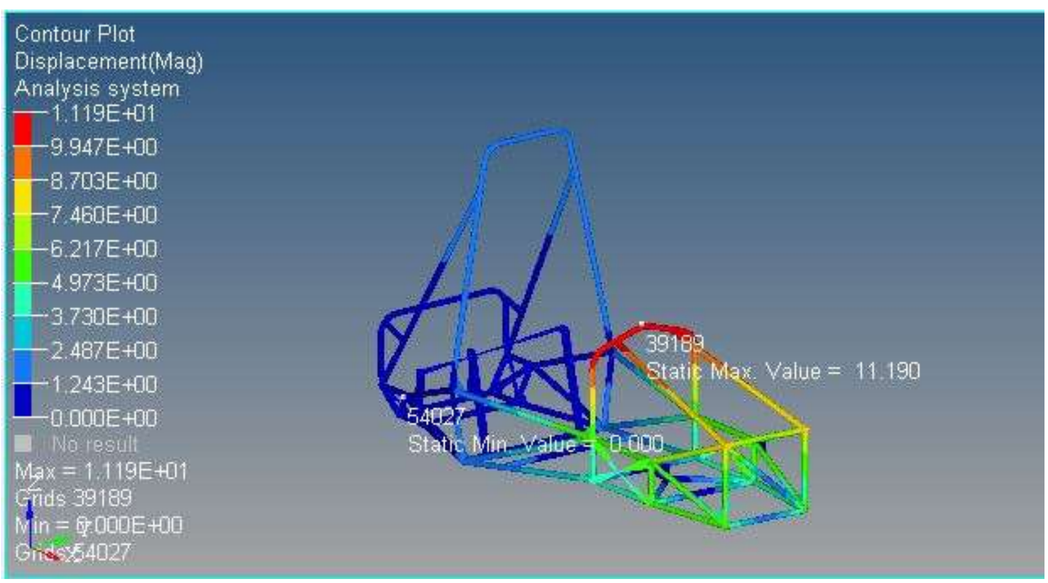
Torsional Analysis

Torsional stiffness is used to determine the torsional stiffness of structure i.e. how much the structure can resist the twisting. It is a very important parameter of any vehicle to resist torsional stresses and deflection during turning, drifting cornering and undulating road surface. It is good to have high torsional stiffness because it permits to preciously control handling parameters by adjusting the suspension parameters. If car is sufficiently stiff under torsional loading then it will normally withstand bending and longitudinal/lateral bending.

Initial Conditions

1. Rear suspension points were constrained.
2. Equal and opposite forces in Z-Direction were applied on front suspension points.
3. Track width = 1200mm
4. Standard Load= 1G.
5. Weight of vehicle =280kg

Figure:



Displacement Plot

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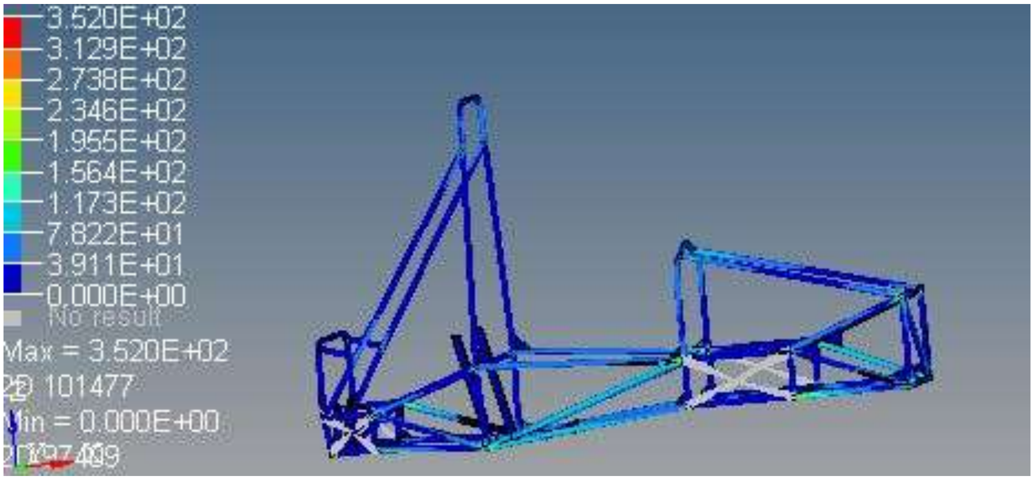
Figure:



Von-Mises Stress Distribution

Results

1. Vertical Deflection = 11.19 mm.
2. Max Von-Mises Stress = 352 MPa
3. Torsional Stiffness =1541.6 Nm/degree

Calculation and Formulae:

Calculations for Torsional Stiffness
Roll Cage Weight = 27 kg
Car Weight = 280 kg
Force (F) = 1G
= 1 × 9.81 × 280
= 2746.8 N
Torque = F × (1/2) Track width (1)
= 2746.8N × (1/2) × 1.2m
= 1648.08

$$\theta = Angle\ of\ Deflection = \tan^{-1}\left(\frac{Vertical\ Displacement}{\left(\frac{1}{2}\right)Track\ width}\right) \quad (2)$$

$$= \tan^{-1}\left(\frac{11.19}{\left(\frac{1}{2}\right) \times 1200}\right)$$

$$= \tan^{-1}(0.0186666)$$

$$= 1.069^0$$

$$\text{Torsional Stiffness (k)} = \frac{Torque}{Angle\ of\ Deflection} \quad (3)$$

$$= \frac{1648.08}{1.069}$$

$$= 1541.6\ Nm/degree$$

Specific Torsional Stiffness = $\frac{\text{Torsional Stiffness}}{Roll\ Cage\ Weight}$ (4)

$$= \frac{1541.6}{27}$$

$$= 57.09 \frac{Nm}{kg - degree}$$

4. Specific Torsional Stiffness =57.09$\frac{Nm}{kg-degree}$

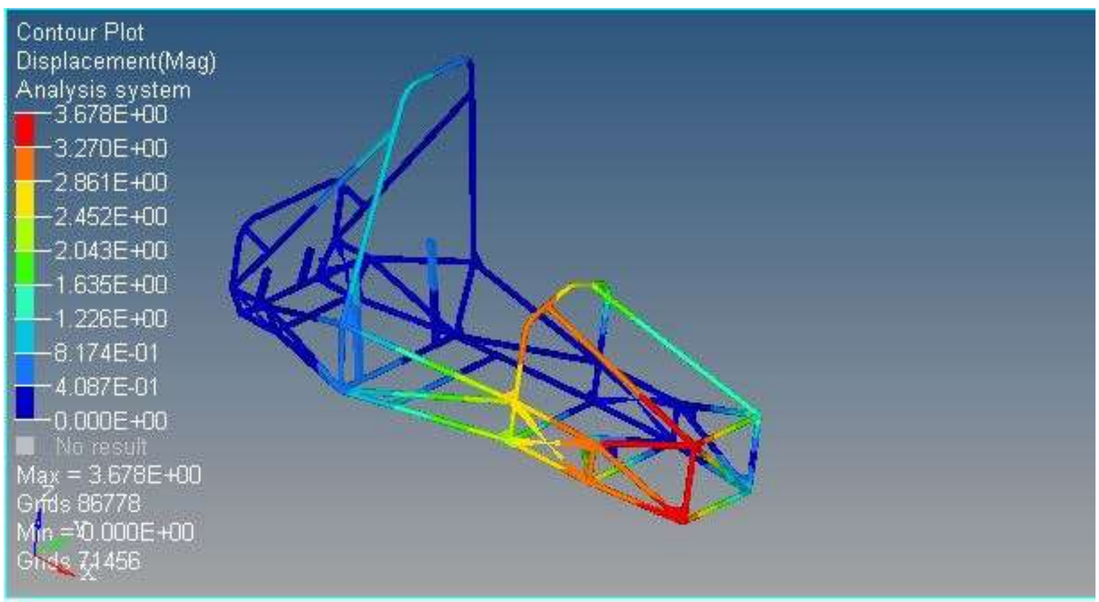
Bump Analysis:

It shows how roll cage will distribute the load in case there is failure of suspension in bump. In this situation, all the bump force from the ground gets transferred to the roll cage. Thus it becomes important to understand the stress generated in the roll cage.

Initial Condition

1. Constraining all the degrees of freedom of rear suspension point and one suspension point in front.
2. A load of 0.8G is applied along +eve Z-Direction on one front suspension point.
3. Weight of Vehicle =280kg

Figure:



Displacement Plot

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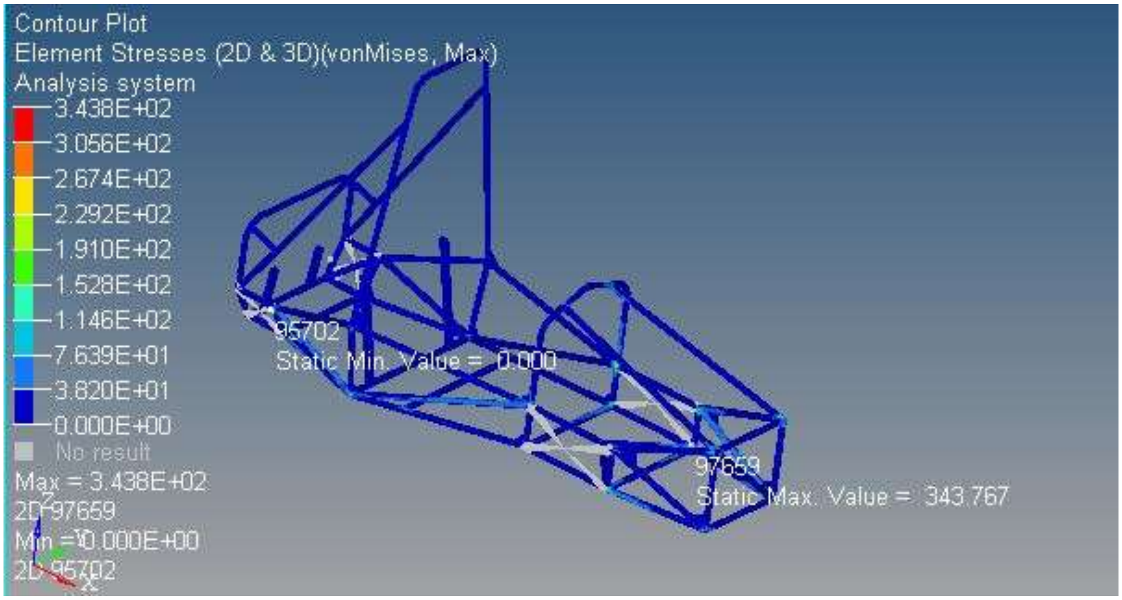
Figure:



Von-Mises Stress Distribution

Result

1. Max Deflection = 3.63mm
2. Max Von-Mises Stress = 343.8MPa

Modal analysis:

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. Modal analysis is the field of measuring and analyzing the dynamic response of structures and or fluids during excitation. In cars it is used to determine natural frequencies of vibrations. Higher the natural frequency better is the structure to sustain Modal analysis determines the mode shape (vibration shape) and frequencies for the particular mode shape of a structure for a free vibration analysis. Normal Modes Analysis, also called eigenvalue analysis or eigenvalue extraction, is a technique used to calculate the vibration shapes and associated frequencies that a structure will exhibit. It is important to know these frequencies because if cyclic loads are applied at these frequencies, the structure can go into a resonance condition that will lead to catastrophic failure. It is also important to know the shapes in order to make sure that loads are not applied at points that will cause the resonance condition.

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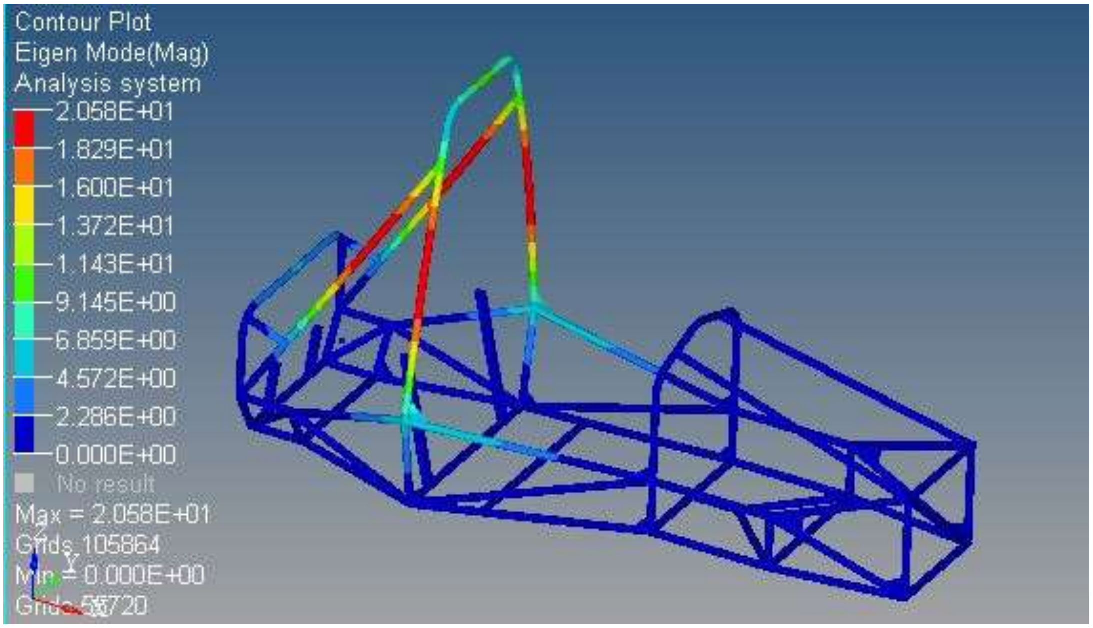
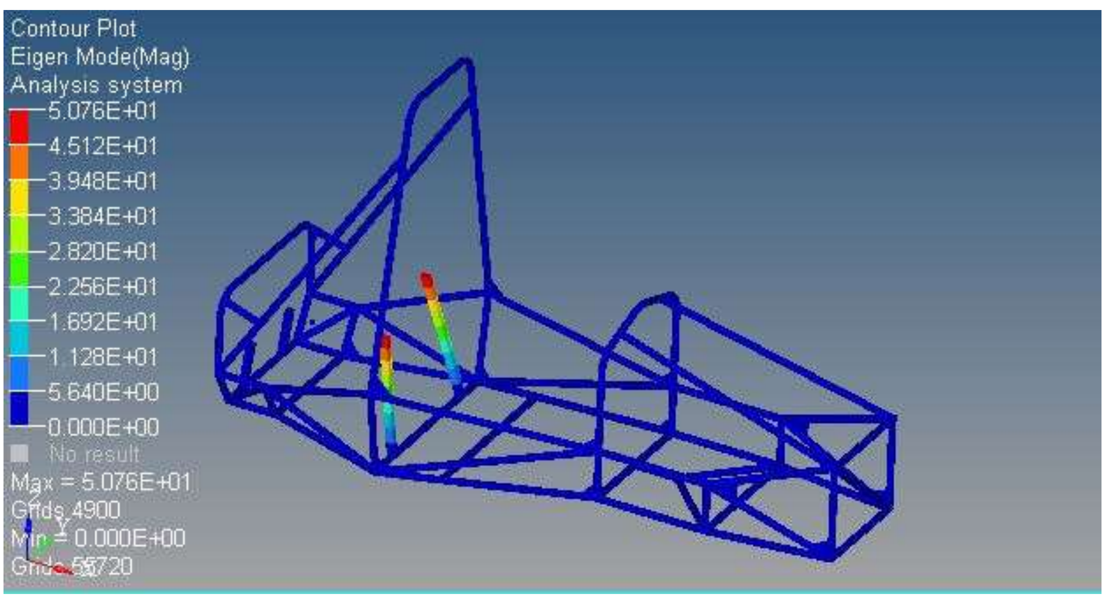
Figure:



1st Mode

Figure:



2nd Mode

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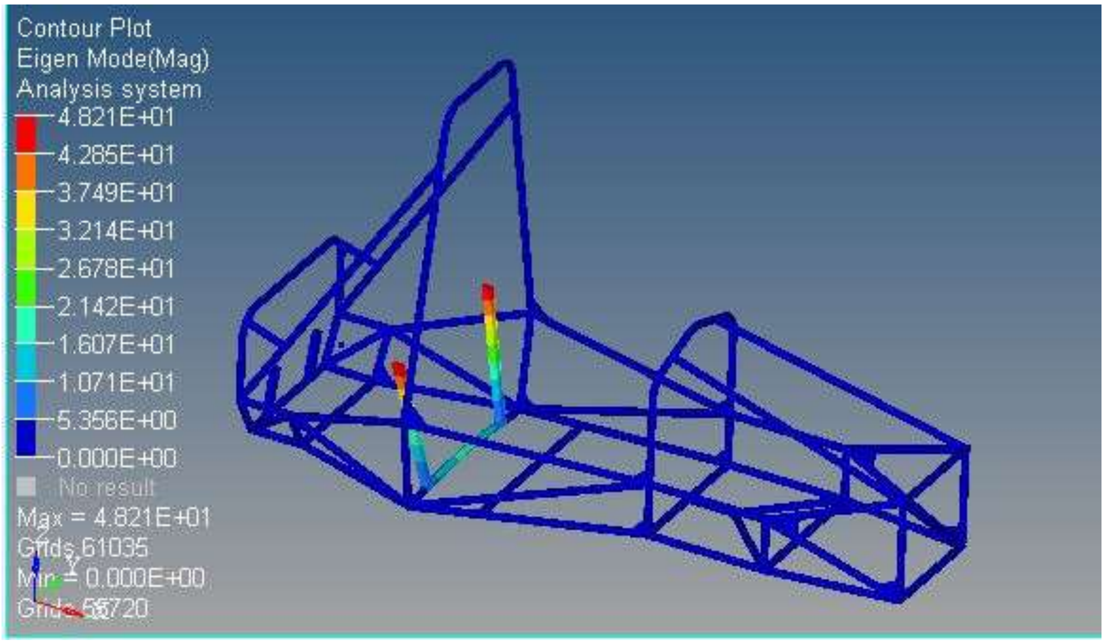
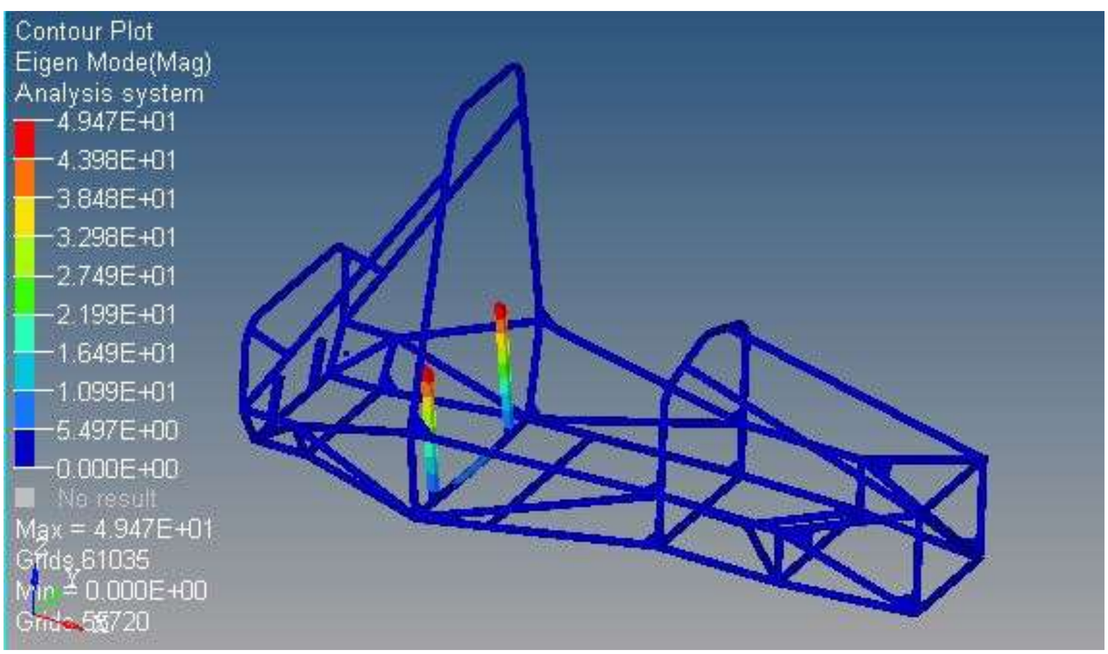
Figure:



3rd Mode

Figure:



4th Mode

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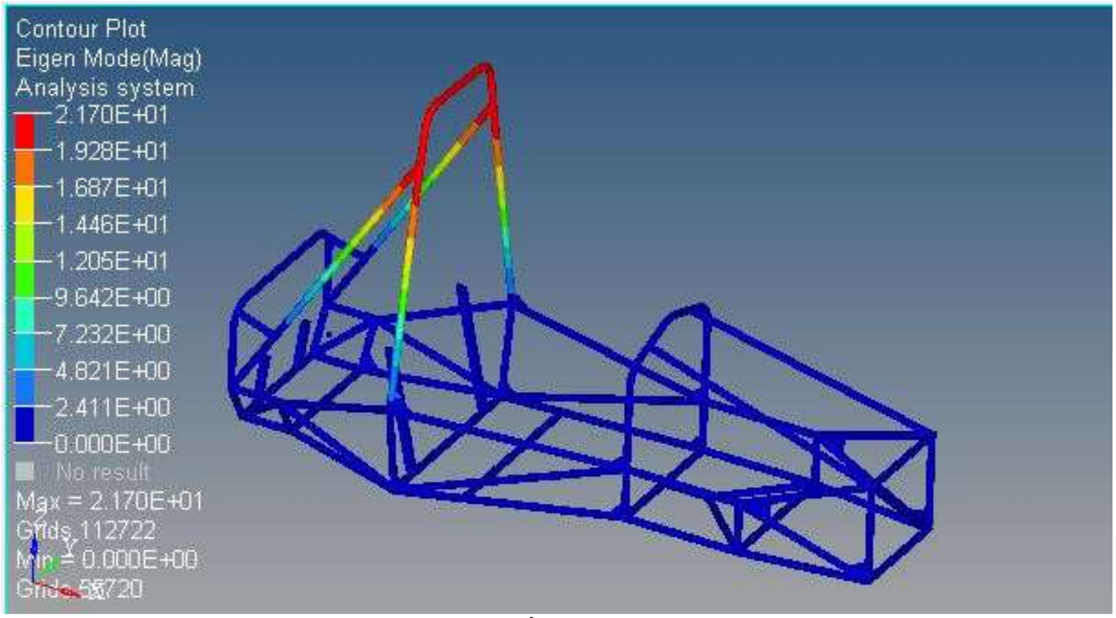
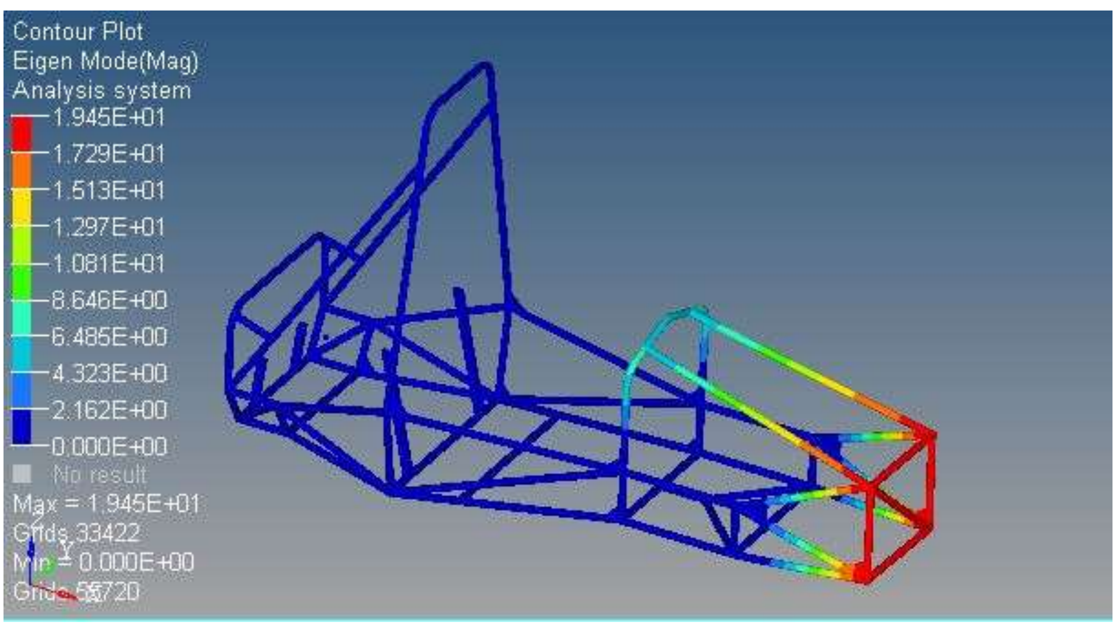
Figure:



5th Mode

Figure:



6th Mode

Direct Frequency response analysis

Frequency response is used to calculate structural response to steady state oscillations. Here excitation is explicitly defined in frequency domain. Oscillations are sinusoidal in nature. Here we have shown how the oscillations in structure damp exponentially as shown in figure. In this case we consider the structural damping coefficient as 0.2. The equation which the software uses is

Mü + Bů + Ku=F (t)

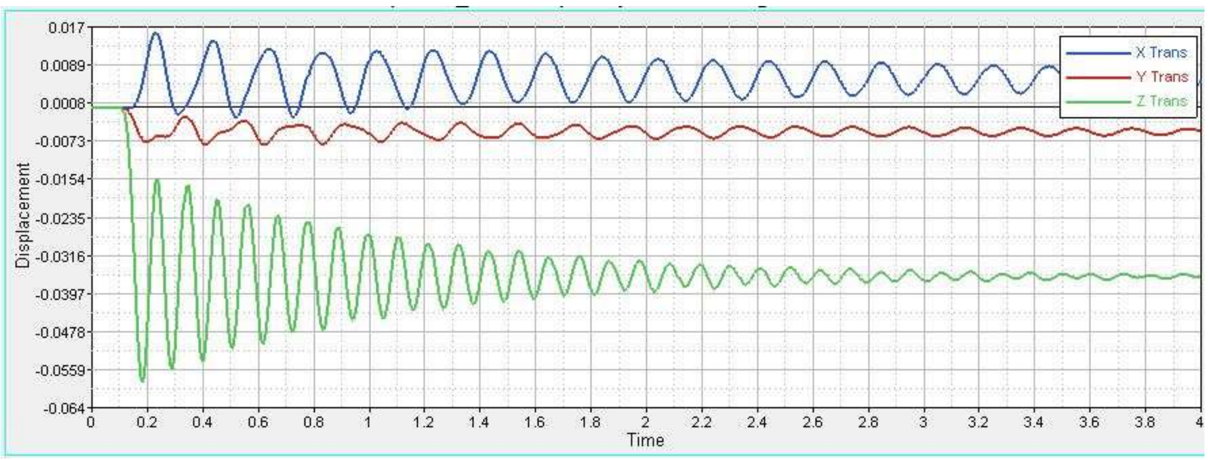
M= Global mass matrix

K= Global stiffness matrix

B = Global Damper Matrix

F (t) = loads an applied as a function of time.

Figure:



Displacement V/S Time Graph

From the displacement V/s time graph can see how the oscillations decrease i.e. the modal damping tendency.

CONCLUSION

The FEA Analysis showed that the vehicle can sustain in various condition and that the stress values are within the permissible limits. The basic need of a formula type car, which is lower weight to strength ratio, is also satisfied by the roll cage. Keeping the manufacturing in mind, the design of the car is kept very simple. Thus it can be concluded that this roll cage demonstrates good strengths in all tests and can be used to make a Formula Student Race Car.

REFERENCES

[1] Thomas D. Gillespie. Fundamentals of Vehicle Dynamics. Society of Automotive Engineers, Inc.
[2] Ammar Qamar Ul Hasan , Simulation of ATV Roll Cage Testing ,
[3] IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 3 Ver. II (May. - Jun. 2015), PP 45-49
[4] Richard Stone and Jeffrey K.Ball. SAE International Warrendle, Pa. Automotive Engineering, Fundamentals.
[5] Sandeep Garg, Ravi Shankar Raman , DESIGN ANALYSIS OF THE ROLL CAGE FOR ALL – TERRAIN VEHICLE , International Journal of Research in Engineering and Technology ,eISSN:2319-1163,Volume:02,Issue:09,2013

ISSN: 2277-9655
Impact Factor: 4.116

[6] Milliken, William F., Milliken, Douglas L., 1997. Race Car Vehicle Dynamics, Society of Automotive Engineers.
[7] Vehicle Refinement Controlling Noise and Vibration in Road Vehicles , Matthew Harrison , SAE International 400 Commonwealth Drive Warrendale PA 15096-0001