Structural Analysis of Student Formula Race Car Chassis

Arindam Ghosh[1], Rishika Saha[2], Sourav Dhali[3], Adrija Das[4], Prasid Biswas[5], Alok Kumar Dubey[6]

[1]Assistant Professor, Dept. of Mechanical Engineering, University of Engineering & Management, West Bengal, India
[2]Dept. of Electrical & Electronics Engineering, University of Engineering & Management, Kolkata, West Bengal, India
[3,4,5,6]Dept. of Mechanical Engineering, University of Engineering & Management, Kolkata, West Bengal, India

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Abstract - *Chassis is a major part of any automotive design. It is responsible for supporting all functional systems of a vehicle and also accommodates the driver in the cockpit. Designing of a chassis for driver's safety is always been a concern, especially for a race car. In this paper, few techniques are mentioned on how to analyze a formula student race car chassis in order to ensure its structural stability for driver's safety. Aim of this paper is to produce a clear idea about the types of analysis to be run on a student formula chassis with the amount of load or G forces to be applied on it using Solidworks software, in order to make sure that the driver is safe inside the cockpit.*

Key Words: Automotive Design, Cockpit, Analysis, G Force, Driver's Safety, Solidworks Software.

1. INTRODUCTION

In INDIA, several events are conducted like SAE SUPRA, FS INDIA, FFS INDIA etc in order to provide an opportunity to the engineering students to explore their knowledge in the field of design and manufacturing a student formula race car. This type of event bridges the gap between theoretical and practical knowledge and also provides hands on experience to the engineering students. Students follow a rule book to design their car. The event is divided into 2-parts, Static and Dynamic. In static event, the team has to present the Design report, business report and Cost report to the judges and points are awarded based on the performance of the team. Dynamic event includes Tilt test, Autocross, Skid Pad, Acceleration- Brake test, Endurance etc. In this paper, the chassis of team CYGNUS RACING is used to perform every possible analysis using SOLIDWORKS software to ensure its stability for driver's safety.

2. RACE CAR DESIGN PROCEDURE

A rulebook is followed to design the student formula vehicle. Once the designing of the car is completed, the next task is to carefully select material for the chassis. Strength, Weight to Strength ratio and Cost of the material should be considered while selecting the material. Comparative chart of the properties of few available materials is shown.

Table – 1: Comparison of material properties

Material Name	Tensile Strength(N/mm²)	Yield Strength (N/mm²)	Mass Density (Kg/m³)	Cost (Rs./Meter)
AISI4130	731	460	7850	450
AISI1020	420.5	351.5	7900	375
AISI1018	440	370	7870	390

AISI 4130 is selected for chassis material after the comparison and extensive market survey. Cost per meter is high but strength to weight ratio is more. So, AISI 4130 is being considered as the structural member for the construction of student formula car chassis by team Cygnus Racing.

3. STUDENT FORMULA VEHICLE ANALYSIS TYPES

Now, after the selection of chassis material, types of analysis to be performed to ensure its stability under various conditions is mentioned below:

(i) Front impact analysis
(ii) Rear impact analysis
(iii) Side impact analysis
(iv) Front torsional analysis
(v) Rear torsional analysis
(vi) Modal or Frequency analysis
(vii) Static vertical bending analysis
(viii) Acceleration test
(ix) Lateral bending analysis

Most of the formula1 drivers usually experience 5g force while braking, 2g force while accelerating and 4g to 6g while cornering. Several softwares are available in the market for analysis purpose. Here SOLIDWORKS software has been used to perform the analysis and the steps are mentioned below:

(a) Open the required design or import the chassis file if it is designed in any other software.
(b) Apply the material properties to the design.

(c) Fix the required points of the chassis using fixtures (usually the suspension points) shown with green arrow head in Fig -1.

(d) Apply required loads on the pipe nodes, shown with pink arrow heads in Fig -1.

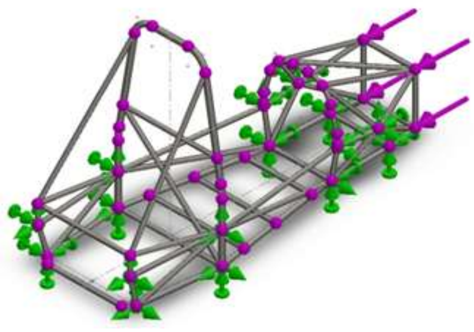


Fig – 1: Fixture and Load applied on Chassis

(e) Create mesh for the chassis.

(f) Once, meshing is done. Run the analysis.

(g) Using analysis result, i.e. Von Mises stress, Equivalent strain, Displacement and Factor of Safety, the chassis will be judged for its stability.

Now, the sample calculation and results of the above discussed analysis types is discussed below.

4. Front Impact Analysis

In this analysis type, front and rear suspension points are fixed as shown with green arrow and load is applied on the front 4 nodes as shown with pink arrow in fig – 2. Weight

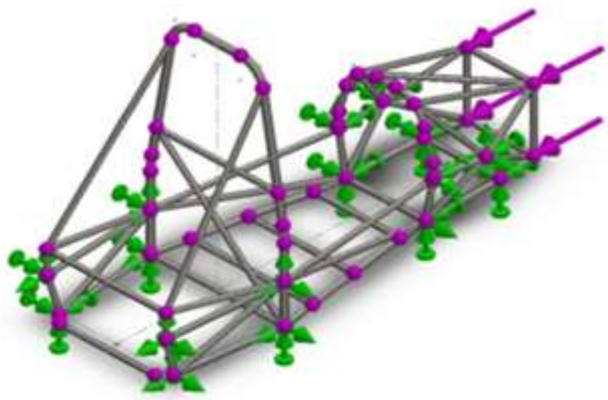


Fig - 2: Boundary condition during front impact analysis

of the entire vehicle is 320 Kg and 6 G-Force(320 x 6 x 9.8 = 18816/4=4704N) is applied on each nodes of the front bulk head of the chassis for structural analysis as shown in the fig 2.

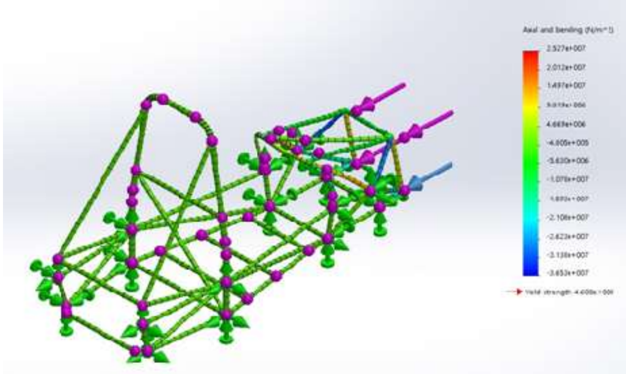


Fig – 3: Stress generated during Front Impact

Maximum stress of 3.65279e+007 N/m^2, maximum displacement of 0.115634 mm and minimum Factor of Safety as 13 is recorded in this analysis.

5. Rear Impact Analysis

In this type of analysis also, the front and rear suspension points are fixed as shown with green arrow and load is applied on the rear 4 nodes as shown with pink arrow in Fig – 4.

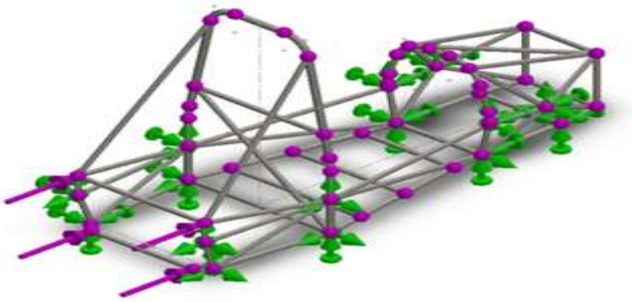


Fig - 4: Boundary condition during Rear Impact Analysis

Weight of the entire vehicle is 320 Kg and 6 G-Force (320 x 6 x 9.8 = 18816/4=4704N) is applied on each nodes of the rear section of the chassis for structural analysis as shown in the fig 4 above to check its stability. Maximum stress of 1.66292e+008 N/m^2, maximum displacement of 0.387799 mm and minimum Factor of Safety as 2.8 is recorded in this analysis.

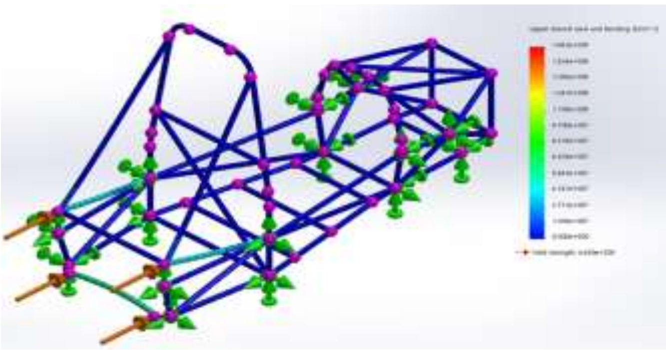


Fig – 5: Stress generated during Rear Impact

6. Side Impact Analysis

In this type, the side members which will first face the impact in case of collision is tested with 6 G – Force as shown in the Fig – 6. In this analysis also, front and rear suspension points are constrained as shown in Fig – 6.

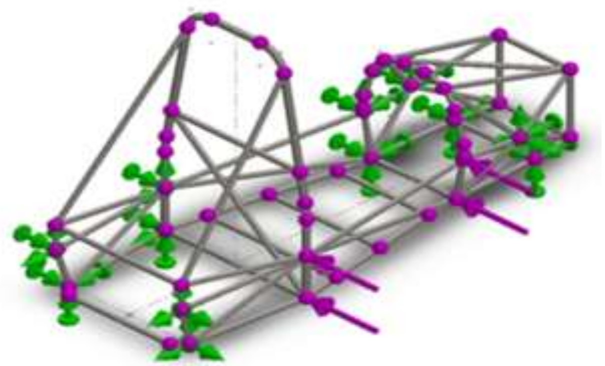


Fig - 6: Boundary condition during side Impact Analysis

Maximum stress of 2.32067e+008 N/m^2, maximum displacement of 2.11901 mm and minimum Factor of Safety as 2 is recorded in this analysis.

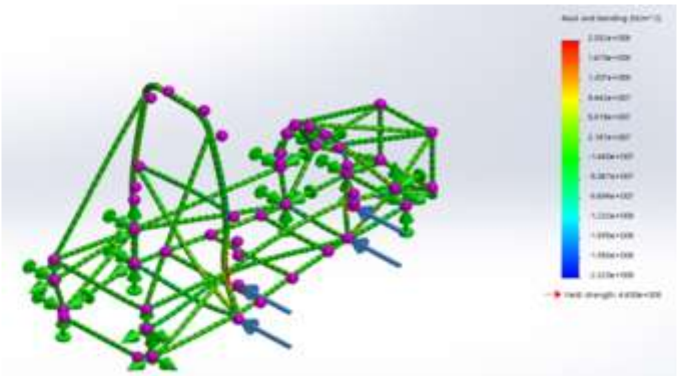


Fig – 7: Stress generated during Side Impact

7. TORSIONAL ANALYSIS

Torsional analysis is considered to be one of the most important analysis on which the structural stability of the chassis depends upon. In this test, the chassis is set to act like a cantilever with one end fixed and other end is subjected to torque. The analysis is to be performed for both the front and rear section. Chassis should be designed for high torsional stiffness with low weight of the vehicle. If the chassis vibrates due to significant twisting, it affects the vehicle handling performance. The torsional rigidity can be determined using the formula [1] stated below with the given figure.

$K = R/\theta$

$K = (F \times L)/ \tan^{-1}[(\Delta y_1 + \Delta y_2)/2L]$

Where, K = Torsional stiffness

T = Torque

Θ = Angular Deflection

F = Shear force

y_1, y_2 = Translation displacement

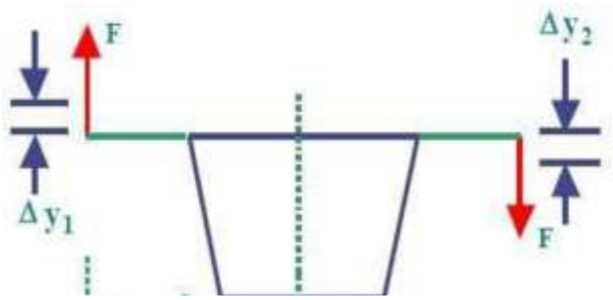


Fig – 8: Suspension testing loads

7.1 Front Torsional Analysis

3 G - Force is considered for this analysis. Weight distribution of the car is taken as 40-60%. So the weight on front suspension points is 128kg (40/100 x 320= 128kg). 64kg (128/2 = 64kg)of weight should be exerted on each side but to make the chassis safe, the analysis will be carried out considering 128kg of load on each side. Upward load (128 x 3 x 9.8 = 3673.2N) to be applied on 4 nodes of one side of the front suspension and downward force 3673.2N to be applied on the 4 nodes of the other side. Upwards force is shown with blue arrow and downward force is shown with pink arrow in fig – 9 below.

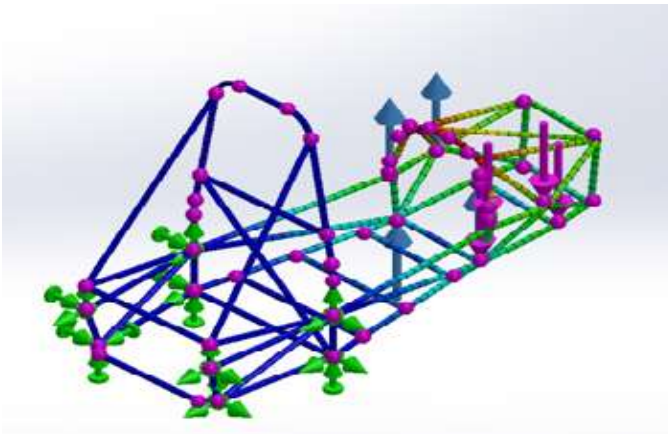


Fig – 9: Boundary condition for Front Torsional Analysis

Rear suspension points are fixed and the load is applied on the front suspension points as shown in the figure above. Maximum stress 3.66549e+008 N/m^2, maximum displacement of 23.6564 mm and minimum Factor of Safety as 1.3 is recorded in this analysis. Front torsional rigidity can now be calculated with the above obtained values.

K = $3763 \times 0.695/ \tan^{-1}[(0.023 + 0.023)/2 \times 0.695]$

= 1383.7 Nm/deg

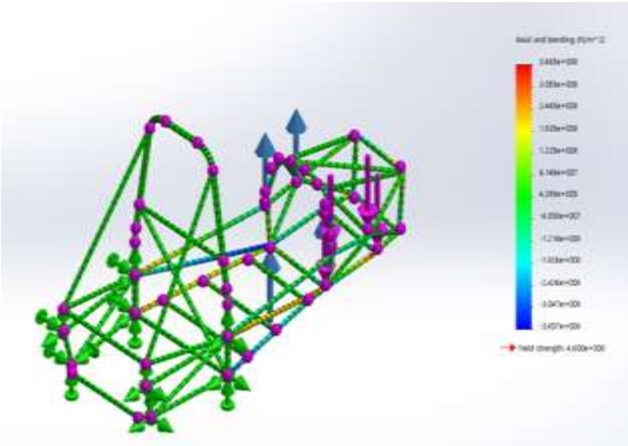


Fig – 10: Stress generated for Front Torsional Analysis

7.2 Rear Torsional Analysis

3 G – Force is again considered for this analysis. Rear section has 60% of the total load. So, the load on rear suspension points is 192kg. 96kg of load should be applied on each side of suspension but to ensure better stability of the chassis, 192kg of load is considered on each side for worst case scenario. Here, front suspension points are constrained and loads are applied on rear suspension points. Upward load (192 x 3 x 9.8 = 6545N) to be applied on 4 nodes of one side of the front suspension and downward force of 6545N to be applied on the 4 nodes of the other side. Upwards force is shown with pink arrow and downward force is shown with blue arrow in fig – 11 below.

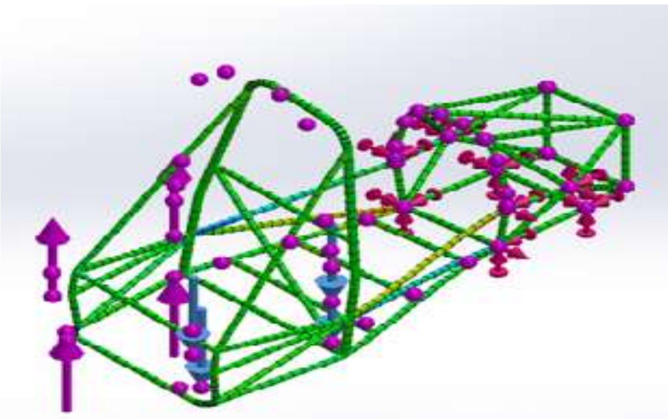


Fig – 11: Boundary condition for Rear Torsional Analysis

Maximum stress 3.72938e+008 N/m^2, maximum displacement of 32.3287 mm and minimum Factor of Safety as 1.2 is recorded in this analysis. Rear torsional rigidity can now be calculated with the above obtained values.

K = $4008 \times 0.710 / \tan^{-1}[(0.032 + 0.032)/2 \times 0.710]$

= 1560 Nm/deg

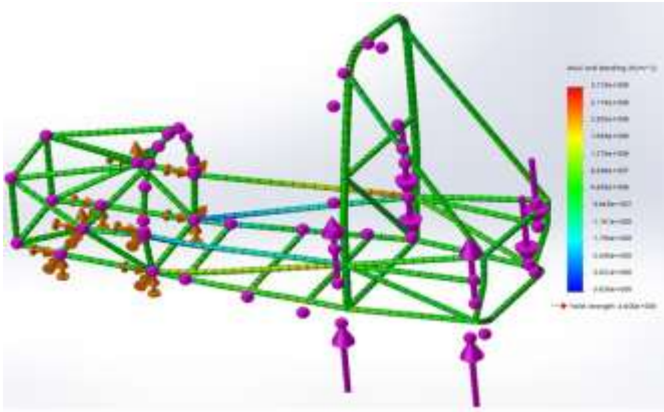


Fig – 12: Stress generated for Rear Torsional Analysis

8. MODAL or FREQUENCY ANALYSIS

Every structure has thte tendency to vibrate at certain frequencies which is commonly known as Natural Frquency. The lowest frequency of vibration is called Fundamental frequency and higher frequencies are known as Harmonics.Every natural frequency is linked with certain shape of a structure called Mode Shape. If dynamic load coincides with any of the natural frequency, they can undergo large displacements which is known as Resonance [3]. Resonance causes infinite motions. Natural frequencies depends on [3]:

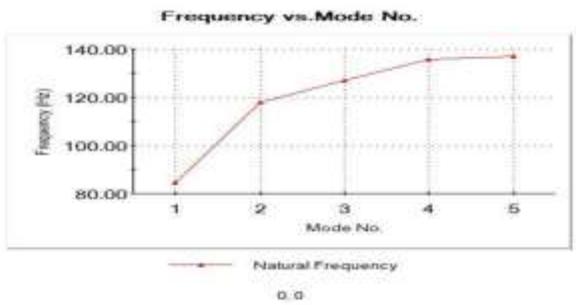
(a) Geometry of the structure
(b) Mass and material properties
(c) Fixtures or support conditions and
(d) In plane loads.
(e)

Resnance can be avoided by altering these characteristics. Computation of natural frequencies in mode shapes is known as: (a) Modal analysis (b) Frequency Analysis and (c) Normal Mode analysis.Frequency is given by Hertz or Hz and it can be given by RPM = Hz * 60 [3]. Modal analysis is important to test the structural behavior of the chassis during certain range of frequencies. In this analysis, the front and rear suspension points are constrained and only the structural mass of the chassis is considered with no load applied on it. SOLIDWORKS software has shown the results from 84.276 Hertz to 136.74 Hertz automatically. At high speed, the engine frequency is around 100Hz [2]. The results obtained during the analysis is tabulated below.

Table – 2: Frequency analysis results

Frequency Number	Rad/sec	Hertz	Seconds
1	529.52	84.276	0.011866
2	740.63	117.87	0.0084836
3	796.42	126.75	0.0078893
4	852.66	135.71	0.0073689
5	859.13	136.74	0.0073134

It is noted that, from the above data, none of the frquency matches with the natural frequency of the four stroke single cylinder petrol engine which is 100Hz. So, the chassis is said to be safe during vibration. Frequency Vs Mode number graph is given below for better understanding of the results.



Graph 1: Frequency Vs Mode No. graph

9. STATIC VERTICAL BENDING ANALYSIS

The sub systems of the car which is installed in the chassis also exerts a Vertical downward force to the chassis especially on the ladder of the frame as shown in figure – 13 below with blue arrow. A force of 320 x 9.8 = 3136N is applied downwads along the driver and engine compartment.

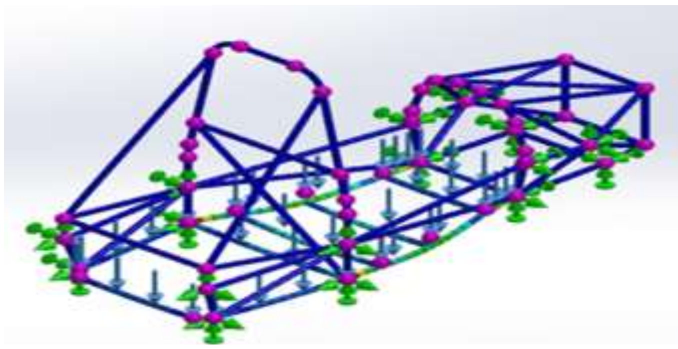


Fig – 13: Boundary condition for Vertical bending Analysis

Front and Rear suspension points are costrained in this analysis type. Maximum stress of 5.92384e+007 N/m^2, maximum displacement of 0.710322 mm and minimum Factor of Safety as 7.8 is recorded in this analysis.

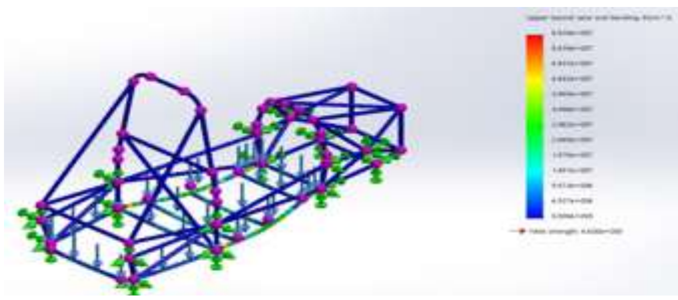


Fig – 14: Stress generated for Vertical bending Analysis

10. ACCELERATION TEST

Acceleration force acts opposite to the direction of the motion of the vehicle. Force exerted on the vehicle due to acceleration is calculated using formula F = m x a. Acceleration of Royal Enfield thunderbird 500 is considered as 8m/s^2 and mass of the vehicle is assumed as 320kg with driver. So, F = 320 x 8 = 2560N. 2560N is distributed within the main hoop, front hoop, front bulkhead and engine compartment in the direction opposite to the motion of the vehicle. Also, 320 x 9.8 = 3136N is applied vertically downward to the ladder and its supportive members in the driver compartment, drivetrain and engine compartment to create a real life loading situation [1] as shown in figure – 15 below .

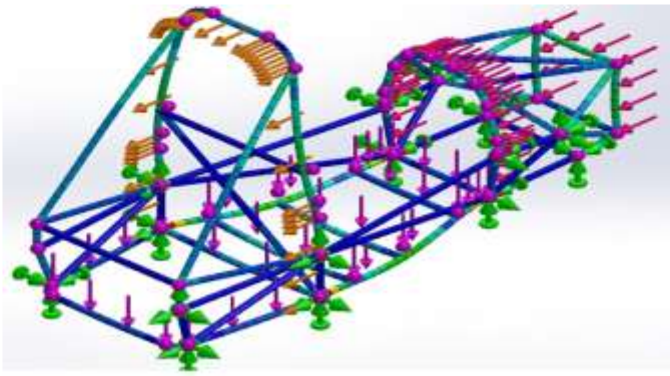


Fig – 15: Boundary condition for Acceleration Test

In this case also, front and rear suspension points are constrained. Maximum stress of 5.92217e+007 N/m^2, maximum displacement of 0.709507 mm and minimum Factor of Safety as 7.8 is recorded in this analysis.

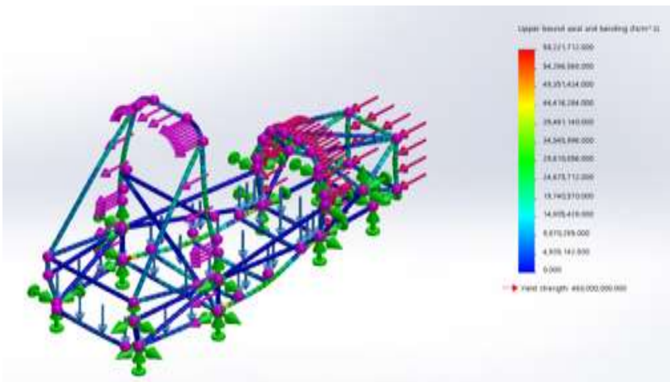


Fig – 16: Stress generated during Acceleration Test

11. LATERAL BENDING ANALYSIS

Centrifugal force acts on the chassis of a car due to cornering and also because of wind force in some cases. Longitudinal axis of a car experiences lateral forces which are resisted by axle, tyre, frame members etc [1].

320 x 9.8 = 3136N of load is applied on the side members from inwards of the chassis i.e., from driver

cabin, drive train side braces hoops and bulk head. Front and rear suspension points are constrained for the analysis and load is applied on the chassis as shown in figure – 17 below.

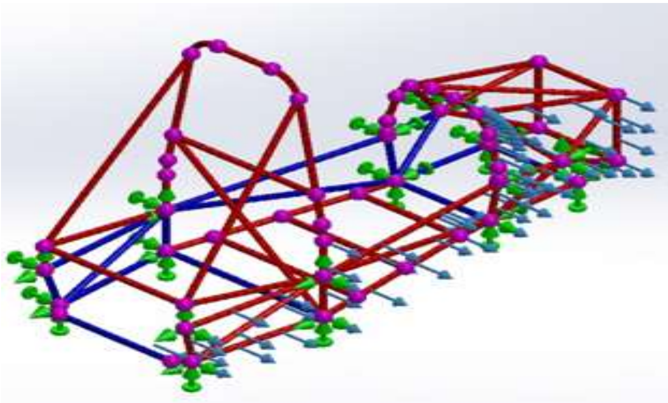


Fig – 17: Boundary condition for Lateral bending Analysis

Maximum stress of 3.17297e+008 N/m^2, maximum displacement of 3.23867 mm and minimum Factor of Safety as 1.4 is recorded in this analysis.

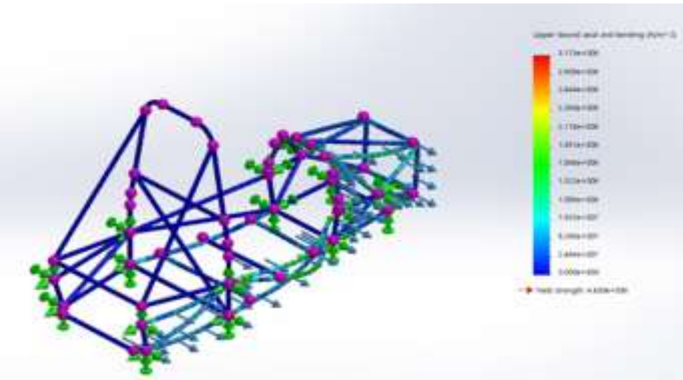


Fig – 18: Stress generated for Lateral bending Analysis

12. CONCLUSION

It is being observed that selection of material plays a vital role in chassis stability and its behavior during loading conditions. Factor of safety should be always considered for proper designing of a race car chassis. In this paper, few analysis are carried out and in all of them except for Modal Analysis, the maximum stress generated is much less than the yield strength of the material AISI 4130. Torsional rigidity is important because a soft chassis is more prone to failure and the suspension actuation may get affected with twisting or bending action of chassis. Modal analysis is also performed to check that the frequency of engine and chassis should not match to avoid resonance.

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2) K. Thriveni, Dr. B. Jaya Chandraiah, Modal Analysis of A Single Cylinder 4-Stroke Engine Crankshaft, IJSRP, Volume 3, Issue 12, December 2013.

3) https://m.youtube.com/watch?v=VllBl6nrnRc&t=6s