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Design and Analysis of FSAE Race Car Chassis

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Abstract: This article focuses on the design and analysis of tubular space frame chassis used for FSAE race cars. The objective of this work is to design and analyze the chassis for different load conditions for different materials and perform a comparative study. Space frame chassis has been used for this study as it is the most popular type of chassis used for such race cars. Chassis is considered as an important component of automobile system. It provides a platform that supports, carries and connects other components, assemblies and sub-systems of the automobile. It should be strong enough to sustain the loads acting on it without failure. Also the chassis should be lightweight. However, while creating a strong, stiff and lightweight chassis the safety of the driver should not be compromised. Hence factor of becomes an important factor that should be considered while designing the chassis. We have used SOLIDWORKS software for design and analysis of the chassis model.

Keywords: Tubular Space Frame chassis, FSAE, Factor of Safety, Design, Analysis, Stress

I. INTRODUCTION

A chassis is an important component of an automobile. It supports, carries and connects all components of the automobile together. Its main function is to support other components of the automobile and to sustain the loads acting directly or indirectly on it that the automobile is subjected to while in operation without any excessive deflection or distortion. A chassis provides support to large as well as small assemblies and sub-assemblies of the automobile. Hence it can be considered as the backbone of the automobile. There are different types of chassis such as monocoque, space frame etc. Space frame chassis is widely preferred type of chassis for FSAE race cars. Tubular space frame chassis consists of multiple trusses that are formed by joining a series of tubes together in a triangular pattern. Working principle of spaceframe chassis is similar to working of truss. The chassis should be strong, stiff and light weight. The designing of the chassis should be done in accordance with the rules stated in the FSAE rulebook. Material selection is also one of the most important part of chassis design and analysis. Analysis is performed on chassis for different load conditions to ensure that the chassis model is safe.

II. ATTRIBUTES OF GOOD CHASSIS

1) *Weight:* Weight is a significant attribute of an automobile. It has a greater impact on the performance of the vehicle. In race cars, high performance is required to make the car more competitive hence weight becomes an important aspect. It has a direct impact on the acceleration ability of the vehicle. As chassis is considered one of the important components of the vehicle hence it is required to create the lightest possible design for ensuring high performance.
2) *Strength and Stiffness:* Strength can be defined as the ability of the structure to withstand the load applied on it without structural failure. Stiffness is defined as the ability of the material to resist deformation or deflection in response to an applied force. The chassis should have high strength and stiffness so that it can sustain the loads that are acting on it without structural failure and it should exhibit minimum deformation on the application of forces. These attributes are very important with the safety perspective as it ensures the safety of the driver.
3) *Safety:* Factor of safety is an important aspect that should be considered while designing the chassis. The chassis should be able to sustain the loads acting on it without structural failure and it should be able to absorb kinetic energy in case of impact. In FSAE competitions the car is designed and tested by the students themselves hence safety is of much importance. Thus, to ensuring the safety of the driver certain guidelines/rules are stated in the FSAE rulebook. This attribute can be achieved by designing the chassis under guidelines/rules stated in the rulebook.
4) *Design Complexity and Manufacturability:* Design complexity refers to that the design created should not be complex i.e. in the case of tubular space frame chassis the triangular arrangement should be done in such a way that the design should not become complex. The sections should be easily accessible as it would help access the components that would be mounted on the chassis. This in turn would help in the proper and fast assembly of the race car. Manufacturability can be defined as the degree up to how easily the product can be manufactured. This attribute refers to how easily the structure can be manufactured at minimum cost and using finite resources.

III. LOADING CONDITIONS

The most important step to designing any vehicle structure/frame, is to identify different loads acting on in different scenario/cases.[3][7]

1) *Longitudinal Torsion:* It happens due to un-even lifting any of the wheel with respect another which develop equal and opposites pair of forces which creates torsional effect.

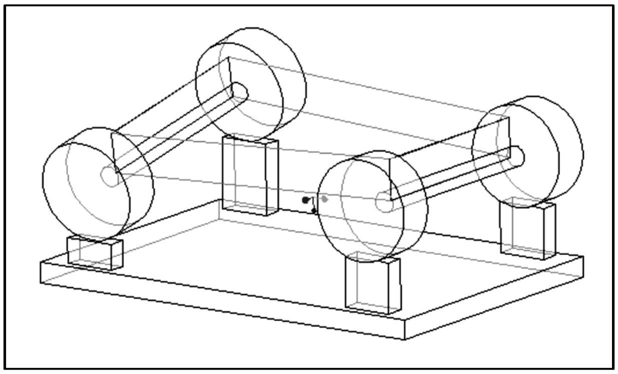

Figure 1: - Longitudinal Torsion [3]

2) *Vertical Bending:* Vehicle experience vertical bending due to weight of driver, engine and other major and minor components mounted on the chassis.

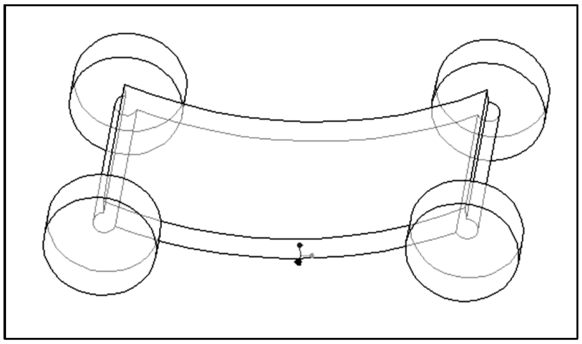

Figure 2: - Vertical Bending [3]

3) *Lateral Bending:* Vehicle experience Lateral bending due to Centrifugal Forces caused by Cornering, Road Camber, and Side wind loads.

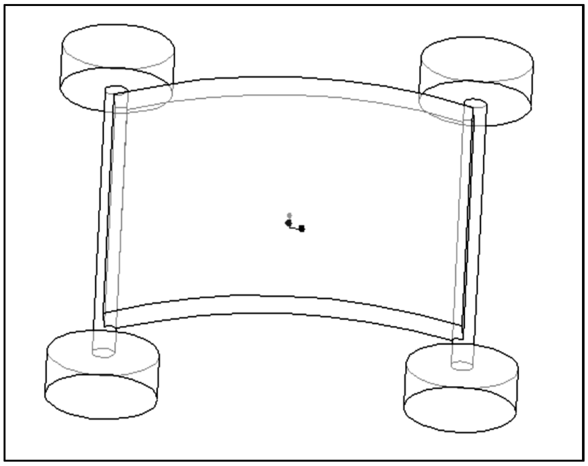

Figure 3: - Lateral Bending [3]

4) *Horizontal Lozenging:* In this structure distort in parallelogram due forward and backward forces acts at opposite wheels cause deformation. The causes of these forces are vertical variation in the pavement.[3][7]

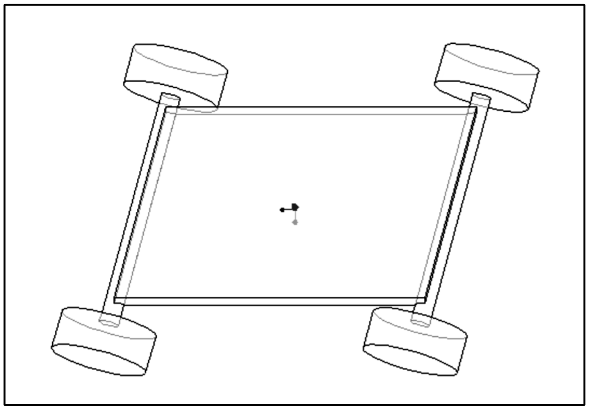

Figure 4: - Horizontal Lozenging [3]

IV. METHODOLOGY

A. Frame Type

Space frame chassis has been used because it most common and popular among university level race car formula competition. It is so popular because of design freedom that comes with it is basically based on the principle of working of truss [1]. These chassis formed by joining metal tubes together form structure.

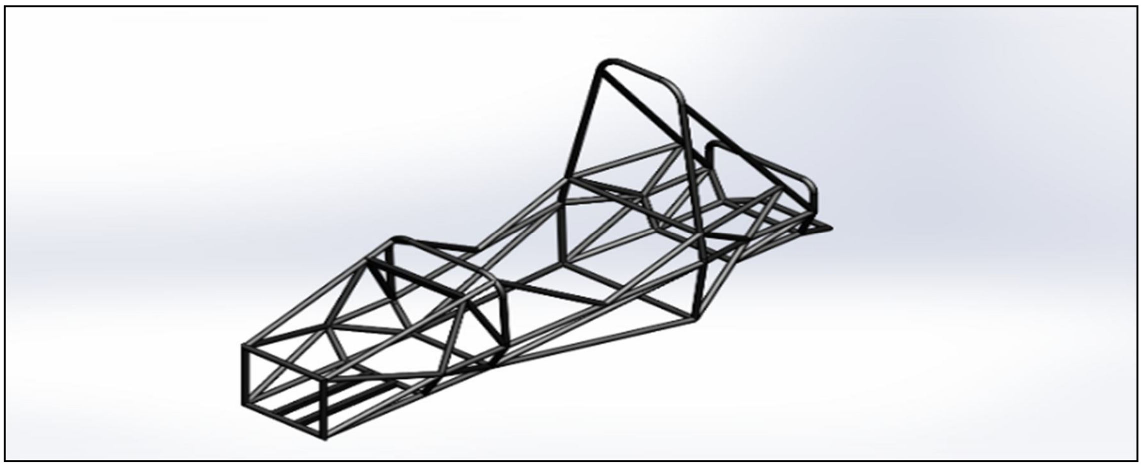

Figure 05: - Chassis Solid Model

B. Material Selection

Material Selection plays vital role in chassis design. Consideration while material selection should be on the basis strength, stiffness, machinability, weight ratio and cost [2]. Material should absorb all type vibration occurring in working conditions and withstand loads without failure [2]. Most of the formula student teams use **AISI 4130 and AISI 1020** material because of relatively higher strength and easy availability. We will analyze both material and conclude by final comparison.

Non-welded strength for continuous material calculations [11]:

1) Young's Modulus (E) = 200 GPa
2) Yield Strength (Sy) = 305 MPa
3) Ultimate Strength (Su) = 365 MPa

Welded strength for discontinuous material such as joint calculations [11]:

a) Yield Strength (Sy) = 180 MPa
b) Ultimate Strength (Su) = 300 MPa

Table no: - 01 Material property of AISI 1020 [10]

Property	Value	Units
Young's Modulus	200	GPa
Poisson's Ratio	0.29	N/A
Shear Modulus	77	N/m^2
Mass Density	7900	kg/m^3
Tensile Strength	420.507	MPa
Yield Strength	351.571	MPa
Thermal Conductivity	47	W/(m·K)
Specific Heat	420	J/(kg·K)

Table no: - 02 Material property of AISI 4130 [10]

Property	Value	Units
Young's Modulus	205	GPa
Poisson's Ratio	0.285	N/A
Shear Modulus	8.00E+10	N/m^2
Mass Density	7850	kg/m^3
Tensile Strength	560	MPa
Yield Strength	460	MPa
Thermal Conductivity	42.7	W/(m·K)
Specific Heat	477	J/(kg·K)

V. DESIGN PROCEDURE

A. Component Design

First Design aimed to simply satisfy all rules guidelines provided by ***FSAE RULES 2020 Booklet.***

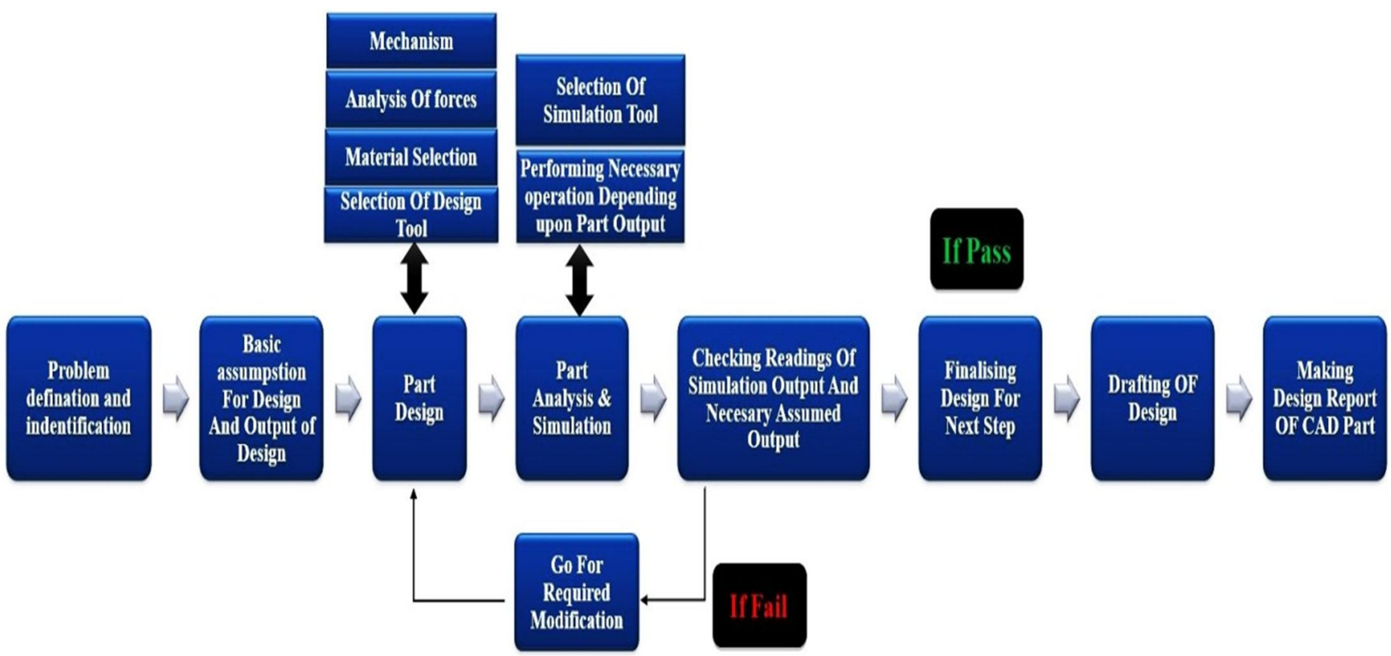

Figure 06: - Flow Chart of Sequential Design Procedure

B. Chassis Model

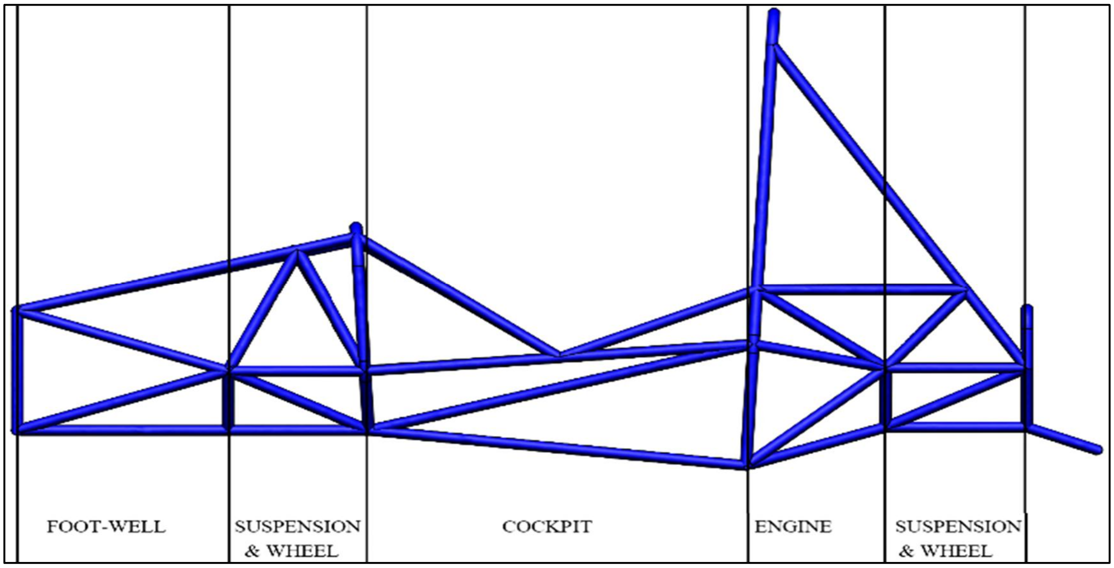

Figure 07: - Chassis Sections Model

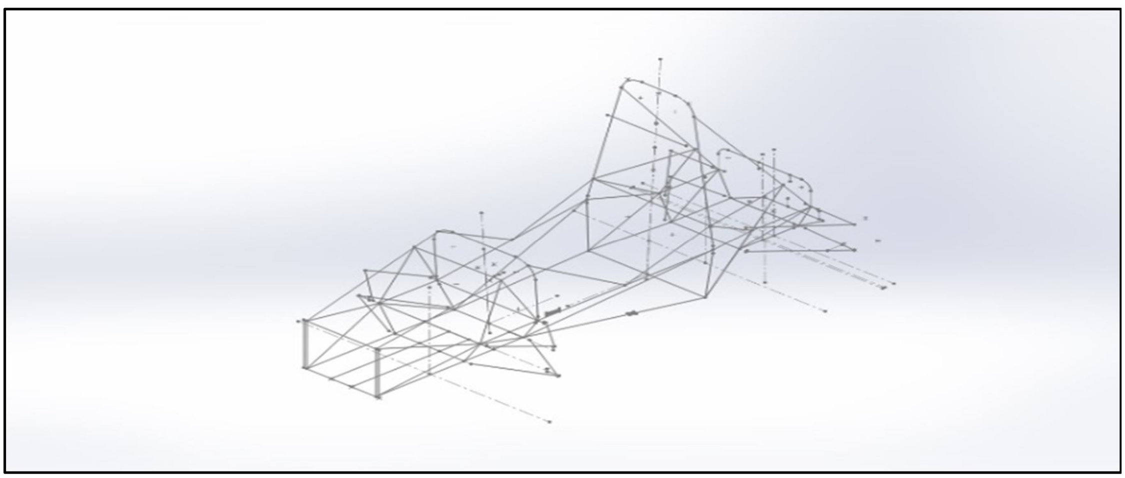

Figure 08: - Chassis Sketch Model

VI. ANALYSIS

Analysis: - It is most important step in designing in which we analyze model in different conditions by applying loads and fixtures. All analyses are performed in the SOLIDWORKS Simulation Software.

Chassis is analyzed for the following cases. [4]

A. Front impact analysis
B. Rear impact analysis
C. Side impact analysis
D. Front torsional analysis
E. Rear torsional analysis
F. Modal or Frequency analysis
G. Static vertical bending analysis
H. Acceleration test
I. Lateral bending analysis

Usually Formula1 Drivers Experience 2G Force while Accelerating 5G, Force While Braking and 4G to 6G force while cornering [4].

Steps involved in analysis are as follows:

- Select appropriate case and identify loading conditions.
- Apply suitable material.
- Apply Loads and constrains and according to conditions.
- Create mesh and run the analysis.
- Compare results and perform modification if required.

Displacement, Von mises stress, Equivalent strain and FOS (Factor of Safety) of chassis will be judged to claim status of analysis Safe or Not.

1) *Front Impact Analysis:* In this analysis front and rear suspension points are fixed as shown in Green Tri-Directional Arrow Symbol in Figure- 09. Force applied is calculated by as follows.

Vehicle Weight with driver= 325 Kg [5] [6]
Force= 6G = 6 x 9.81 x 325 = 19129.5 N
Force on Each Node = 19129/4 = 4782.37N

We are taking 19000N Instead of 4782N to design for worst case scenario.

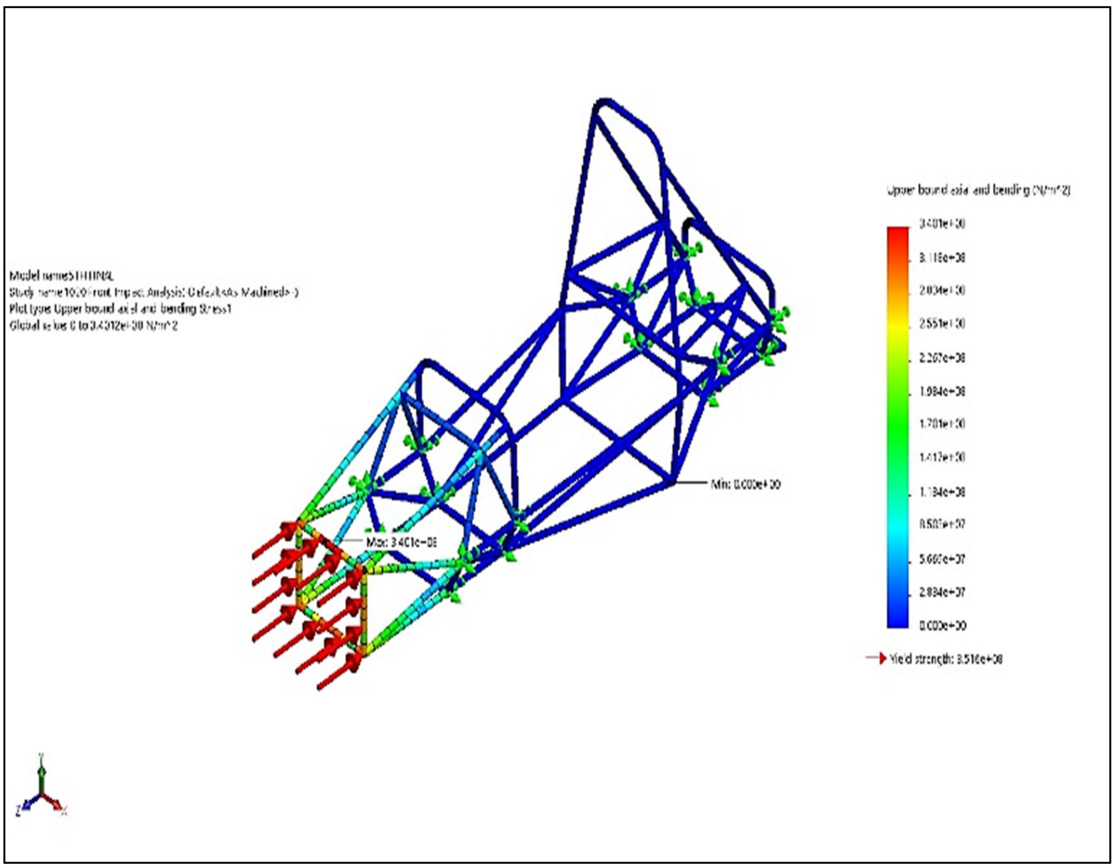

Figure 09- Stress Developed in Front Impact Analysis

Material= AISI 1020
Maximum Stress Developed = 340.1 MPa
Maximum Displacement = 1.62 mm
Minimum FOS Recorded = 1.034

2) *Rear Impact Analysis:* It is Similar to Front impact analysis only difference is instead of force applied at rear bulkhead of chassis. All loading conditions and fixtures are same.

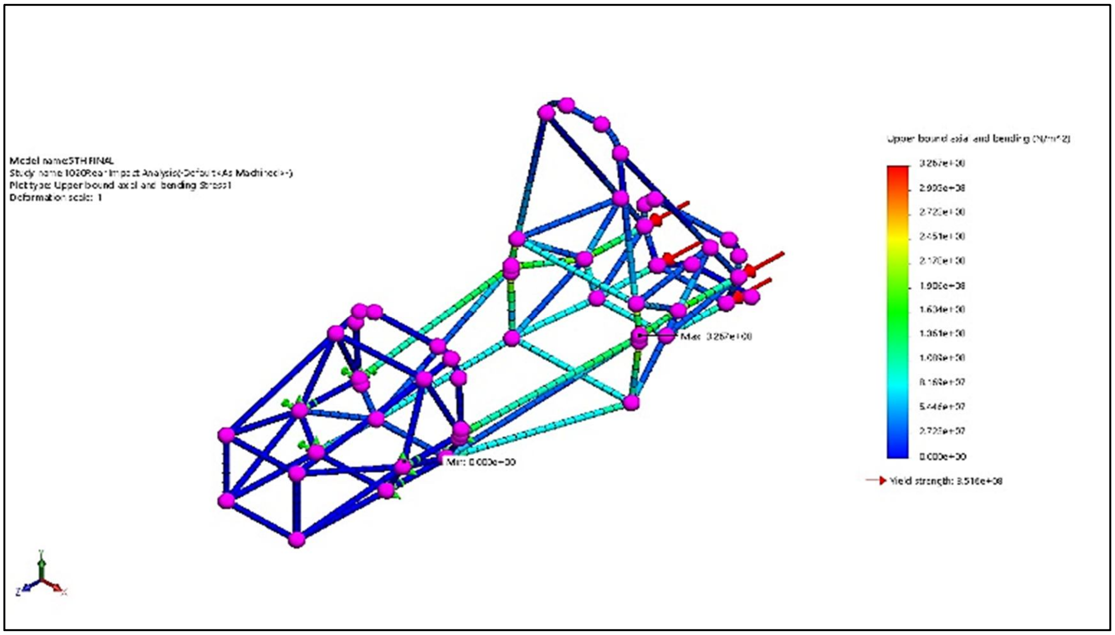

Figure 10- Stress Developed in Rear Impact Analysis

Maximum Stress Developed = 326.7 MPa
Maximum Displacement = 4.044 mm
Minimum FOS Recorded =1.076

3) *Side Impact Analysis:* In this all suspensions points are fixed except point on which force applied.

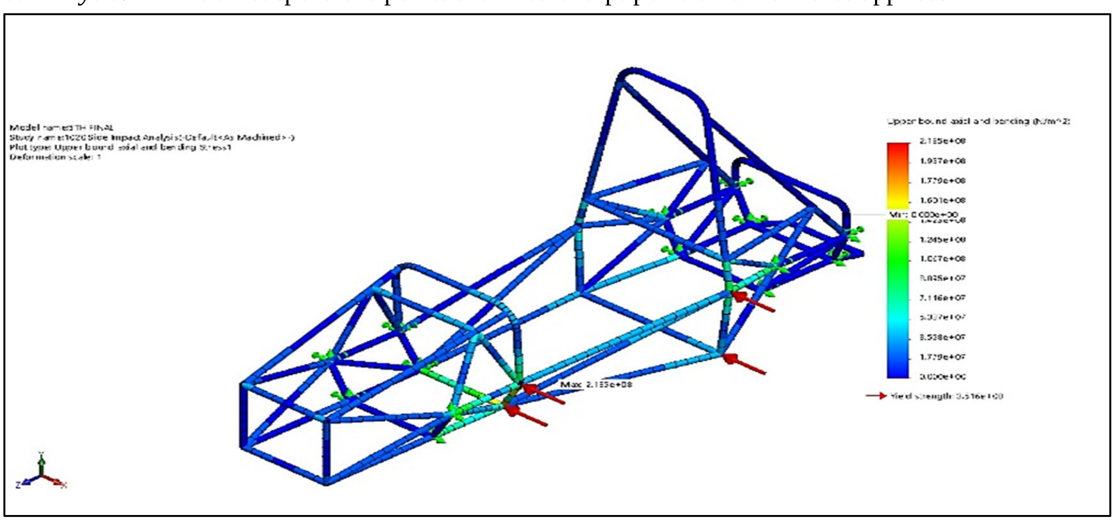

Figure 11- Stress Developed in Side Impact Analysis

Force= 6G = 6 x 9.81 x 325 = 19129.5 N
Force on Each Node = 19129/4 = 4782.37N
Approximately= 5000N is considered
Maximum Stress Developed = 213.5 MPa
Maximum Displacement = 1.218 mm
Minimum FOS Recorded = 1.647

a) Torsional Analysis: It is very important analysis is considered for structural stability of chassis. It will be performed by fixing one side of chassis and equal and opposite forces applied on another side of chassis by considering appropriate weight distribution which depends upon component mounted on chassis. And it is 40 – 60% in which 40% of total weight considered in front and 60% of total vehicle weight in rear.

Formula [7]

K= R/θ

$$K = \frac{(F \times L)}{\tan^{-1}[(\Delta y1 + \Delta y2)/2L]}$$

Where, K = Torsional stiffness

T = Torque

θ = Angular Deflection

F = Shear force

y1, y2 = Translation displacement

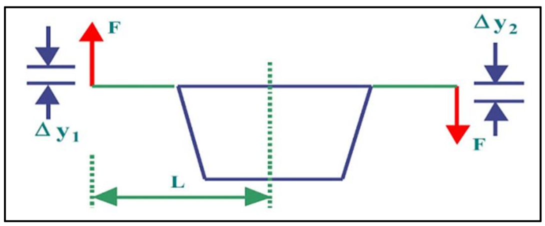

Figure 12 -Torsional Loads [3]

4) Front Torsional Analysis: This analysis performed by considering weight distribution of 40-60%. Weight in front is 40% of Overall Weight of 325Kg is 130Kg and force acting on each node is [(130/2) x 3 x 9.81 = 1912.9 N]. We are taking Round up 2000N force. Rear Suspension points are fixed for this analysis.

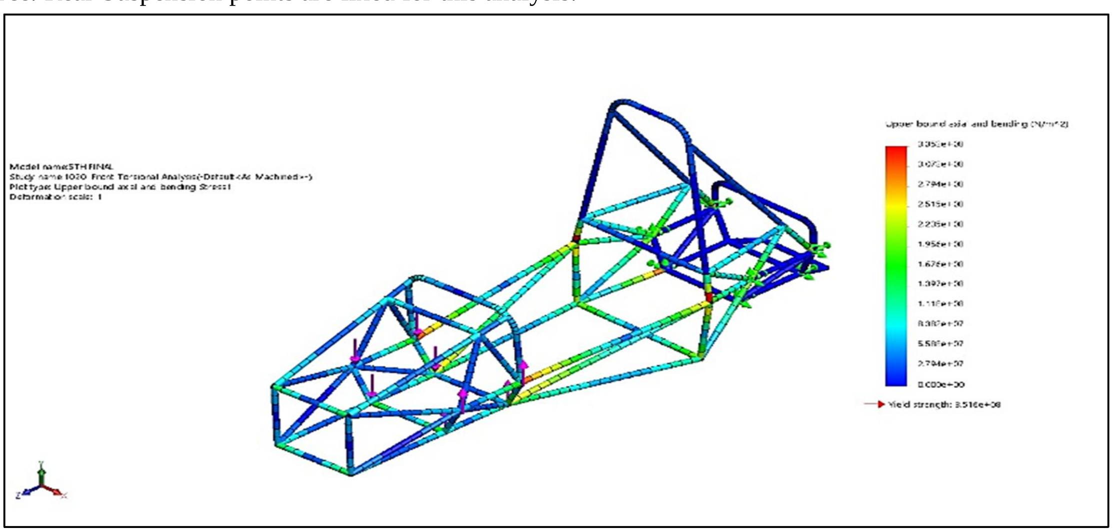

Figure 13 - Front torsional analysis

Maximum Stress Developed = 335.3 MPa

Maximum Displacement = 12.336 MM= 0.012336 M

Minimum FOS Recorded = 1.049

L= 545.86 MM Round up 550/2 = 275 MM=0.275 M

$$K = \frac{(2000 \times 0.275)}{\tan^{-1}[(0.012336 + 0.01234)/(2x0.275)]}$$

K= 214.0665 Nm/deg

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5) *Rear Torsional Analysis:* This analysis performed by considering weight distribution of 40-60%. Weight in Rear is 60% of Overall Weight of 325Kg is 195Kg and force acting on each node is [(195/2) x 3 x 9.81 = 2869.4 N]. We are taking Round up 3000N force. Front Suspension points are fixed for this analysis.

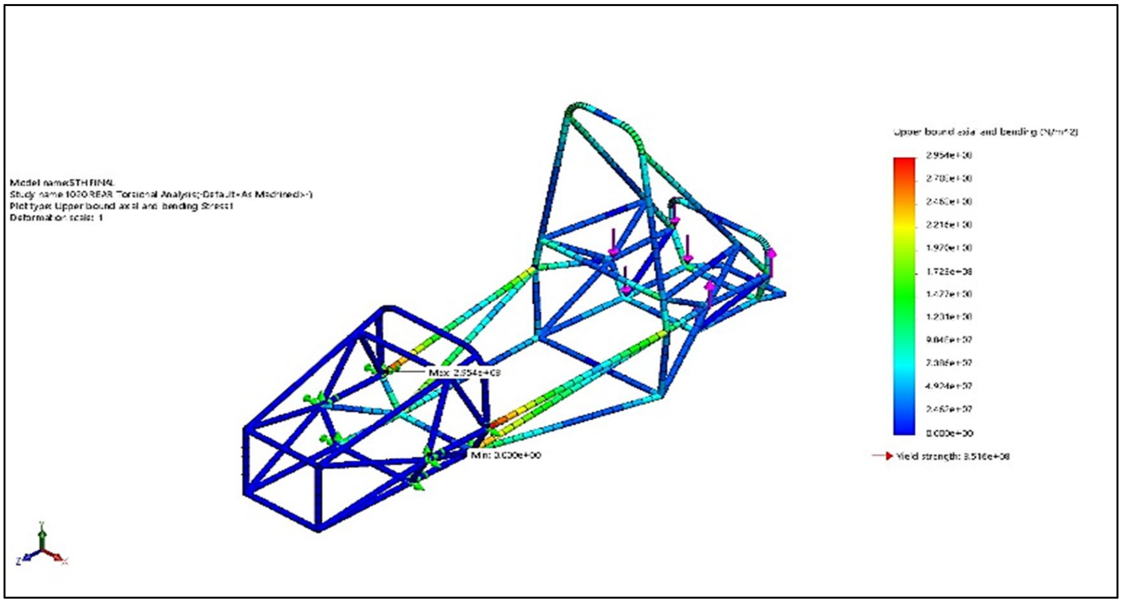

Figure 14 - Rear torsional analysis

Maximum Stress Developed = 295.4 MPa
Maximum Displacement = 5.77 MM = 0.00577 M
Minimum FOS Recorded = 1.19
L= 545.86 MM = 550/2 = 275 MM=0.275 M

$$K = \frac{(3000 \text{ x } 0.275)}{\tan^{-1}[(0.00577 + 0.00577)/(2x0.275)]}$$

K= 686.36 Nm/deg

6) *Modal or Frequency Analysis:* This analysis is performed to check natural frequency of structure under vibration (because structure has tendency to vibrate) should not match with natural frequency of four stroke single cylinder petrol engine which is 100Hz. At high speed, the engine frequency is around 100Hz [7]. This effect is Known as Resonance.

Table no: - 03 Frequency table with mode number

Mode No.	Frequency (Rad/sec)	Frequency (Hertz)	Period (Seconds)
1	326.07	51.896	0.019269
2	900.99	143.4	0.0069737
3	904.2	143.91	0.0069489
4	956.56	152.24	0.0065685
5	995.1	158.38	0.0063141

It is observed that natural frequency of structure is not with natural frequency of four stroke single cylinder petrol engine which is 100Hz hence it is safe.

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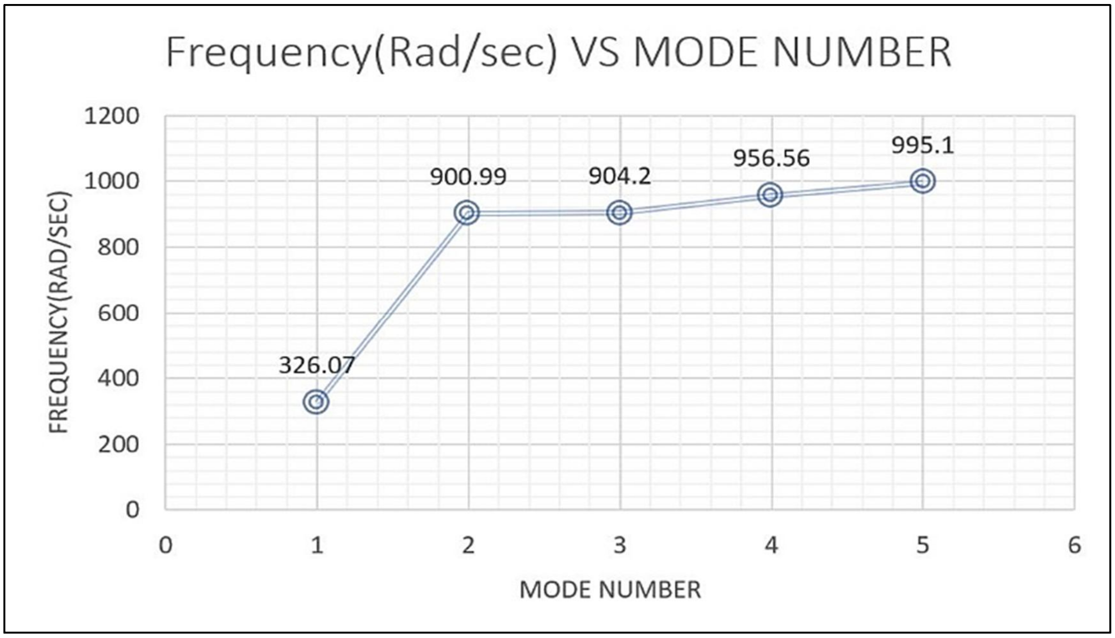

Figure 15:- Frequency Vs Mode Number graph

7) *Static Vertical Bending Analysis:* Vehicle experience vertical bending due to driver weight and other major and minor mounted components. Force is 325 x 9.81= 3200N. vertically downward and all suspension points are fixed.

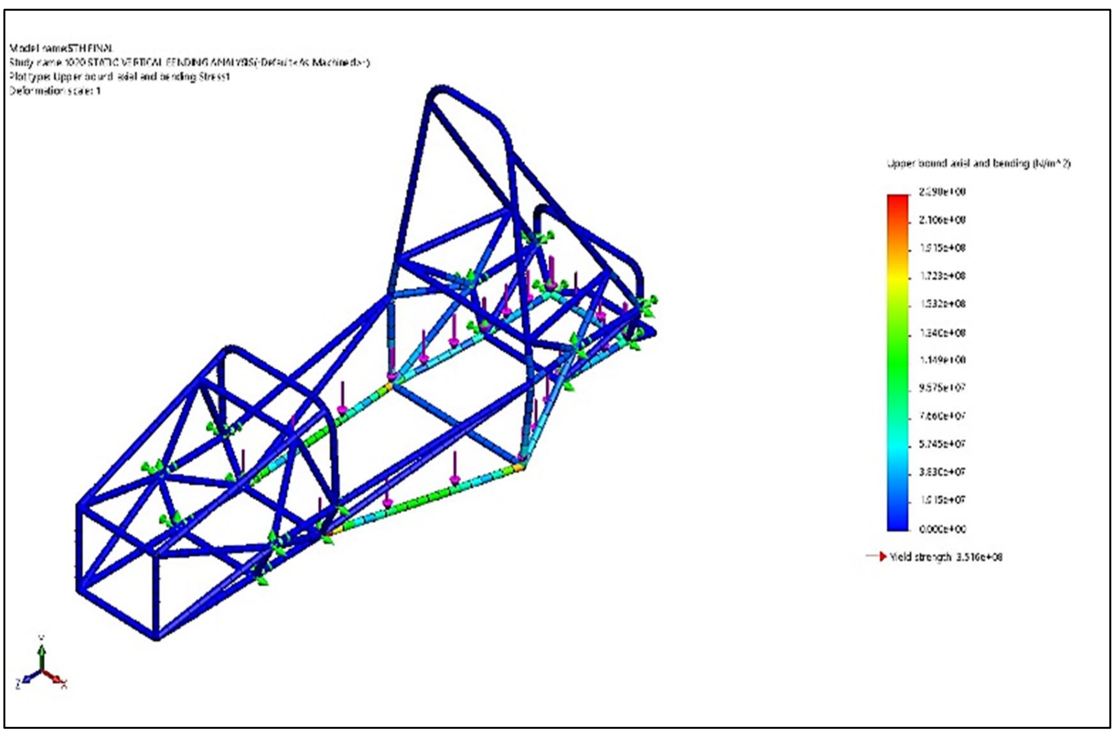

Figure 16 - Static vertical bending analysis

Maximum Stress Developed = 229.8 MPa
Maximum Displacement = 1.995 mm
Minimum FOS Recorded = 1.53

8) *Acceleration Test:* In the acceleration test force acted opposite to the direction of motion of vehicle. Acceleration of Royal Enfield thunderbird 500 is considered as 8m/s^2 [4] And mass of the vehicle is assumed as 325kg with driver. Force = 325 x 8 = 2600N distributed within Front bulkhead, front hoop, main hoop and engine compartment. Also, 325 x 9.81 = 3188.25N is applied vertically downward by rounding up we taken 3200N.

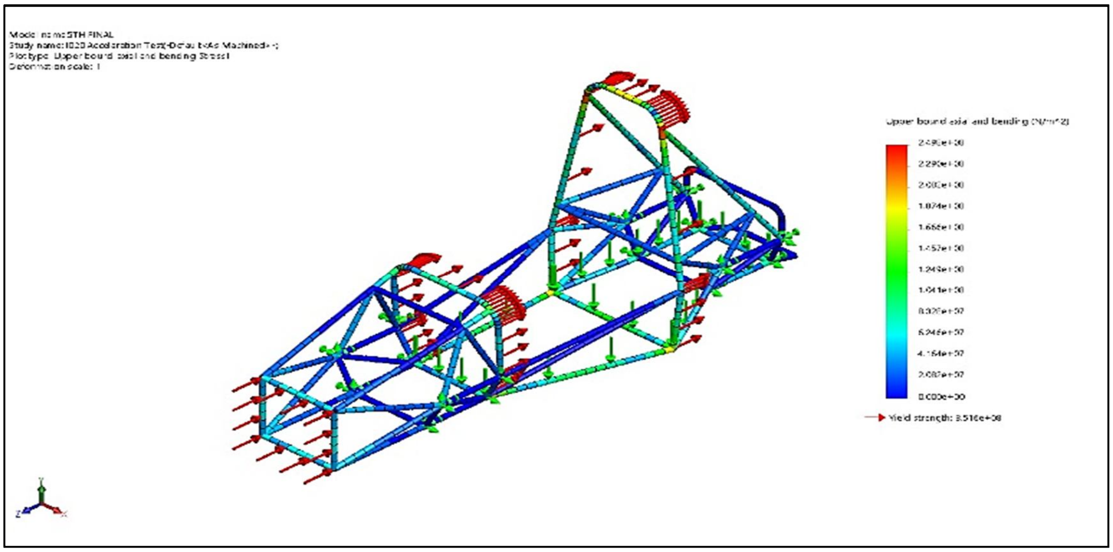

Figure 17- Acceleration test

Maximum Stress Developed = 249.8 MPa
Maximum Displacement = 2.37 mm
Minimum FOS Recorded = 1.407

9) *Lateral Bending Analysis:* The main cause of this reaction is centrifugal force acts on the chassis while cornering and wind force in some cases. The longitudinal axis of a car experiences lateral forces which are resisted by axle, tire, frame members, etc., [7]. Load is applied 325 x 9.81 =3,188.25 N by rounding up we taken 3200N.

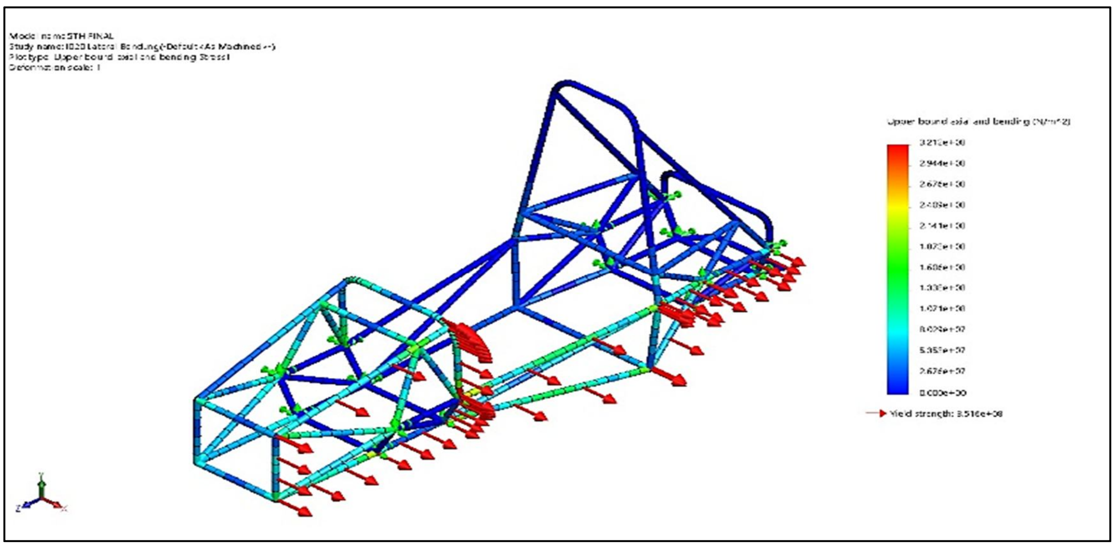

Figure 18- Lateral bending analysis

Maximum Stress Developed = 321.2 MPa
Maximum Displacement = 2.58 mm
Minimum FOS Recorded = 1.0995

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VII. RESULT COMPARISON

We have analyzed our model in different materials as discussed before. And the comparison will be based on stress developed, displacement, and Factor of safety.

Table no: - 04 Stress Comparison

Parameter / Cases	Maximum Stress Developed	
	AISI 1020	AISI 4130
UNITS	MPa	MPa
Tensile Strength	420.5	560
Yield Strength	351.6	460
(1) Front impact analysis	340.1	340.1
(2) Rear impact analysis	326.7	326.7
(3) Side impact analysis	213.5	213.5
(4) Front torsional analysis	335.3	335.3
(5) Rear torsional analysis	295.4	295.4
(6) Static vertical bending analysis	229.8	229.8
(7) Acceleration test	249.8	249.8
(8) Lateral bending analysis	321.2	321.2

As we can see there is no difference in stress developed in both materials in all cases are same, because stress induce in material is independent upon material properties.

$$\sigma = \frac{F}{A}$$

σ = Stress
F = Force applied
A = Cross-sectional Area
Stress induced is same but using higher grade material is safer because they are having more tensile, yield strength compared to lower grade materials.
Status: - From table no .04 we can claim our model is SAFE in both materials.

Table no: - 05 Displacement Comparison

Parameter / Cases	Maximum Displacement	
	AISI 1020	AISI 4130
UNITS	mm	mm
Tensile Strength (MPa)	420.5	560
Yield Strength (MPa)	351.6	460
(1) Front impact analysis	1.6218	1.6
(2) Rear impact analysis	4.044	3.94
(3) Side impact analysis	1.218	1.185
(4) Front torsional analysis	12.336	5.77
(5) Rear torsional analysis	8.68	8.43
(6) Static vertical bending analysis	1.995	1.946
(7) Acceleration test	2.37	2.315
(8) Lateral bending analysis	2.58	2.516

As we can see there is a difference in the displacement of both material analyses because of higher grade material having good property compare to lower grade.
And displacement results are not too huge for which we should concern about hence material **SAFE**

Table no: - 06 Factor of Safety Comparison

Parameter / Cases	Minimum Factor of safety	
	AISI 1020	**AISI 4130**
Tensile Strength (MPa)	**420.5**	**560**
Yield Strength (MPa)	**351.6**	**460**
(1) Front impact analysis	**1.034**	**1.35**
(2) Rear impact analysis	**1.076**	**1.26**
(3) Side impact analysis	**1.647**	**2.15**
(4) Front torsional analysis	**1.049**	**1.3**
(5) Rear torsional analysis	**1.19**	**1.56**
(6) Static vertical bending analysis	**1.53**	**2**
(7) Acceleration test	**1.407**	**1.841**
(8) Lateral bending analysis	**1.095**	**1.433**

1) *Factor of Safety (FOS):* It is the ratio of Yield stress to working stress. It expresses how much stronger the system is for different working condition.[8]

$$FACTOR\ OF\ SAFETY = \frac{YIELD\ STRESS}{WORKING\ STRESS}$$

Factor of safety for our model ranges between 2.15 to 1.034. And factor of safety should range between 1 – 3 for optimum design model [9].

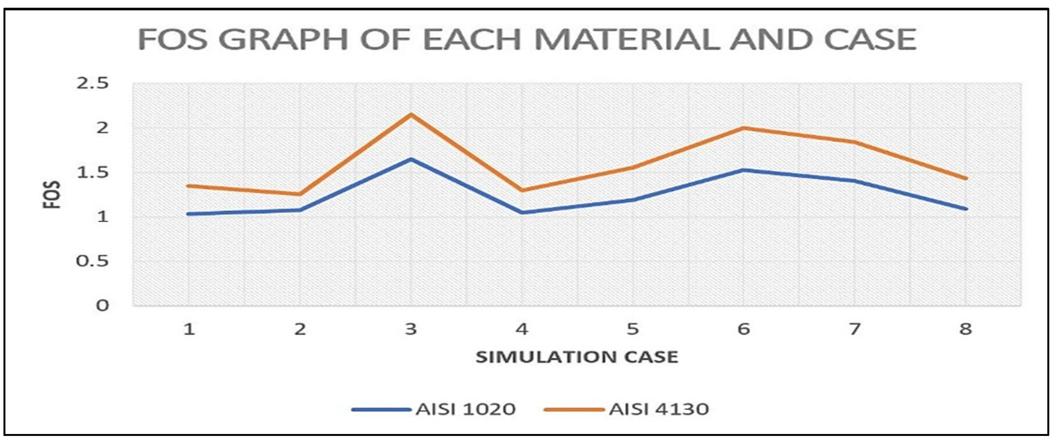

Figure 19: - FOS graph for different cases and material

Red line: - For AISI 4130 Material
Blue Line: - For AISI 1020 Material
1,2,3….8: - Indicates Different cases as per Table no: - 06 Factor of Safety Comparison

VIII. CONCLUSION

Thus, we have successfully performed the analysis of the Tubular Space frame chassis. It is observed that the selection of material plays important role in the analysis as well as for design safety and various factors such as strength, cost, availability etc. should be considered while selecting the material. Following a systematic approach for design and analysis helps to create a better design. Also, while designing we have to consider some parameters/attributes which directly or indirectly affect the performance of the chassis. From the different loading conditions, analysis cases and their results, we can conclude that the Chassis model is safe for both the materials AISI 1020 and AISI 4130. Also, we noted that FOS for both materials ranges between 2.15 to 1.034, and for the optimum design model it should between 1 - 3. However, from table no. 05 it can be seen that the deformation for AISI 4130 material was low compared to AISI 1020. Also, from table no. 06 the FOS values obtained for AISI 4130 are high as compared to AISI 1020. Hence by considering Factor of Safety (FOS) as the dominating factor we can say that AISI 4130 will be more suitable material for the chassis compared to AISI 1020.

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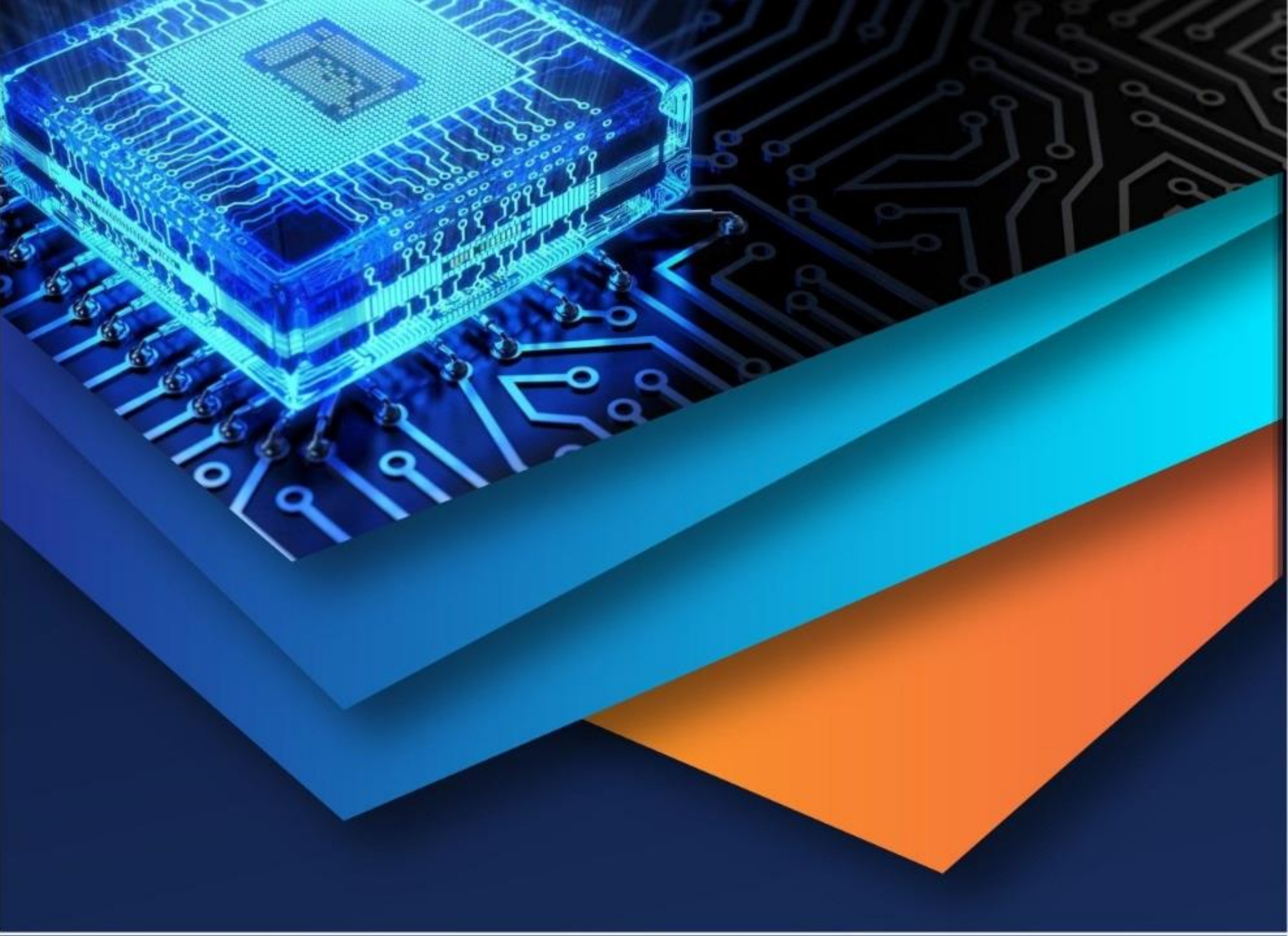

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