Design, Development and Analysis of Race Car Chassis

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Abstract - *A fundamental approach to design an FSAE race car chassis is discussed in this paper. The most important part of any vehicle is the chassis. The vehicle will rely on the chassis for torsional and flexural rigidity. Thus designing the chassis will not only help in supporting the components but also for improving the performance and aesthetics of the vehicle. Clearance and compliance stacking of the chassis also play a crucial role in the assembly of the vehicle. The design should be such that the weight of the overall distributed by balancing the vehicle. The chassis includes several important segments: Main Hoop, Front Hoop, Side Impact Structure, and Crush Zone. Designing of the chassis should be such that the load acting in the suspension, the weight of the driver, engine, etc. should be sustained by it which can be done by making it stiffer. Limiting the weight of the chassis can help to increase the performance of the vehicle.*

***Key Words*: Light Weight, Stiff, Torsional Rigidity, Chassis Design, Material, Solid Works, Calculation, ANSYS**

1. INTRODUCTION

This paper involves designing the chassis which meet all the regulations of the FSAE and complies with other components. Designing a chassis that would meet all the requirements like stiffness, lightweight was the goal. The vehicle will rely on the chassis as it would be the most crucial part of the vehicle. Mounting points for all subsystems will be integrated into the chassis with sufficient strength and stiffness. The overall ingress and egress will be determined by the profile of the chassis. The main goal was to design a lightweight race car chassis of a Structural, Aesthetic, Ergonomic, and Crash Resistant properties while maintaining low cost but better reliability of the vehicle with impressive performance and ensuring driver's safety. Also, the structure should not be complicated in order to provide easy access to any component for maintenance and inspection. Through various iterations of the design process, an optimal design was reached.

2. METHODOLOGY

The Selection of the proper methodology is important for any research work. An experimental approach along with a numerical approach should be considered to quire verified results. In this proposed work stress calculations are done and results are verified using ANSYS Software. The project is about designing and constructing a race car chassis, which requires basic knowledge about the various types of existing chassis or frame designs and the materials used for their manufacture, as well as the current trends of the automotive industry. As this is a product development project, we have made use of all the different stages of product development. The workflow is shown below.

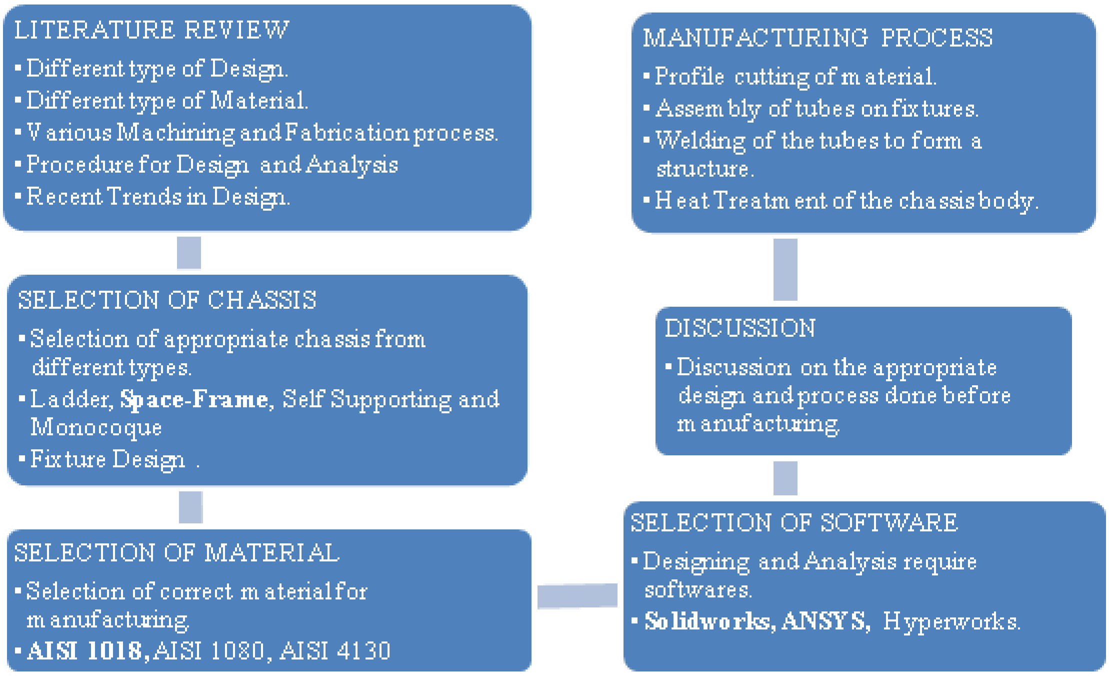

Chart 1- Methodology

2.1 Design Specification

Chassis-

Weight	32KG
Material	AISI 1018

Engine-

Model	Honda CBR 600f4i
Displacement	600 cc
Max power	92 HP
Max torque	60NM

Vehicle dimensions-

Wheelbase	1727.13 mm
Front track width.	1200mm
Rear track width.	1150mm
Ground clearance	60mm

2.2 Design Constraints

We identified the areas of design that need to be designed permanently, like driver position, engine mounting, wheelbase, track width, etc. The mounting plate for the Impact Attenuator was also designed as per the standards available.

2.3 Design Methodology

The selection of space frame chassis design was done over monocoque chassis design. Apart from being heavy in weight, the manufacturing of the space frame chassis is economically effective, and any destruction to the structure or improper alignment can be easily repaired. The chassis design started with implanting the suspension points, and engine mounting points.

2.4 Basic Design

The design procedure initiated by designing the cockpit section. This included designing the Front Hoop, Side Impact Structure, and Main Hoop according to the driver's requirement and standard 95th percentile Male Percy. The Front Hoop was designed by considering the suspension as well as the steering points. The height of the Main Hoop was designed such that the distance between the helmet of a 95th percentile male and the straight line drawn from the top of the main hoop to the top of the front hoop should be at least 50.8mm.

More space was given to the cockpit for a more comfortable driving position and in order to incorporate the 95th Percentile Male Percy. Battery and fuel tank was also to be installed in the cockpit section. The height of the Front Bulkhead was fixed according to the length of the legs of the driver and pedal box position. The Supports between the Front bulkhead and Front Roll Hoop were designed such that they hold the suspension points on nodes. Triangulation (truss) for connections of nodes was used. Triangulation was used in the frame structure to provide it with strength and support. Triangulation involves the use of triangular shapes to give stability to structures. It relates particularly to pinned or hinged structures. Usually, these types of structures offer no resistance to bending moments when a force is applied. Members trying to resist bending do not need to be as strong. This method of connections helps to distribute the force concentration on several members, thus preventing the failure of any single member.

The Design of Rear Bulkhead was made to sustain the force transmitted by the engine, suspension, and drivetrain. Engine mounting points, Suspension Points, and Drivetrain mounting points helped to design the Rear Bulkhead as per requirement.

3. MATERIAL SELECTION

The chassis undergoes various kinds of forces during motion. Thus a material that would help the chassis to stay intact without yielding, and should also be stiff enough to absorb vibrations, and should resist high temperatures is important. The material property of the chassis is an important touchstone while designing and manufacturing the car. The two commonly used materials are Chromium-Molybdenum Steel (Chromoly) and SAE-AISI 1018. AISI 1018 was selected for manufacturing chassis.

Table -1: Properties of Material:-

Properties	AISI 1018	AISI 1080	AISI 4130
Density[kg/m^3]	7.8	7.8	7.8
Young's Modulus[GPA]	210	210	210
Brinell Hardness	120	174	200
Yield Strength[MPA]	360	375	460
Ultimate Strength[MPA]	420	450	560
Strength to weight ratio[KN-m/Kg]	55-60	55-60	72-75
Cost per meter	250	200	500
Elongation at break[%]	19	11	26

4. STATIC STRUCTURAL ANALYSIS

The next task is to analyze the design. Static and Dynamic analysis can be done on the chassis. Static analysis is carried out when a vehicle is stationary whilst Dynamic analysis is carried out when a vehicle is in motion. The analysis is carried out by keeping some points constraint. The constrained points may differ according to the analysis that is carried out. The result obtained gives us information about deflection, stress and strain, and the factor of safety. The deflection is seen in the vehicle when forces act on points that are weak. In order to obtain desirable results, the stresses should be evenly distributed throughout the chassis. The analysis result indicates the critical points where the chassis can deflect due to stresses and forces. Better design of chassis can be obtained by adding or removing components according to results obtained from the analysis.

Types of Analysis:-

1. Front Impact Analysis
2. Rear Impact Analysis
3. Side Impact Analysis
4. Front Torsional Analysis
5. Rear Torsional Analysis
6. Static Vertical Bending Analysis
7. Lateral Bending Analysis

Load Calculation:

- An optimal speed of 60 KM/hr. (maximum allowable speed of the formula student vehicle)
- Mass of 300 kg (an average mass of a student formula race car)
- Time of impact collision 0.3 seconds (average time of impact)

Then by using the above date, it can be written as:

V_F=0 (Post-collision velocity of the vehicle)

V_I=16.67m/s (initial velocity)

T=0.3 sec (Time taken for impact)

a=? (Acceleration)

By using the formula:

$V_F = V_F + a \times T$

$0=16.67 + a \times (0.3)$

$a=55.56\ m/s^2$

We know,

Force = mass × acceleration

Force =300 × 55.56

Force = 16,668 N

G Force= force/ (mass of the vehicle × 9.81)

G-Force =16,668/ (300 × 9.81)

G Force=16,668/2943

G Force= 5.66

So here we can conclude that a normal **6 G load** is to be applied in order to analyze the chassis in different aspects.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 09 | Sep 2020 www.irjet.net p-ISSN: 2395-0072

4.1 Front Impact Analysis

This analysis is carried out by constraining rear suspension points and applying the load to the four nodes. The weight of the entire vehicle is 300kg and a force of 6G (300*6*9.81=16670/4=4167.5N) is applied on each node of the front bulkhead of the chassis for structural analysis. The maximum stress of 138.5 MPA is generated which is less than the yield strength of the material, the maximum displacement of 6.667 mm, and the minimum factor of safety as 2.67 is observed during this analysis.

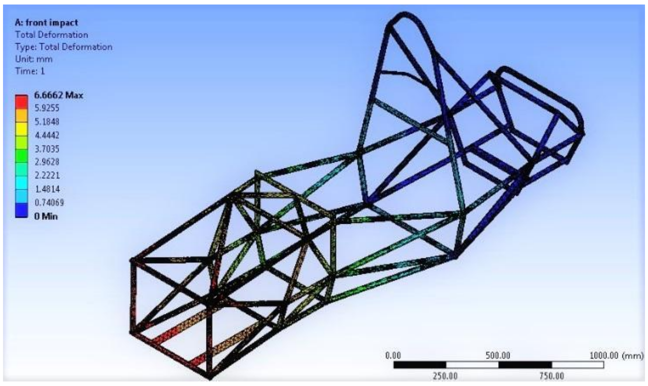

Fig -4.1(a): Total Deformation

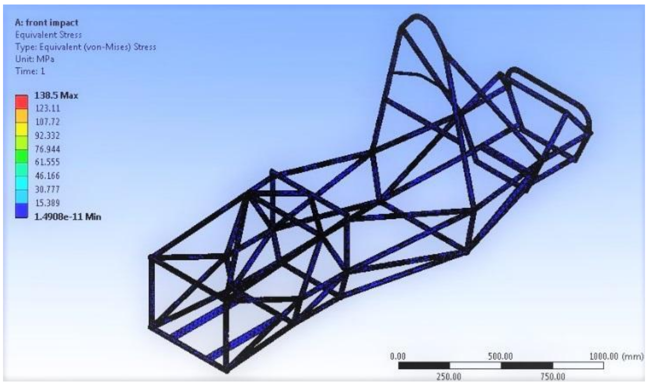

Fig -4.1(b): Maximum Stress

4.2 Rear Impact Analysis

For this analysis, front suspension points are constrained and load is applied at the rear bulkhead of chassis. The weight of the entire vehicle is 300 kg and 6G force (300*6*9.81=16670/4=4167.5N) is applied on each node of the rear section of the chassis for structural analysis. The maximum stress of 250.68 MPA generated which is less than the yield strength of the material, the maximum displacement of 2.687 mm, and a minimum factor of safety as 1.48 is observed during analysis.

Fig -4.2(a): Total Deformation

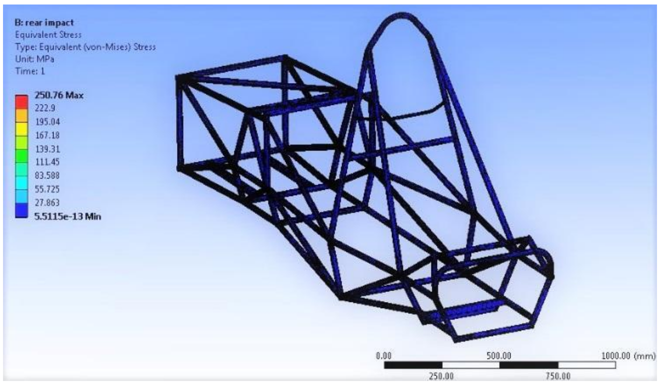

Fig -4.2(b): Maximum Stress

4.3 side impact analysis

The side members are analyzed for post-impact deflection. For this analysis, front and rear suspension points are constrained and the load is at the outermost members of either side. The maximum stress of 279.61 MPA is generated which is less than that of yield strength of the material, the maximum displacement of 10.514 mm, and a minimum factor of safety as 1.32 is observed during analysis.

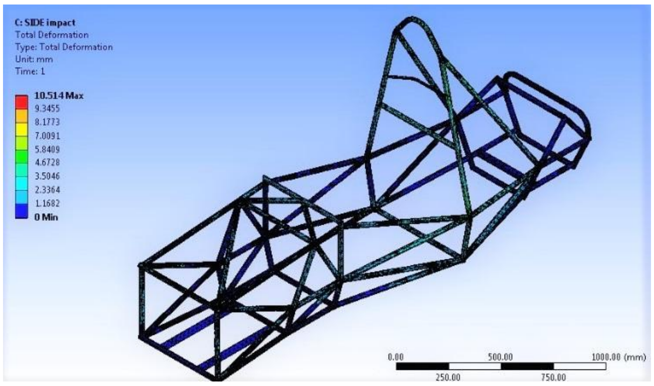

Fig -4.3(a): Total Deformation

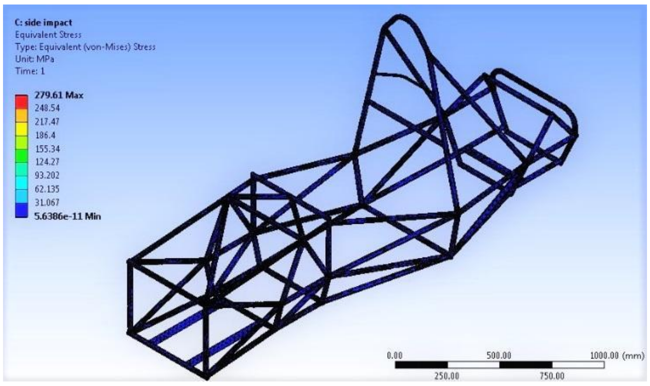

Fig -4.3(b): Maximum Stress

4.4 Front Torsional Analysis

For this analysis, the 3G force is considered. The weight distribution of the car is considered as 45-55%. So the weight on front suspension points is 135kg (40/100 * 300). 67.5kg (135/2 = 67.5kg)of weight should be exerted on each side but to make the chassis safe, the analysis will be carried out considering 135kg of load on each side. Upward load (128 x 3 x 9.8 = 3973.05N) to be applied on 4 nodes of one side of the front suspension and downward force 3973.05N to be applied on the 4 nodes of the other side. In this analysis type, rear suspension points are fixed and the load is applied on the front suspension points. Maximum stress 250.76MPA generated which is less than that of yield strength of the material, the maximum displacement of 23.17 mm, and the minimum Factor of Safety as 1.47 is observed during this analysis. Front torsional rigidity can now be calculated with the above-obtained values which are 543.74 Nm/degree.

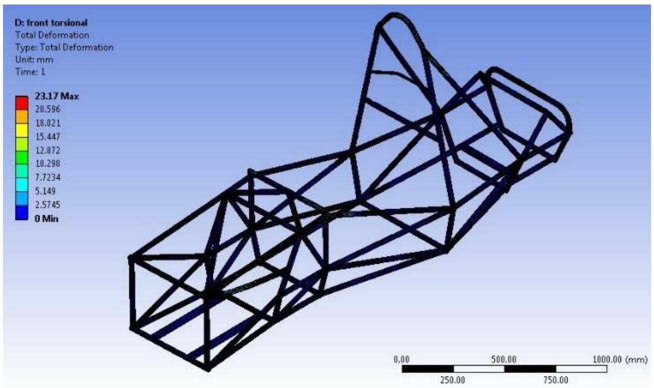

Fig -4.4(a): Total Deformation

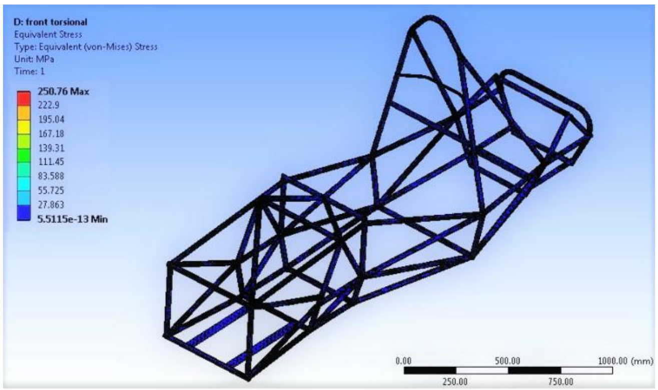

Fig -4.4(b): Maximum Stress

4.5 Rear Torsional Analysis

For this analysis, a force of 3G force is considered. The rear section has 55% of the total load. So, the load on rear suspension points is 165kg. 82.5kg of the load was applied on each side of the suspension. In order to ensure better stability of the chassis, a load of 165kg is considered on each side for the worst-case scenario. Here, front suspension points are constrained and loads are applied on rear suspension points. Upward load (165 x 3 x 9.8 = 4851N) to be applied on 4 nodes of one side of the front suspension and downward force of 4851N to be applied on the 4 nodes of the other side. Maximum stress 250.76MPA generated which is less than the yield strength of the material, the maximum displacement of 11.675 mm, and the minimum Factor of Safety as 1.47 is observed during this analysis. Rear torsional rigidity can now be calculated with the above-obtained values which are 2547.69 Nm/degree.

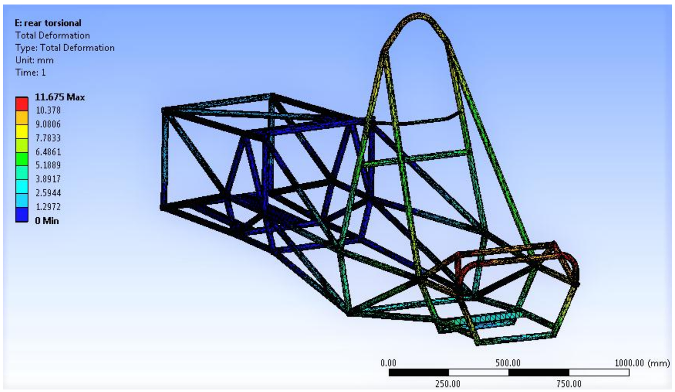

Fig -4.5(a): Total Deformation

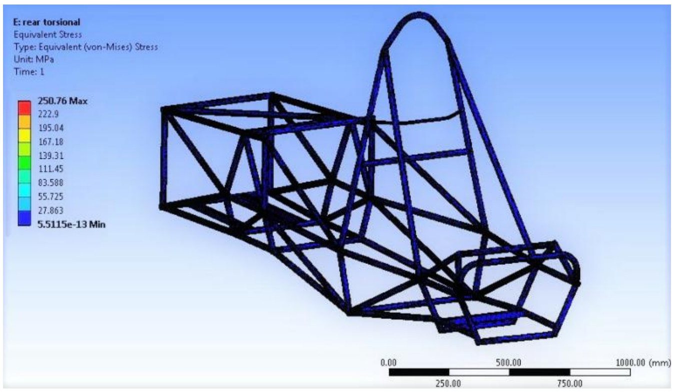

Fig -4.5(b): Maximum Stress

4.6 Static Vertical Bending Analysis

The components of the car which are mounted on the chassis also exert a vertically downward force to the chassis especially on the ladder of the frame. A force of 300 x 9.8 = 2940N is applied vertically down along with the driver and engine compartment. Front and Rear suspension points are constrained during this analysis. The maximum stress of 138.5 MPA generated which is much less than that of yield strength of the material, the maximum displacement of 0.24732 mm, and the minimum Factor of Safety as 2.5 is observed during this analysis.

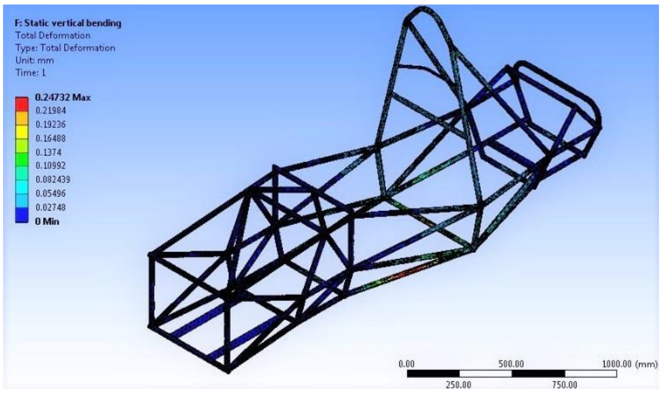

Fig -4.6(a): Total Deformation

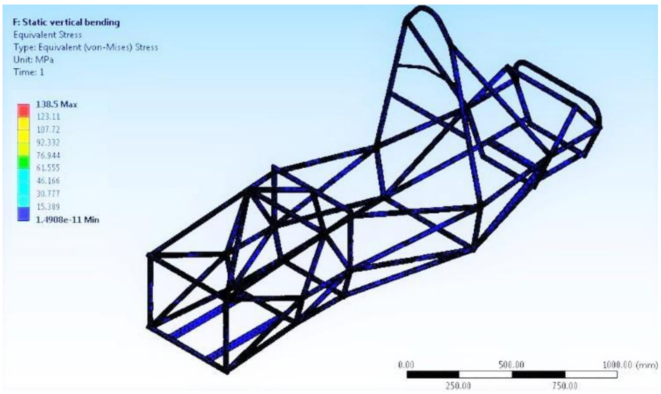

Fig -4.6(b): Maximum Stress

4.7 Lateral Bending Analysis

Centrifugal forces act on the chassis during cornering. The longitudinal axis of a car experiences lateral forces that are resisted by axle, tire, frame members, etc. 300 x 9.8 = 2940N of the load is applied on the side members from inwards of the chassis i.e., from the driver cabin, drivetrain side braces hoops and bulkhead. Front and rear suspension points are constrained and load is applied on the chassis. The maximum stress of 279.61 MPA generated which is less than that of the yield strength of the material, the maximum displacement of 2.5117 mm, and the minimum Factor of Safety as 1.32 is recorded in this analysis.

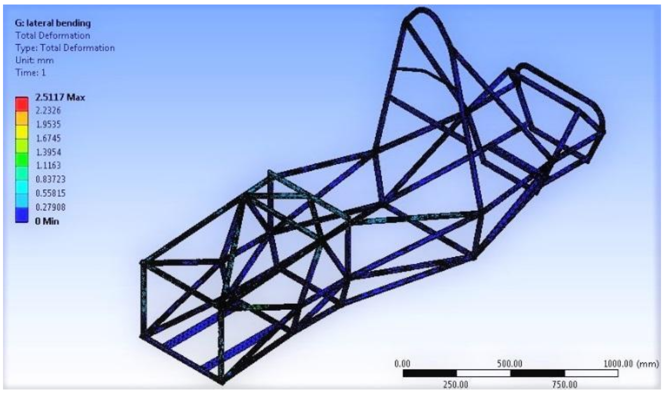

Fig -4.7(a): Total Deformation

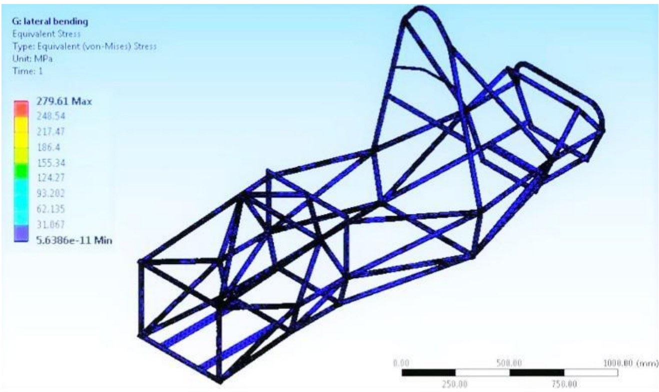

Fig -4.7(b): Maximum Stress

5. RESULTS

Analysis	Force	Deformation (mm)	Stress (MPA)	FOS
Front Impact	16.670 KN	6.667	138.5	2.67
Rear Impact	16.670 KN	2.687	250.68	1.48
Side Impact	8.335 KN	10.514	279.61	1.32
Front Torsional	3.97305 KN	23.17	250.76	1.47
Rear Torsional	4.85595 KN	11.68	250	1.47
Static Vertical Bending	2.943 KN	0.24732	138	2.5
Lateral Bending	2.943 KN	2.5117	279.6	1.32

The above table shows the deformation obtained during the analysis which is within the limit that means the design is safe. And the stress generated during the analysis which is less than that of the yield strength of the material which means the design is safe.

6. CONCLUSION

In conclusion, the overall project goals were taken into account and the best performance of each goal was achieved after research throughout the project. This paper consists of the design and analysis of a formula-styled race car chassis. The chassis of the car is made according to the standards provided. The objectives to get high torsional rigidity and weight reduction were achieved without any compromise with the driver's safety. After performing various analyses, it was concluded that the chassis is safe. It was also concluded that the factor of safety obtained after analysis should be in 1.5 to 2.6, as it is considered as an appreciable FOS for any formula student race car. Torsional rigidity is important because a weak chassis is more prone to failure and the suspension actuation may get affected with twisting or bending action of the chassis. Appropriate material selection is important in order to enhance the performance and ensure the safety of the driver.

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