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ANALYSIS OF STUDENT FORMULA CAR FOR OPTIMUM SAFETY AND PERFORMANCE

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ABSTRACT

The Formula Student competitions are held everyyear. This paper is the result of the analysis done on the sample car design that can be presented in the Formula Student competition. The purpose of the paper is to provide a final summary on chassis analysis and structural performance. It also talks about all the important analysis that is to be done on a Formula Student car to make it safe and perform well on the track. The design has been made such that it focusses on maximum adjustability, reliability, performance, safety, weight reduction and ease of manufacturing. The analysis was done to make sure the objectives of design are fulfilled.

After going through many papers, documents, blogs and videos we found that many people get confused about the loading conditions and boundary conditions for different types of tests so this paper prioritizes to make people understand about those conditions as well as about the major tests required to perform complete analysis of Formula Student cars.

The weight of the chassis was calculated as 36 kg approximately according to the data obtained from design modeler of Ansys workbench as well as Solidworks. The design sustained all the loading conditions and passed all the tests. Thus, one of the objective of this paper is to help other universities and passionate students to successfully design and analyze their cars that can pass all necessary tests included in the paper.

KEYWORDS—*Formula Student; FEA; Boundary Conditions; Loading Conditions; Ansys; Solidworks*

I. INTRODUCTION

Formula student competitions are organized every year at different levels and at different platforms to give the opportunity to students to have a hands on experience on vehicle design, analysis, fabrication and management.

The most popular events being the Formula SAE and Formula Student competitions. The main motto of this competition is that the students have to build and represent their vehicles in such a way that people are likely to buy their products and invest in their future ventures. Thus it also gives the students to showcase their managerial and marketing skills along with the technical skills .The car is expected to perform well in case of ergonomics, acceleration, braking, maintenance etc. The vehicle is also assumed to have a proper security for drivers as well as the people around it. The car is designed for 5th percentile female to 95th percentile man. The impact attenuators, side impact members and other supportingmembers are essential in ensuring the security and safety of the vehicle as well as the driver. Also the main aim of the chassis analysis is to do the weight optimization as well as making it cost effective and make sure that it is able to withstand all the necessary forces.

This paper is Casted from the work done for Formula Bharat 2019 competition .The work submitted through this paper is the result of the study from different papers as well as books based on chassis design and analysis. Formula Student basic rules, load estimation method ,study of stresses and modes of load transfer, concept of deformation, boundary conditions, etc. are taken care off and has been explained in as short as possible way to help other new interested candidates to perform the FEA analysis on their formula cars.

II. MATERIAL SELECTION

Material of chassis was selected as AISI 4130.The factors that dominate in selection of material were its availability and uses in past competitions. After analysis the material properties, cost and other significant factors AISI 4130 was our best option.

TABLE I.

S.N	Steel Grade : AISI 4130	
	Property	Value
1	Young's Modulus	205e+09 N/m^2
2	Poisson Ratio	0.29
3	Density	7850kg/m^2
4	Yield Strength	435MPa

III. SOLID MODELLING

The major steps for any analysis is to find the force approximation, selection of material properties, preparing models and analyzing it. The cad model was designed in Solidwork software. The design was made as per the latest rule book specifications. Manikin was also created using anthropometric data and checked under realistic condition. After many iterations the cad model was proposed as shown below.

The tubular space frame chassis model was made of up round hollow cross section tubes of AISI 4130 steel throughout chassis.

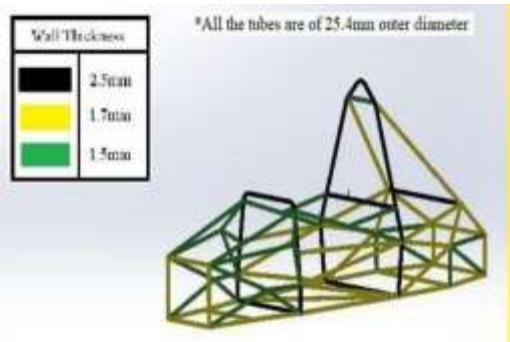

Fig 1. Thickness and diameter of chassis

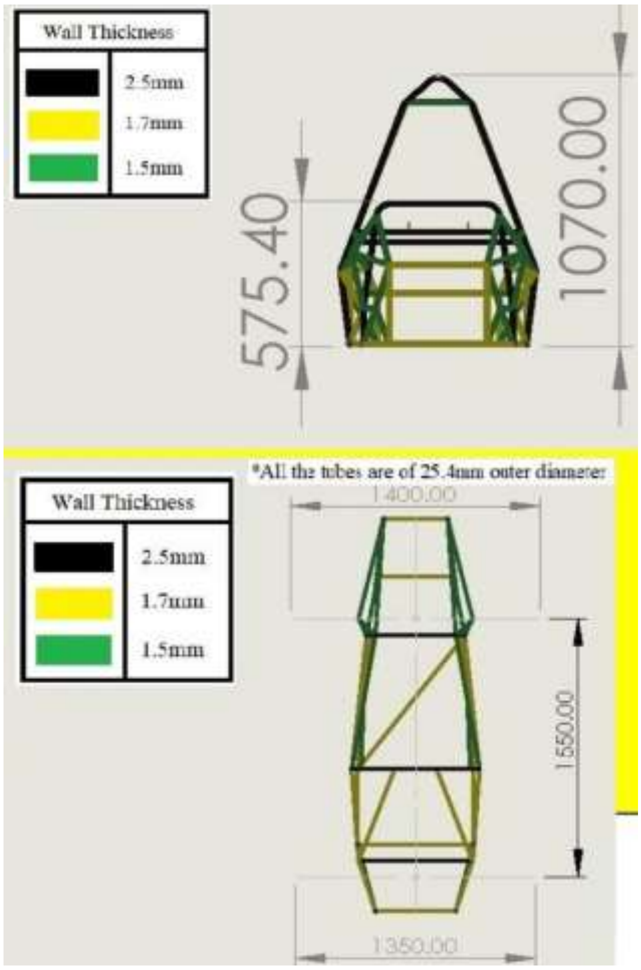

Fig 2. Dimension of chassis modelled in Solidworks

IV. FINITE ELEMENT ANALYSIS

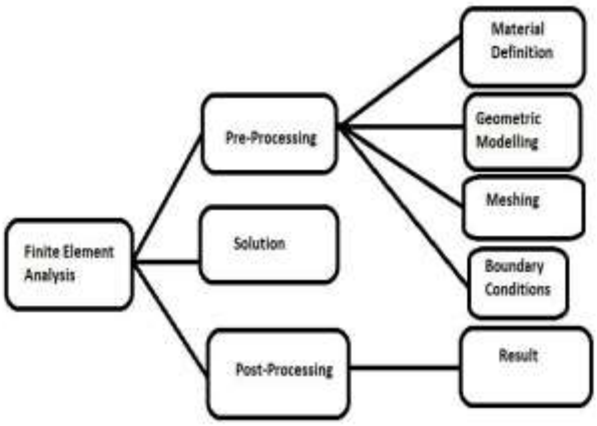

Fig 3. Steps in FEA analysis

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The process of modelling is followed by finite element analysis since the model can be tested and validated. There are other methods such as finite volume method or finite discretization method but we have adopted FEA because of its role in the world of solid mechanics where the equations are dominated with elliptical equations and we are acquainted with it thus making it much familiar .The software we chose for this is Ansys workbench. Ansys is one of the most popular FEA software environment.

The whole model is discretized and the frame is subdivided into elements. The nodes are kept at important points and joints. A meaning full result is only obtained when orientation, size of element number, load condition and boundary condition are properly dealt.

V. MESHING

Meshing is the process of dividing the whole domain into number of elements so that the loads can be distributed properly to approximate the domain.

TABLE II.

S.N	Mesh Quality	
	Mesh Detail	Value
1	Mesh type	Linear tetrahedral
2	Mesh size	5mm
3	Skewness	0.15 (0-1) where 0 being the perfect result
4	Aaspect Ratio	0.9 (0-1) where 1 being the perfect result

VI. MAJOR FEA ANALYSIS PERFORMED ON CHASSIS

Below are the list of major FEA analysis that are performed on Formula Student car chassis to test its functionality and safety. The loading conditions and boundary conditions have also been explained in the table.

TABLE III.

S.N	Tests performed	Boundary Conditions	Loading Conditions
1.	Static Shear	Clamping of rear suspension mounts	Downward force at front bulk head in downward direction.
2.	Acceleration Test	Clamp-front and rear suspension mounts	Force on main roll hoop and front roll hoop in direction opposite to motion of vehicle.
3.	Static Torsional	Clamp-diagonally opposite rear suspension mounts	Force on diagonally opposite front suspension mounts.
4.	Static Overall Bending	Clamp-front and rear suspension mounts	Uniformly distributed loading at driver cabin, engine bay and drive-train section.
5.	Front Impact	Clamp-rear suspension mounts	Uniformly distributed load on front bulk head.
6.	Rear Impact	Clamp-front suspension mount	Uniformly distributed load on rear bulkhead
7.	Side Impact	Fix one side of frame	Uniformly distributed loads on side members.
8.	Roll Over	Fix the lower part of frame	Force at top most part of front roll hoop at angle of 45^0
9.	and Modal Vibration Analysis	Clamp-rear and front suspension points	Give the displacement obtained from modal inpu analysis as t to the vibration analysis.

VII. RESULTS

The results of FEA analysis are given in a tabular form. The input loading conditions has also been explained to help other students to do the analysis on their own and have better understanding of loading conditions.

A. Static Shear Test

Shear test is performed to check the structural integrity of the body.

TABLE IV.

S.N	Load Parameters	Value	FOS
1	Force(weight of impact attenuator + drivers legs +Steering system +miscellaneous weight)	1500N	2.9

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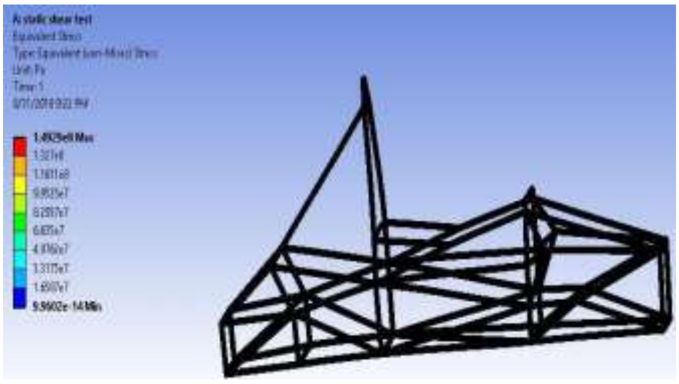


Fig 4. Von-mises stress during Static ShearTest

B. Acceleration Test

Acceleration test is performed to check whether the main roll hoop and front roll hoop can withstand the inertial forces or not.

TABLE V.

S.N	Load Parameters	Value	FOS
1.	Force due to acceleration of vehicle considering weight of driver and engine	1600N	2.8

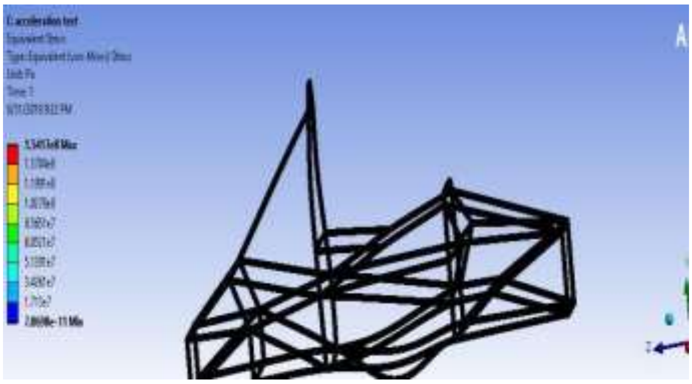


Fig 5. Von-mises stress during Acceleration Test

C. Static Torsional Test

The static torsional test is done to find the deflection on suspensions in y direction so as to find the torsional stiffness of the chassis.

TABLE VI.

S. N	Load Parameters	Value	Deflection	Torsional stiffness	FOS
1.	acting Force due to dynamic suspension loads	3G	1.56mm	9340.5 Nm/degree	1.8

Calculation of Stiffness:

1. Force(F)=Mass of car * 'G' force
   Force= 280*3*g
   Force= 280*3*9.81
   Force= 8240.4 N
2. Maximum displacement on suspension points in vertical Y-axis (D)= 1.56 mm= 0.00156 m
3. The length between diagonally opposite suspension points where loads are placed (L)= 0.45 m
4. Angle of twist(ϴ)= $\tan^{-1}$(D/2*L)
   ϴ= 0.397°
5. Torsional Stiffness= (F*L)/ϴ
   Torsional Stiffness= (8240.4*0.45)/0.397
   Torsional Stiffness= 9340.5 Nm/degree

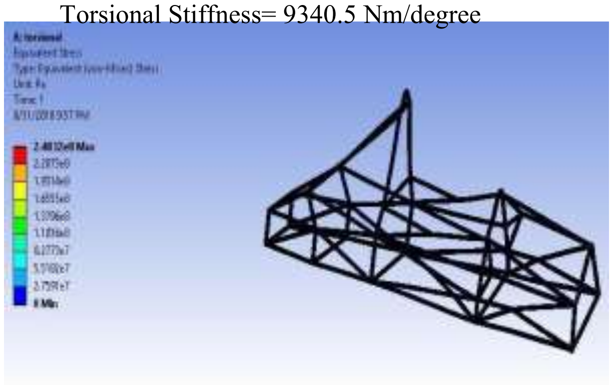


Fig 6. Von-mises stress during Torsion Test

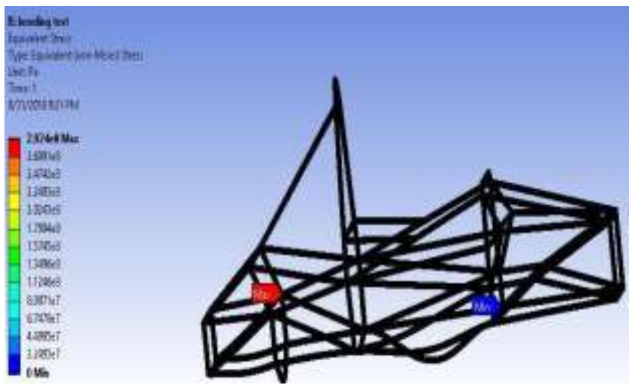
D. Static Overall Bending Test

The static bending test is to find the stresses at points where maximum bending effect takes place so as to find its ability to withstand bending forces

TABLE VII.

S.N	Load Parameters	Value	FOS
1.	Force due to weight of parts in driver cabin, engine bay and drive train sections.	1600N	1.5

Fig 7. Von-mises stress during Bending Test



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E. Front Impact Test

This test is performed to check whether the frame structure is capable of taking the frontal impact from collisions.

TABLE VIII.

S.N	Load Parameters	Value	FOS
1.	Force due to impact at 15 m/s with time of impact 0.3 s	16000 N	1.2

Fig 8. Von-mises stress during Front Impact Test

F. Rear Impact Test:The rear impact test is performed to check the structural integrity of the rear part during collision at rear part.

TABLE IX.

S.N	Load Parameters	Value	FOS
1.	Force due to impact at 11 m/s with time of impact 0.3 s	11734N	1.2

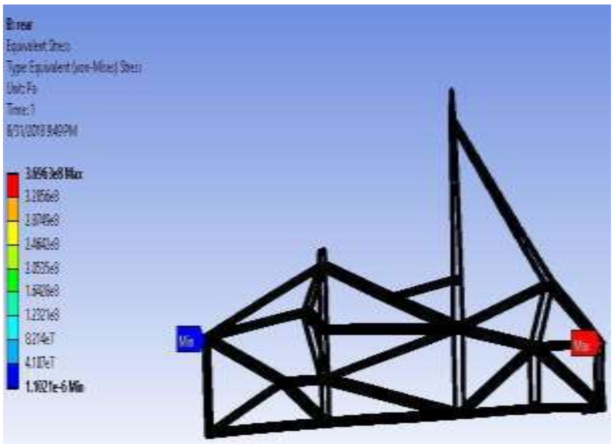

Fig 9. Von-mises stress during Rear Impact Test

G. Side Impact Test

The side impact test is done to make sure the driver will be safe even if the car is hit by another body as the loads will be taken by side members

TABLE X.

S.N	Load Parameters	Value	FOS
1.	Force due to impact at 10 m/s with time of impact 0.3 s	10670 N	1.3

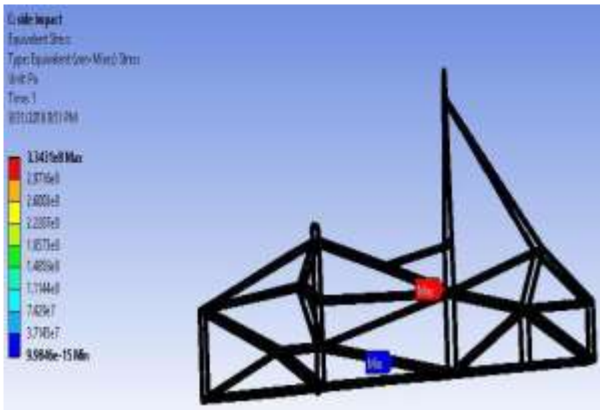

Fig 10. Von-mises stress during Side Impact test

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H. Roll Over Test

The roll over test informs us about the stability and safety of structure of car during bumps and shocks.

TABLE XI.

S.N	Load Parameters	Value	FOS
1.	Force due to bumps and suspension shocks	3G	1.3

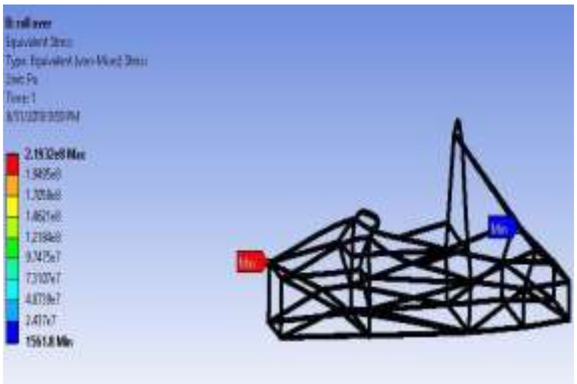

Fig 11. Von-mises stress during Roll Over Test

I. Modal and Random Vibration Analysis

This test is performed to find the working range of frequency of formula car in which it will be safe from excessive vibration and unbearable stresses.

TABLE XII.

S.N	Frequency to Avoid	FOS
1.	Above 135 Hz	0

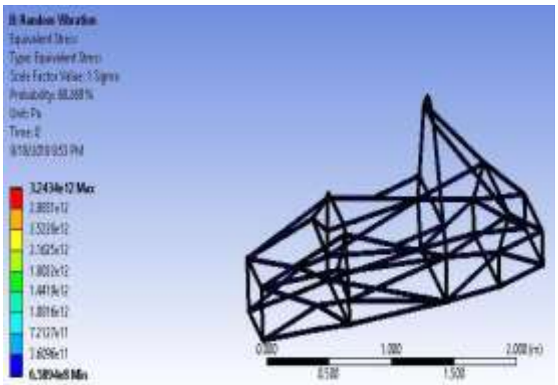

Fig 12. Von-mises stress during Vibration analysis at extreme frequency

Note:

1. The forces are obtained by simple physics calculation and use of Newton's law of motion and equations of motion.
2. The 'G' forces can be obtained by doing simulation on software like MATLAB and Simulink, ChassisSim, Adams, etc. If the software is not available to use then maximum G force can be considered for respective analysis through suitable research on vehicle dynamics.
3. The 'G' forces are converted into Newton force by Multiplying the whole mass of car body by the times of 'G' force acting on it which is divided between the components taking the load. For e.g. If the total bump force at front is calculated then it is to be divided by 2 since there will be two suspension i.e. one on the right and next on the left taking that force.

VIII. CONCLUSION

The FOS has been found to be more than 1 in all the tests thus it is a safe design. Since in all conditions the worst conditions are assumed and also some miscellaneous factors has been considered thus anything above unity is a really good result. It also ensures that the design is weight optimized and all the unnecessary materials has been removed. Similarly as the FOS is not as high as 3 or 4 thus weight optimization is also not required. In case, if the FOS is very high then some parts can be removed or the thickness can be varied for weight optimization. The torsional stiffness is found to be 9340.5 Nm/degree which is also a very good value for stiffness. Thus it is a very good design that can perform very well in case of structural performance.

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