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Static structural analysis of Formula Student Space Frame

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Abstract – *The main objective of this paper is to give detailed calculations and analysis of formula student vehicle's roll cage. Realistic approach of material selection for roll cage is shown followed by designing with the help of SolidWorks 2017. The front impact, rear impact, side impact and torsional analysis are carried out in ANSYS 18.1 for deformation and maximum stress. The major challenge was to optimize the design for light weight without compromising safety of the driver. The design obeys the rules stated by FSAE rulebook and Formula Bharat Rulebook 2019.*

***Key Words*: Roll cage, Material, Calculations, SolidWorks, Static Structural, ANSYS.**

1. INTRODUCTION

There are several options for manufacturing the chassis/ roll cage; space frame, ladder frame, monocoque etc. We opted to manufacture our roll cage in the form of space frame. Space frame can be easily manufactured with conventional tooling and any modifications/repairs can be easily done.

All the systems of a formula student vehicle are mounted on the roll cage. As roll cage being important system absorbing all the static and dynamic loads, the structure must withstand the stresses generated without deformation. The purpose of the paper is to design, calculate and analyse the roll cage for deformation and stresses within permissible limits of rules stated by FSAE. The mass of the roll cage influences widely on the vehicle's mass. So, the roll cage plays vital role in vehicle dynamics requiring lower weight.

2. SELECTION OF MATERIAL

Material selection was a tough job because significant amount of budget was involved. Also, it must sustain any loads or forces acting on it without deforming. Roll cage material must have certain stiffness to absorb all the vibrations and high temperatures produced by the engine. There's plethora of options for material to be used for roll cage. But most widely used materials for roll cage were AISI 1018 & AISI 4130. The AISI 1018 steel was selected to use for the roll cage because it was easy to procure, and the cost is comparatively low. Also, AISI 1018 can withstand the stresses without deforming as per our requirement.

Table -1: Properties of AISI 1018

Density (kg/m^3)	7800
Young's Modulus (MPa)	2.1x10^5
Poisson's Ratio	0.29
Yield Strength (MPa)	370
Ultimate Strength (MPa)	440

3. ROLLCAGE DESIGN

Roll cage was designed by using SolidWorks 2017 complying rules mentioned in the FSAE & Formula Bharat rulebook. The purpose was to rigidly connect the front and rear suspension to the roll cage. Any deformation of these points would affect the handling of the vehicle. The tubing sizes were not explicitly cited by the rulebook. The FEA simulations were carried out to optimize the sizing of the tubes ensuring it withstands the loads. Several iterations of the design were carried out to reduce weight, lowering the centre of gravity and optimizing the dynamics.

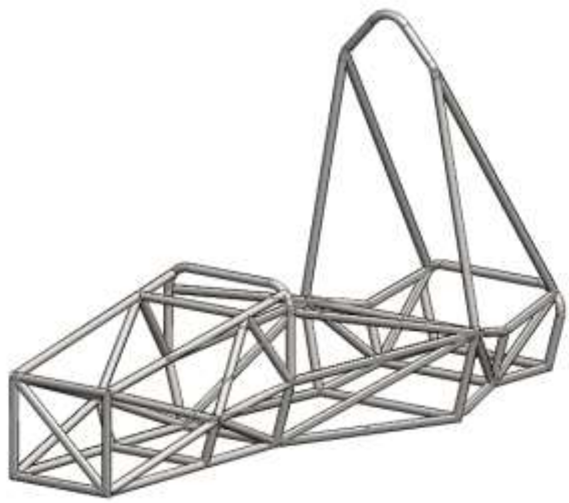

Fig a – SolidWorks model of roll cage

4. STATIC STRUCTURAL ANALYSIS

The forces are calculated from Work-Energy principle and are being applied on the vehicle. These forces are applied in order to check for deformation and max stresses are within acceptable limits.

4.1 Front Impact

In the front impact test, it is considered that the vehicle must be collided with a stationary body. In order to simulate this condition in ANSYS, force is applied on front portion of the vehicle and suspension points are constrained in all directions.

Mass of the Vehicle (M) = 320kg

Initial velocity of vehicle before impact (V1) = 28 m/s

Final velocity of vehicle after impact (V2) = 0 m/s

As per industrial standards: Impact time = 0.13 seconds

From Work-Energy principle,

Work done = Change in kinetic energies

$W = (0.5 \times M \times V2^2 - 0.5 \times M \times V1^2)$

$|W| = |-0.5 \times M \times V1^2|$

$|W| = |-0.5 \times 320 \times 28^2|$

$|W| = 125440$ Nm

Now,

Work done (W)= Force (F) × Displacement (s)__________ (1)

Displacement (s) = Impact time × Vmax (V1)

Displacement (s) = 0.13 ×28 = 3.64 m

So, from (1) we get,

F = W/ s

F = 125440 / 3.64

F = 34461.53 N

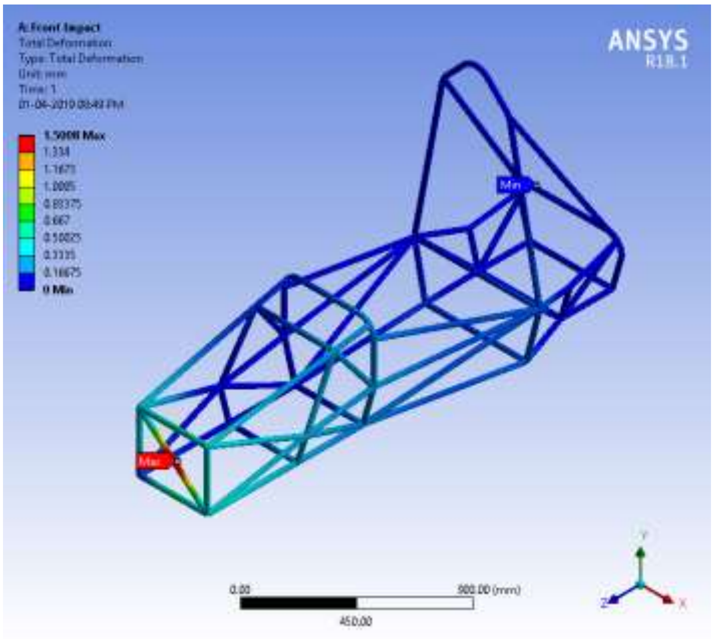

Fig -4.1(a): Total Deformation

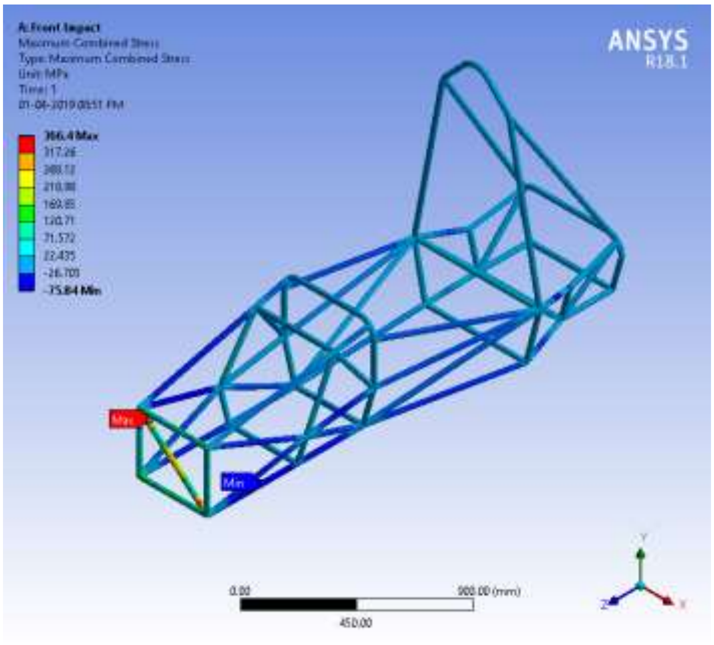

Fig -4.1(b): Maximum Combined Stress

4.2 Rear Impact

In rear impact test, the vehicle is assumed to be stationary and other vehicle hits from rear. The force is applied on the rear end of the vehicle constraining the suspension points.

Mass of the Vehicle (M) = 320kg

Initial velocity of vehicle before impact (V1) = 28 m/s

Final velocity of vehicle after impact (V2) = 0 m/s

As per industrial standards: Impact time = 0.13 seconds

From Work-Energy principle,

Work done = Change in kinetic energies

$W = (0.5 \times M \times V2^2 - 0.5 \times M \times V1^2)$

$|W| = |-0.5 \times M \times V1^2|$

$|W| = |-0.5 \times 320 \times 28^2|$

$|W| = 125440$ Nm

Now,

Work done (W)= Force (F) × Displacement (s)_________ (1)

Displacement (s) = Impact time × Vmax (V1)

Displacement (s) = 0.13 ×28 = 3.64 m

So, from (1) we get,

F = W/ s

F = 125440 / 3.64

F = 34461.53 N

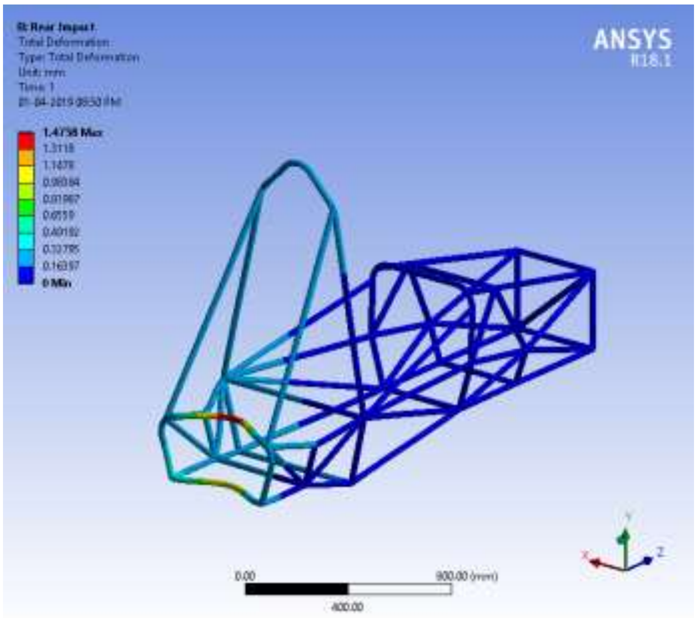

Fig -4.2(a): Total Deformation

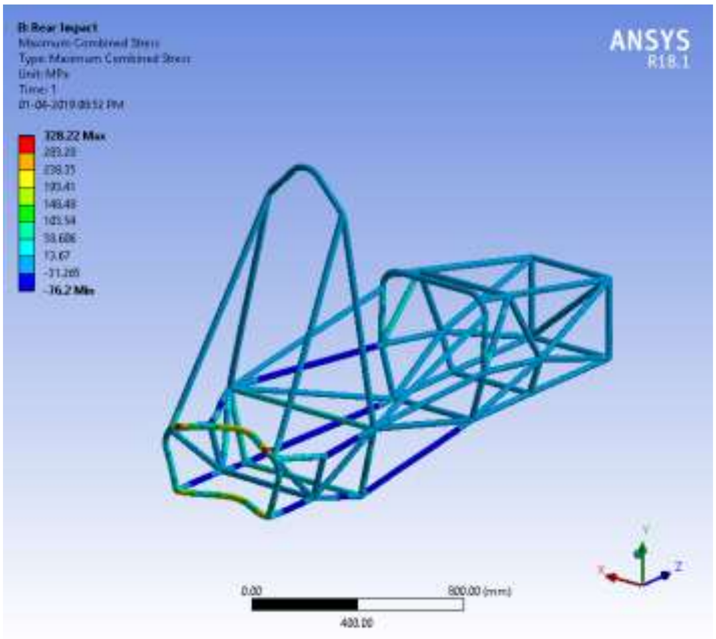

Fig -4.2(b): Maximum Combined Stress

4.3 Side Impact

The side impact test is carried out by applying force on the side impact members constraining the suspension points.

Mass of the Vehicle (M) = 320kg

Initial velocity of vehicle before impact (V1) = 28 m/s

Final velocity of vehicle after impact (V2) = 0 m/s

As per industrial standards: Impact time = 0.3 seconds

From Work-Energy principle,

Work done = Change in kinetic energies

$W = (0.5 \times M \times V2^2 - 0.5 \times M \times V1^2)$

$|W| = |-0.5 \times M \times V1^2|$

$|W| = |-0.5 \times 320 \times 28^2|$

$|W| = 125440$ Nm

Now,

Work done (W)= Force (F) × Displacement (s)_________ (2)

Displacement (s) = Impact time × Vmax (V1)

Displacement (s) = 0.3 ×28 = 8.4 m

So, from (2) we get,

F = W/ s

F = 125440 / 8.4

F = 14933.33 N

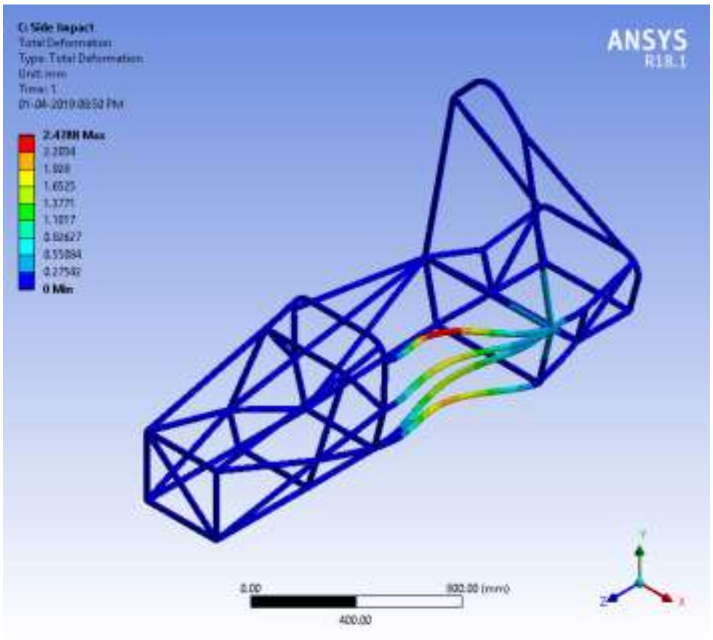

Fig -4.3(a): Total Deformation

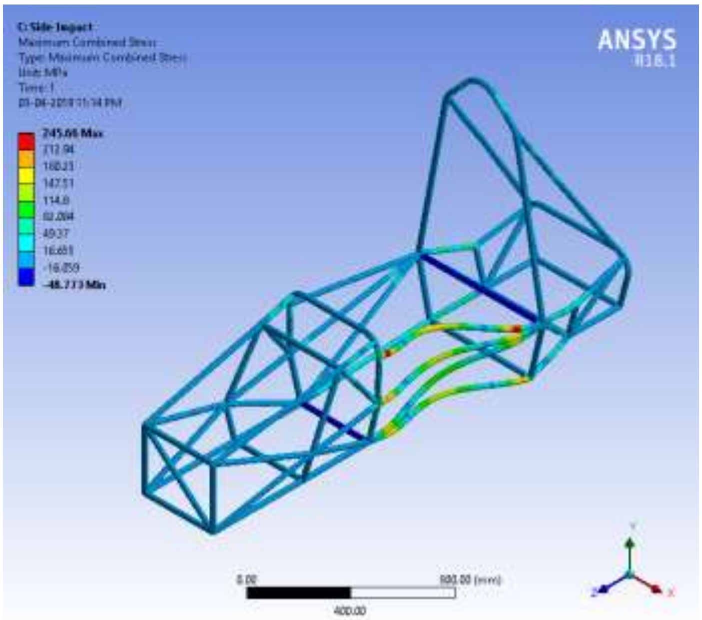

Fig -4.3(b): Maximum Combined Stress

4.4 Torsional analysis

Torsional test is performed by constraining suspension mounting points and force of ±6kN was applied on both front wheels. Torsional Stiffness was then calculated to be 1610.59Nm/degree.

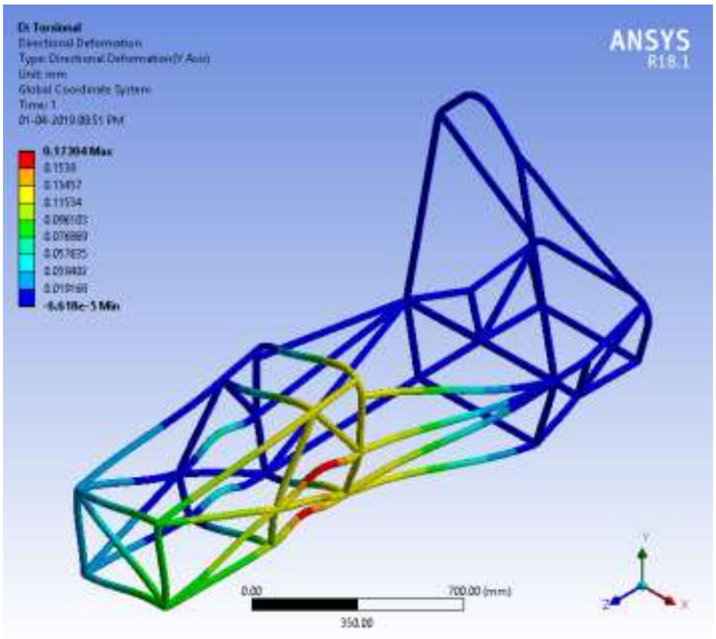

Fig -4.4(a): Directional Deformation

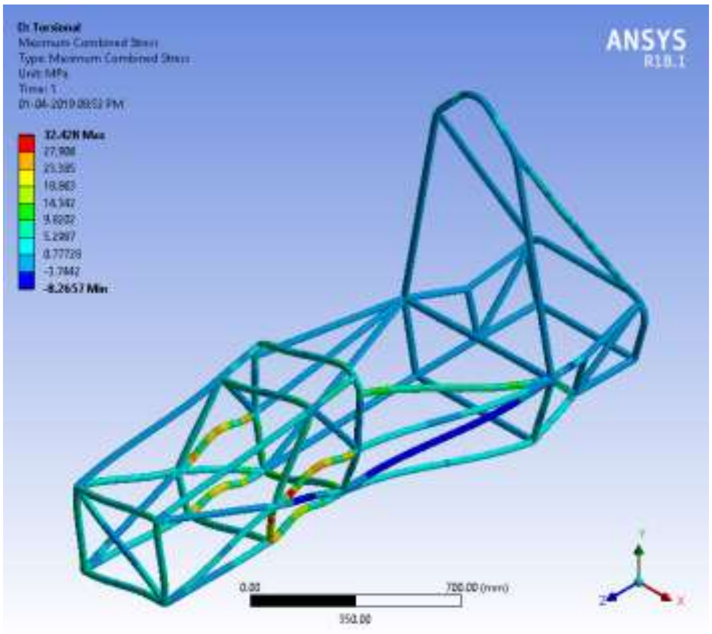

Fig -4.4(b): Maximum Combined Stress

5. CONCLUSION

Design, validation of calculation with the analysis was the focus of this paper. We optimized the models with this project and validated the same on ANSYS in compliance with stringent rules of the event. We also took realistic approach for material selection. Based on the calculation and structural analysis we validate our vehicle's roll cage is within permissible limits and meet the performance standards.

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