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Design, Analysis, and Material Selection of a Student Formula Race Car Roll Cage

Ranjit Kale¹, Nagesh Koli², Darshan Sonawane³, Dipesh Garud⁴, Rohan Korpenwar⁵

U.G. Student, Department of Mechanical Engineering, RMD Sinhgad School of Engineering, Warje Pune. India

ABSTRACT: This research project report, focuses on the construction of a roll cage i.e. Designing & Analysing. Our (Team Tornado Motorsports) purpose for building this roll cage is for a National Level competition “Supra”, organised annually by the Society of Automotive Engineers India (SAEINDIA) in which, Under Graduate students all around India, have to design and fabricate a Formula1 style car representing their college or university. There are certain rules and regulations which the students have to follow while designing a roll cage. This paper illustrates, the process of building a Roll cage using software’s like Catia and Ansys which can meet all the Template rules (95th Percentile, Cockpit & Footwell Template). Theoretical data and methodology with few screenshots are also provided which will help new Teams in building an effective, light weight and a sustainable roll cage. The design shared is our design for Supra 2019.

KEYWORDS: Team Tornado Motorsports, Roll Cage, SUPRA SAEINDIA, Templates, Software.

I. INTRODUCTION

SAE SUPRA is one of the biggest educational competitions in the field of engineering, which challenges the abilities and skills of young engineers. One can develop engineering skills, time and work management, team work and presentation skills. It provides a platform where student can show their skills in designing as well as manufacturing. This competition allows the engineers to apply their theoretical knowledge practically.

Roll Cage can be said as the back bone of a car. It is one of the most important components of a car with multiple functions. Its main function is to hold and support all other components of the car. Ex- Suspension arrangement, powertrain assembly, etc. and the other important function is to provide safety to the driver during accidents. There are certain dynamic events like Skid pad, Acceleration test, brake test, and Autocross to check the performance of the car. As the roll cage holds the suspension assembly, roll cage must be stiff enough to avoid bending and torsion is such driving conditions. At the same time, it should be light in weight, so the material selection and a systematic design of roll cage is important.

1. Types of Roll Cage

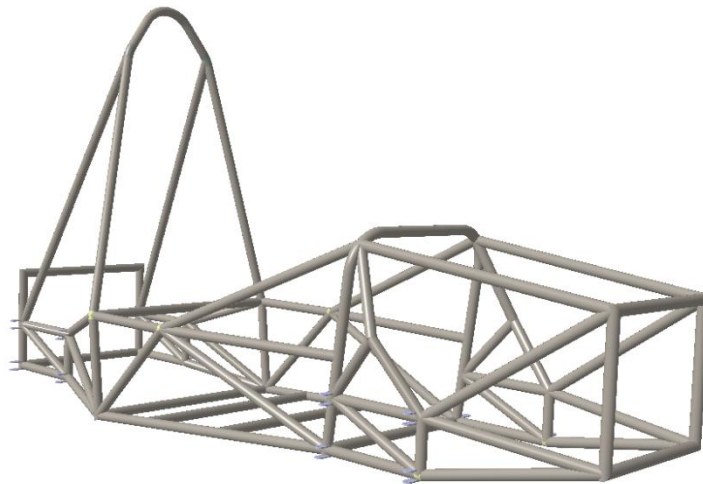
In the automobile field, one can find multiple types of roll cages depending upon the application of the car. Self-Supported, Ladder type, monocoque, and Space Frame are some types of roll cages. According to our application Space Frame is a convenient type due to its low weight, sufficient stiffness and is easy to manufacture.

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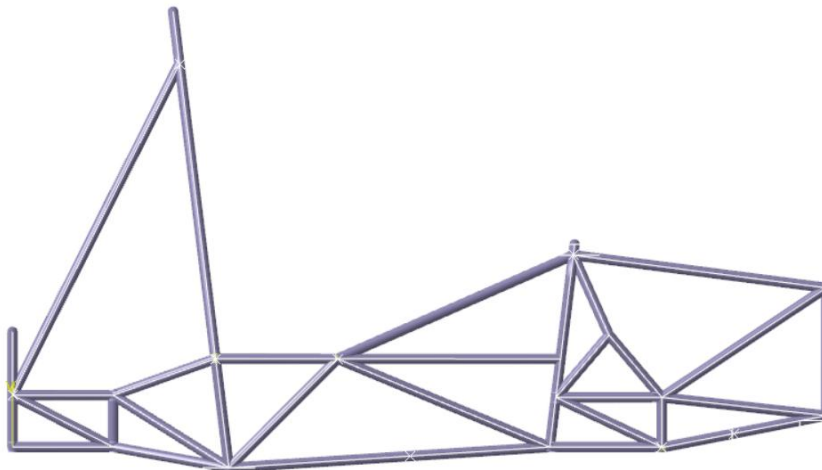
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Tubular Space Frame Roll Cage of Team Tornado Motorsports

2. Why Tubular Space Frame?

In comparison with others, Monocoque and Space Frame type are found to be convenient and suitable for our application. Monocoque being the lightest in weight with good strength, is very costly to build because of its complex structure. Tubular space frame is a bit heavy, compared to monocoque but can still be considered light weight. Tubular Space Frame roll cage is made by steel or aluminium tubes which are integrated together. The tubes are joined in such a way that they produce triangulation in structure. This helps in distribution of force in a better way. Triangulation can be used to increase the torsional stiffness of a frame, since a triangle is the simplest form which is always a structure and not a mechanism. Therefore, an effort should be made to triangulate the chassis as much as possible.



A Triangulated Roll Cage

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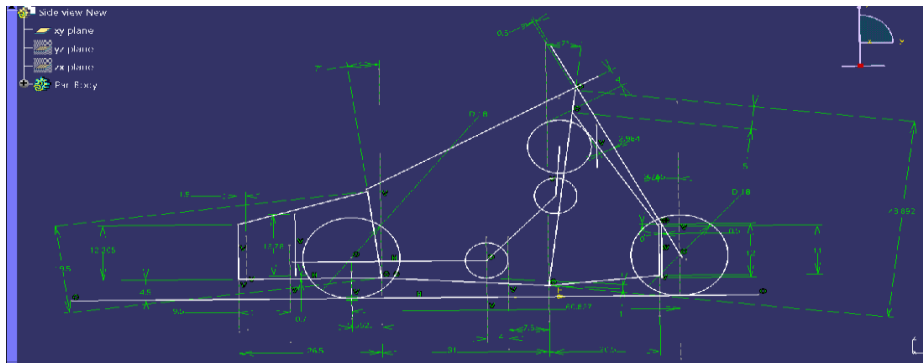
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II. DESIGN CONSIDERATION

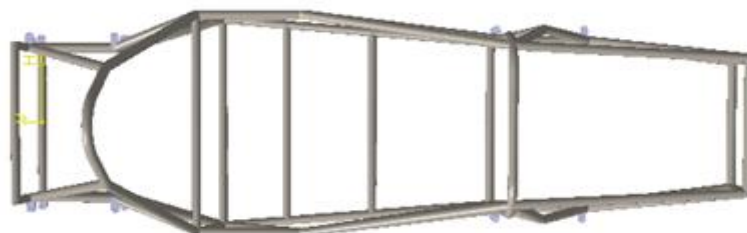
The design process consists of multiple steps. This includes, noting down the rules which need to be taken into account, research design techniques and methodology, determining required performance criteria, which software's to use. While designing a roll cage, the designer must have an idea as to how all other components are going to function in relation to each other. As a result, the designer must know how all parts must interact when designing the roll cage. The design of the roll cage is based on suspension points, power train layout, driver position controls, safety, etc. It also holds various assemblies like the pedal assembly, steering assembly, wheel assembly. It should be designed to withstand high amount of G force. As it absorbs all the static and dynamic loads, the structure should withstand them without crushing or bending.

III. MODELLING

We have used Catia V5R21 for the modelling purpose. First a rough outline of the roll cage has to be made considering the positions of various assemblies. The floor layout is made according to the requirements and component positions. 95th percentile perc5 is used to define the height of the hoops considering the 2-inch helmet clearance rule. Once the Outline is formed it can be turned into a 3D model. Once the 3D model of the roll cage is ready we have to check if the template fits in properly.



1D outline of the roll cage



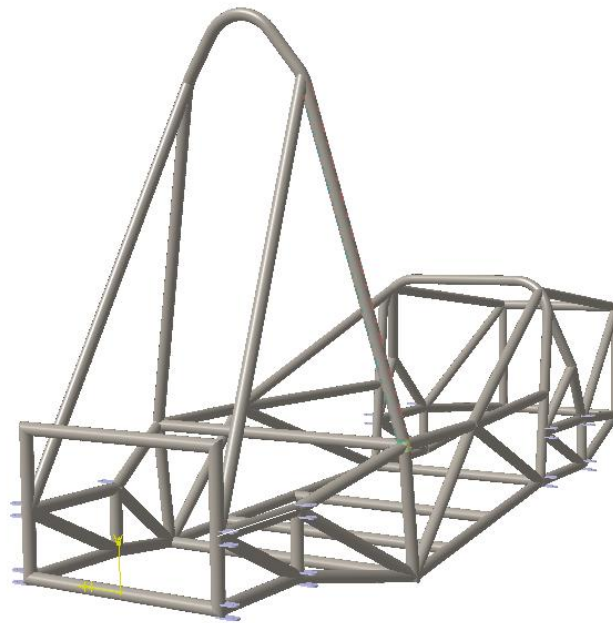
Top View of 3D model

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Isometric view of 3D model

IV. MATERIAL SECTION

The roll cage has to absorb many forces acting on the vehicle at different driving conditions. It should not yield at any conditions. Before selecting the material for your roll cage, you need to find out the composition, mechanical properties, weldability, availability and cost. The two materials which are widely used by many teams are Chromoly Steel 4130 and AISI 1018. As both the materials meet the strength requirements, any one can be used for the frame. As AISI 1018 is available in the market easily and because of its lower cost we choose to use it. Instead of using the same thickness of tubes for all members, we have used tubes of different thickness for weight reduction. We have used 25.4*2.4, 25.4*1.65, and 25.4*1.25.

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Properties of AISI 1018

| Properties | SAE AISI 1018 |
|--|---------------|
| Density (g/cc) | 7.8 |
| Young's Modulus (GPa) | 210 |
| Elongation at break (%) | 19 |
| Brinell Hardness | 120 |
| Strength to weight ratio at Yield (kN-m/kg) | 38 |
| Yield Strength (MPa) | 360 |
| Ultimate Strength (MPa) | 420 |
| Thermal Conductivity: Ambient (W-m/K) | 50 |
| Thermal Expansion: 20C to 100C (µm/m-K) | 11 |
| Specific Heat Capacity Conventional (J/kg-K) | 370 |

We have tested our material for validation of properties. The testing was carried out at the Praj Metallurgy Laboratory, Pune.

| Sr. No. | Sample ID | Yield Strength (Mpa) | Tensile Strength (Mpa) | Elongation (%) | Hardness (HRB) |
|---------|-------------------------------|----------------------|------------------------|----------------|----------------|
| 1 | Tube _1.65mm Thick, AISI 1018 | 511.17 | 514.58 | 12.60 | 69-70 |
| 2 | Tube _2.40mm Thick, AISI 1018 | 377.55 | 525.80 | 23.20 | 62-63 |

V. CALCULATION AND ANALYSIS

Consider,

v = final velocity

u = initial velocity a = acceleration t = impact time

Fa = attenuator force

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We know that,

According to equation of motion,

$$v = u + at$$

Front impact

$$v = 0$$

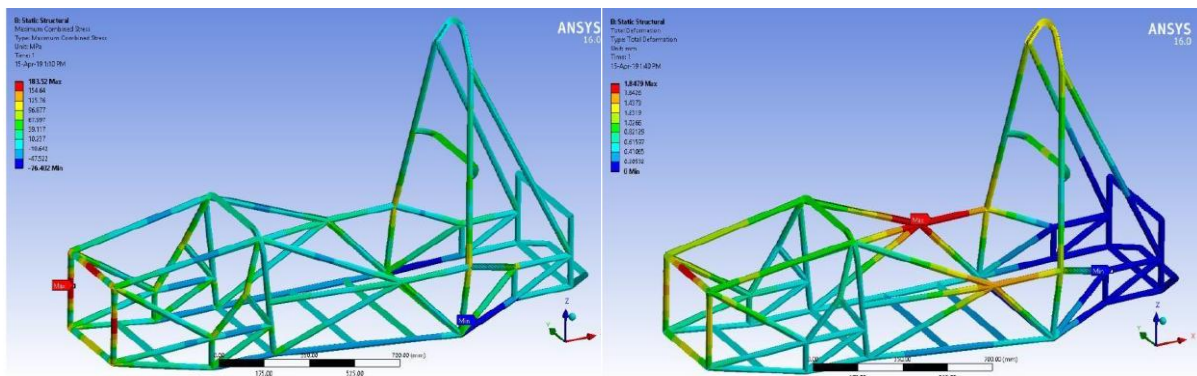
$$u = 75\text{kmph} = 20.833 \text{ m/s} \quad a = 104.651 \text{ m/s}^2$$

According to Newton's second law of motion,

$$F = ma = 230 \times 104.651 = 24069.73\text{N}$$

$$\text{Force taken by impact attenuator} = Fa = 4209.6\text{N}$$

$$F_{\text{overall}} = 19860.13$$



Stress Generated = 183.52 Mpa

Total Deformation = 1.8479 mm

FOS = 1.96

Rear Impact

$$v = 0, t = 0.2,$$

$$\text{Now, Speed} = 45\text{kmph} = 12.5 \text{ m/s}$$

$$\text{Acceleration} = 62.5 \text{ m/s}^2$$

$$t = 0.2 \text{ sec}$$

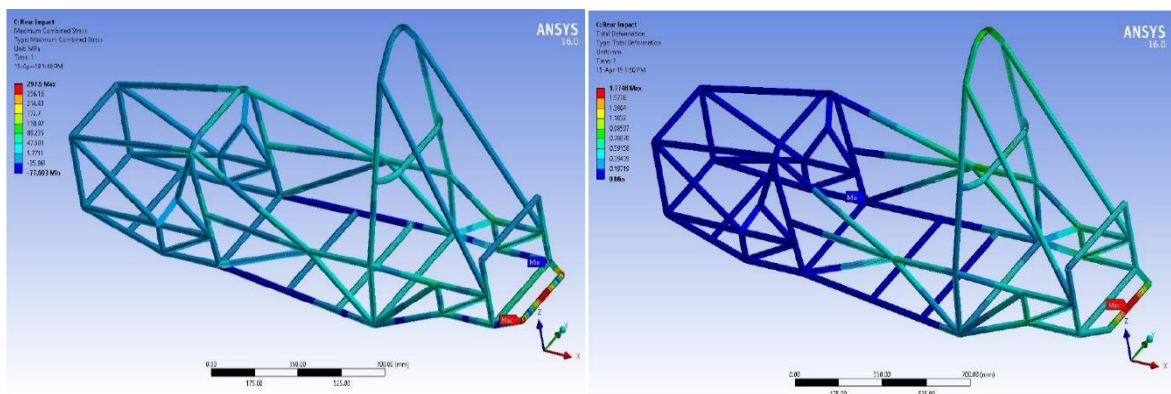
$$F = 14375\text{N}$$

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Stress Generated = 297.9 Mpa

Total Deformation = 1.77 mm

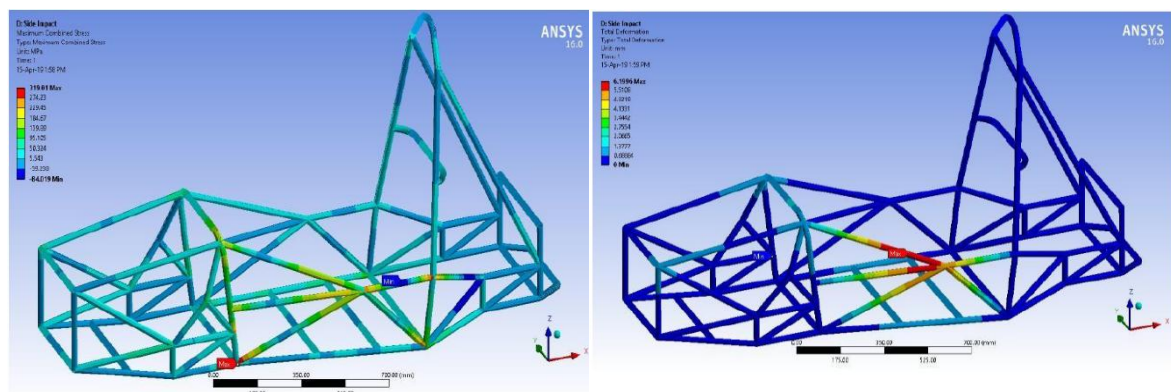
FOS = 1.20

Side Impact

$v = 0, t = 0.2$

$u = 30\text{kmph} = 8.33 \text{ m/s}$ $a = 41.65 \text{ m/s}^2$

$F = 9579.5\text{N}$



Stress Generated = 319.09 Mpa

Total Deformation = 6.19 mm

FOS = 1.12

From the analysis we conclude that the design is safe and the roll cage will sustain heavy load under various driving conditions and impacts.

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VI. CONCLUSION

In this project report, the complete design procedure of a Roll Cage is discussed. The purpose of this paper is not limited to designing a roll cage for a competition, but it also illustrates other aspects needed to finalize a design. We have optimized the design considering the drawbacks in previous years' roll cage and also new ideas given by the judges. Considering the calculations and structural analysis, our roll cage is within the permissible limits and also performs as desired and designed. Teams should manage their time effectively as testing of the vehicle is very important and the best way of validating design.

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