

Finite Element Analysis of Hybrid Trike's Roll Cage

Vedant M. Kulkarni¹, Rahul R. Patil², Shubham D. Sagar³, Mihir M. More⁴

^{1,2,3,4} Graduated Students from the Department of Mechanical Engineering,
Marathwada Mitra Mandal's College of Engineering, Pune, Maharashtra, India

Abstract - Green technological trends are gradually being used to promote eco-friendly attitudes considering the growing concern over a steep decline in global fuel sources and frightening rates of pollution. Efficycle is a three-wheeled vehicle with two human pedals that is powered by electricity to help with daily transportation. The vehicle frame has to be ergonomically designed without compromising performance and safety. The roll cage's design and analysis were focused on improving structural integrity and overall attractiveness. The roll cage material selection method and finite element static structural analysis of the roll cage in FEA software Hypermesh to estimate its structural strength are discussed in this paper. The roll cage materials were chosen with the goal of maximizing strength with reducing weight and cost. The key parameters taken under consideration were driver ergonomics, weight reduction and cost of manufacturing of the chassis.

Key Words: Hybrid Vehicle, Efficycle, Structural analysis, Safety, Von Mises Stress

1. INTRODUCTION

The most significant factor for passenger safety is the vehicle frame. The operator, engine, brake system, fuel system, and steering mechanism are all included in the frame, which must be strong enough to protect the operator in the case of a rollover or crash. The passenger cabin must be able to withstand all forces that are applied to it. This can be accomplished by using high-strength materials or designing superior cross sections to withstand the imposed load. However, the triangulation approach is the most practical way to balance the dry mass of a roll-cage with the optimum number of members.

The roll cage must be made of steel tubing that meets SAE's minimum dimensions and strength criteria. The SAE Efficycle vehicle development handbook also places limitations on the vehicle's weight, shape, and size, as well as its measurements. The circular cross-section is used in the roll cage development because it helps to overcome challenges such as increased size, increased total weight, and decreased fuel economy. It's always great for resisting twisting and rolling impacts, thus it's the best choice for torsional stiffness.

1.1 Design Objectives

1. Ensure the driver's safety by achieving the appropriate strength and torsional stiffness while lowering weight through careful tube selection.
2. To guarantee that both material and production costs are competitive with other SAE vehicles, design for manufacturability as well as cost reduction.
3. More lateral space and leg room in the driver compartment will improve driver comfort.
4. Ensure that roll cage members do not interfere with one another for ease of serviceability.

1.2 Finite Element Analysis

The Finite Element Analysis (FEA) is a numerical approach that simulates any given physical process (FEM). Engineers utilise it to decrease the number of physical prototypes and trials, as well as optimise components throughout the design process, in order to create better products faster.

To fully comprehend and quantify any physical phenomenon, such as structural or fluid behaviour, heat transfer, wave propagation, biological cell proliferation, and so on, mathematics is required. Partial Differential Equations are used to describe most of these processes (PDEs). Numerical approaches have been developed over the last several decades to allow a computer to solve these PDEs, and nowadays one of the most used technique is Finite Element Analysis.

2. CASE STUDY

The roll cage's primary purpose is to protect the driver in the event of a collision or rollover. The secondary goal of chassis design is to offer mountings for all of the components while maintaining a low centre of gravity. Furthermore, in designing the frame, driver's comfort and ergonomics should be considered. These goals can be achieved by careful material selection, the design of a light-weight, durable structure and comprehensive finite element analysis of the roll cage against multiple modes of failure to ensure driver's safety. Numerous iterations were carried out before finalizing the design. Dassault Catia was used to design the vehicle's roll cage, while Altair Hypermesh was used to analyze the results

of testing such as front impact, side impact, rollover and bump impact.

2.1 Frame Material Selection

We have considered AISI 1018 Grade Steel for our Rollcage design & analysis considering various factors such as material availability, cost, strength and weight:

Grade of Steel: SAE AISI 1018

Outside Diameter = 25.4mm

Inside Diameter = 21.4mm

Thickness of Tube = 2mm

2.2 Calculation Of Bending Strength and Bending Stiffness

Bending Stiffness is considered to be proportional to the product EI where:

E = Modulus of elasticity

E = 210 GPa

I = Second Moment of Inertia for the structural cross section.

I = 10136.7445 mm⁴

Bending Stiffness = E*I

$$= 210 * 10136.7445$$

Bending Stiffness = 2128716.343 kNmm²

Bending Strength is given by:

M = (Sy*I)/C

Where:

Sy = Yield Strength

Sy = 365 MPa

C = Distance from neutral axis to extreme fibre.

For SAE AISI 1018

C = 12.7 mm

I = 10136.7445 mm⁴

Bending Strength = (Sy *I)/C

$$= (365 * 10136.7445) / 12.7$$

Bending Strength = 291.33163 N-m

2.3 CAE Analysis Of Vehicle Frame

2.3.1 Assumption & Considerations:

Using the projected vehicle mass of 350 kg i.e. 2 persons weighing 115 kg, kerb weight 100kg and payload 20kg, the impact force was calculated based on a G-load of 4.

- Material : SAE AISI 1018
- Poisson's ratio: 0.3
- Density: 7870 kg/m³
- Modulus of elasticity: 210 GPa
- Suspension pick up points were constrained.

2D meshing was done in Optistruct solver, where the element mesh size was kept 4 using mixed (quad and tria) type of elements.

2.3.2 Calculation of Impact Forces:

$$F \times T = m \times V$$

$$F \times 0.2 = 350 \times 8.34$$

$$F = 14525 \text{ N}$$

where,

"F" is Impact Force.

"T" is the Impulse Time taken as 0.2 seconds which is the standard value.

"m" is the Projected Mass of the vehicle along with the drivers.

"V" is the Average Velocity of the vehicle.

2.3.3 Front Impact Analysis:

We apply 14525 N from the front for the test of front impact of the roll cage structure of the vehicle for determining strength at the time of front collision.

Boundary Conditions:

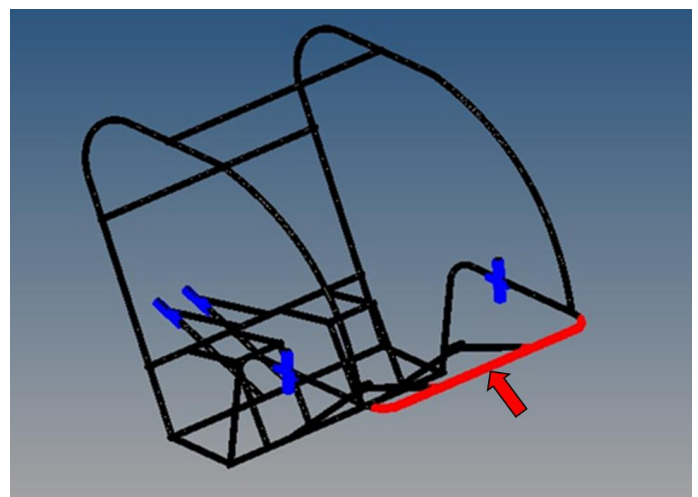


Fig -1: Boundary Conditions for Front Impact

Force applied on the elements highlighted with red colour and elements in blue were constrained.

Analysis Results:

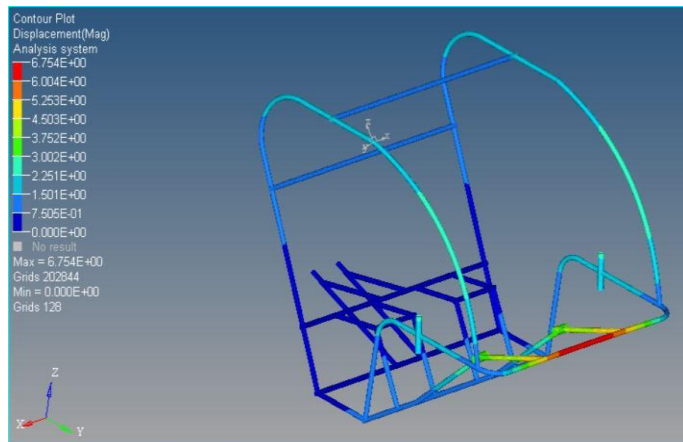


Fig -2: Maximum Displacement Due to Front Impact

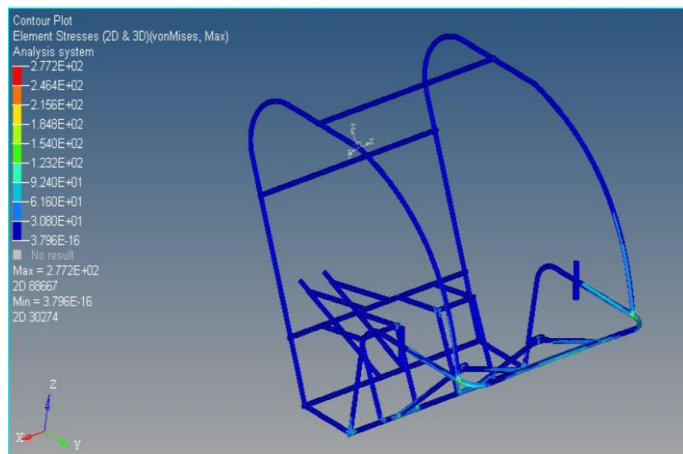


Fig -3: Stresses Induced Due to Front Impact

Yield Strength for AISI 1018: 365 MPa

Maximum Von Mises Stress: 277.2 MPa

Factor of safety = (Yield Strength)/ (Max. VonMises Stress)

Factor of safety: 365/277.2

Factor of safety: 1.3

Maximum deflection: 6.754 mm

2.3.4 Side Impact Analysis:

We apply 14525 N for the test of side impact of the rollage structure of the vehicle for determining strength at the time of side collision. This analysis gives an idea about deflection of rollage side members in case if side impact sustained by the vehicle.

Boundary Conditions:

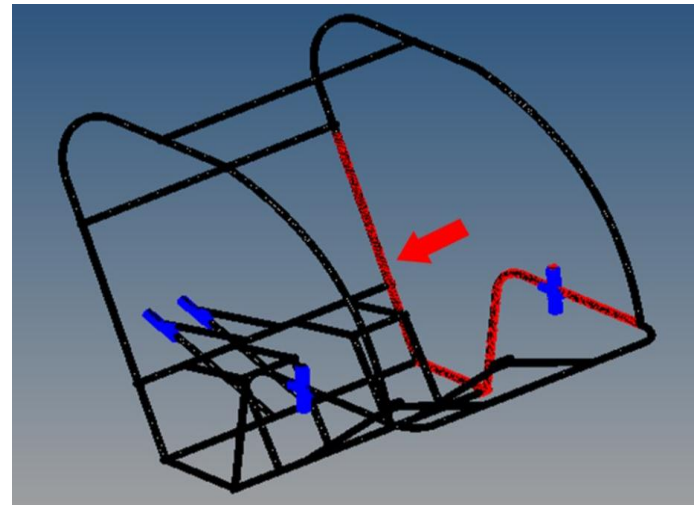


Fig -4: Boundary Conditions for Side Impact

Force applied on the elements highlighted with red colour and elements in blue were constrained.

Analysis Results:

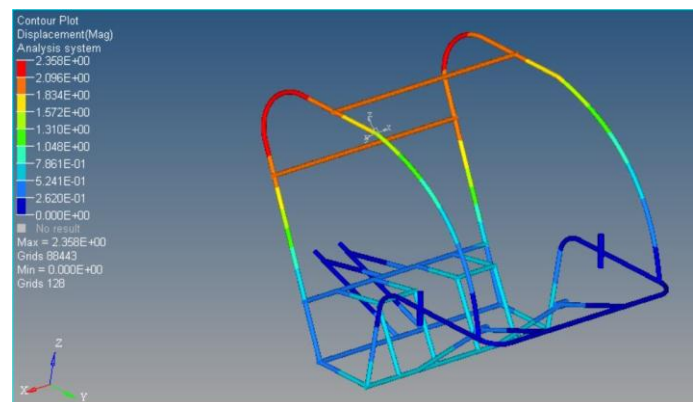


Fig -5: Maximum Displacement Due to Side Impact

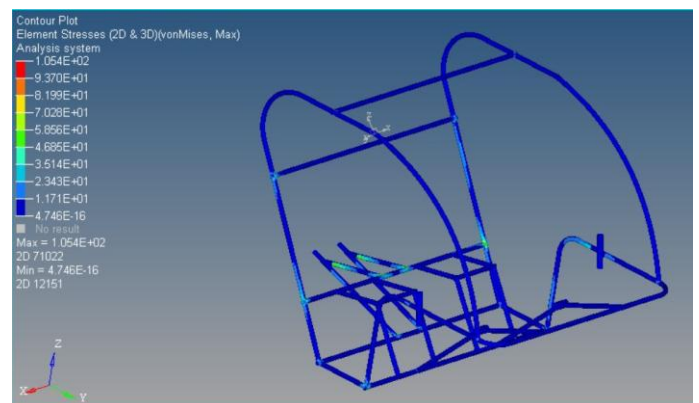


Fig -6: Stresses Induced Due to Side Impact

Yield Strength for AISI 1018: 365 MPa

Maximum Von Mises stress: 105.4 MPa

Factor of safety = (Yield Strength)/(Max. Von Mises Stress)

Factor of safety: 365/105.4

Factor of safety: 3.46

Maximum deflection: 2.358 mm

2.3.5 Rollover Analysis:

We apply 14525 N from the front for the test of rollover of the roll cage structure of the vehicle for determining strength at the time of roll over.

Boundary Conditions:

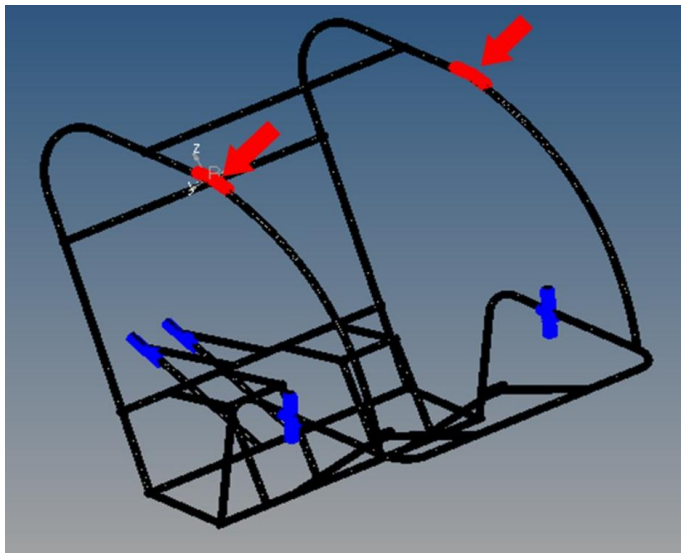


Fig -7: Boundary Conditions for Rollover Impact

Force applied on the elements highlighted with red colour and elements in blue were constrained.

Analysis Results:

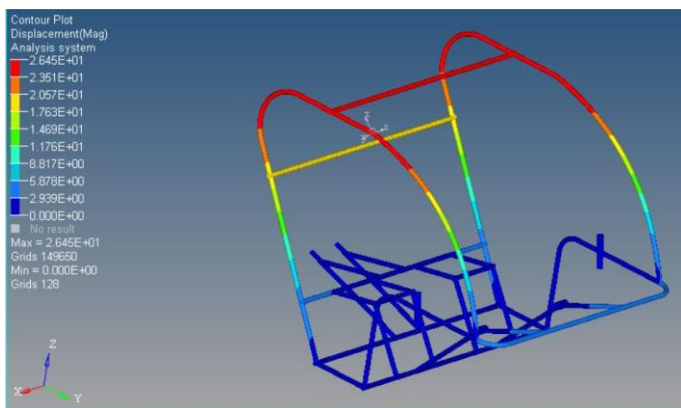


Fig -8: Maximum Displacement Due to Rollover Impact

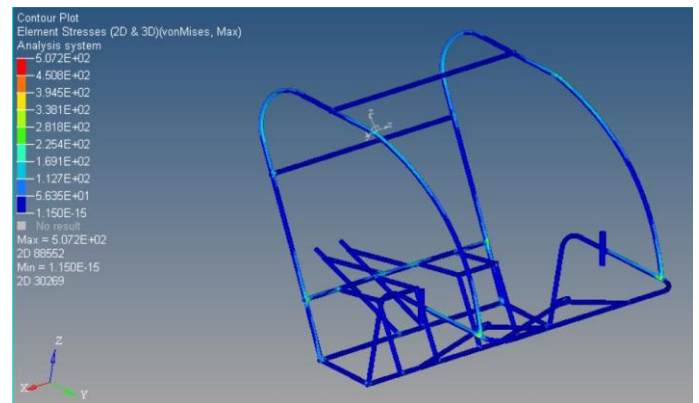


Fig -9: Stresses Induced Due to Rollover Impact

Yield Strength for AISI 1018: 365 MPa

Maximum Von Mises Stress: 253.6 MPa

Factor of safety: (Yield Strength)/(Max. Von Mises Stress)

Factor of safety: 365/253.6

Factor of safety: 1.43

Maximum deflection: 13.22 mm

2.3.6 Bump Analysis:

We apply 14525 N from the bottom for the test of bump of the roll cage structure of the vehicle for determining strength at the time of bumps.

Boundary Conditions:

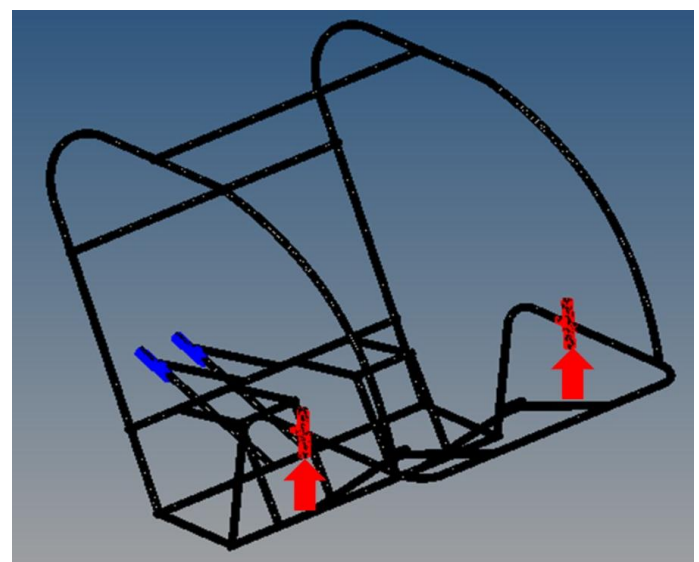


Fig -10: Boundary Conditions for Bump Impact

Force applied on the elements highlighted with red colour and elements in blue were constrained.

Analysis Results:

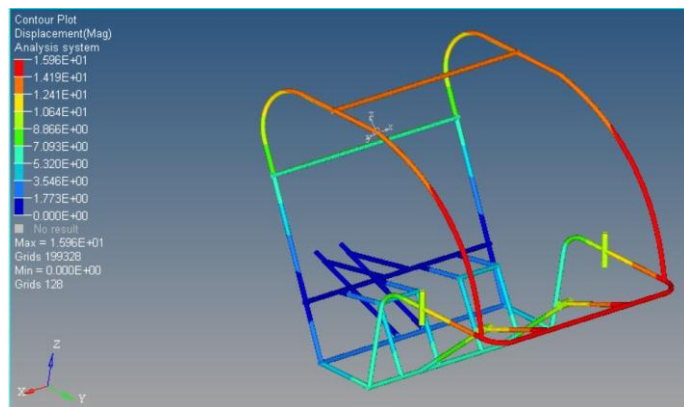


Fig -11: Maximum Displacement Due to Bump Impact

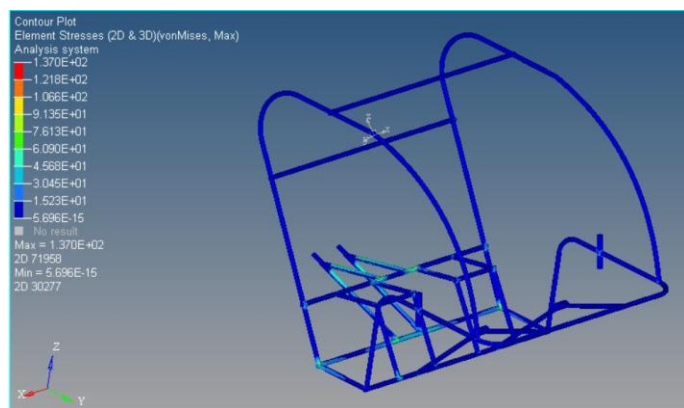


Fig -12: Stresses Induced Due to Bump Impact

Yield Strength for AISI 1018: 365 MPa

Maximum VonMises Stress: 137 MPa

Factor of safety: (Yield Strength)/ (Max. VonMises Stress)

Factor of safety: 365/137

Factor of safety: 2.66

Maximum deflection: 15.96 mm

3. RESULTS & CONCLUSION

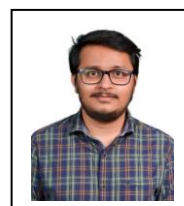
Load Case	Deformation	Stress	FOS
Front Impact	6.754 mm	277.2 MPa	1.30
Side Impact	2.358 mm	105.4 MPa	3.46
Rollover	13.22 mm	253.6 MPa	1.43
Bump Impact	15.96 mm	137 MPa	2.66

After analysing our model using various load cases, such as front impact, side impact, rollover impact, and bump impact, we discovered that the stresses induced are less than the material's yield strength, and the deformation values are in the range of a few millimeters, which have no impact on our driver's safety. The obtained results were well within the limits according to safety and failure aspects. As a result, the design may be considered safe and error-free.

REFERENCES

- [1] Siddharth Aphale, Pradnesh Lachake. Design and Analysis of Roll Cage for an Electric Hybrid Tricycle. K.K. Wagh College of Engineering Education & Research, Nashik 422003, India. 10.14445/22315381/IJETT-V44P215
- [2] R. Bhandari, et al. Simulation and Static Analysis of an Off-Road Vehicle Roll Cage, Department of Mechanical Engineering, N. K. Orchid College of Engineering and Technology, Solapur 413002, India. IJMER | ISSN: 2249-6645 | Vol. 4 | Iss.9| Sept. 2014 | 8
- [3] Prof. S. U. Gunjal, et al. Design, Analysis & Fabrication of Efficycle: A Hybrid Tricycle. Sandip Foundation's - SITRC, Nashik 422213, India. 10.14445/22315381/IJETT-V17P277
- [4] Bharat Kumar Sati, Prashi Upreti, Anirudh Tripathi & Shankar Batra. Static and Dynamic Analysis of the Roll Cage for an All-Terrain Vehicle, College of Technology Pantnagar, India. <https://api.semanticscholar.org/CorpusID:111657226>
- [5] Vikas Sharma; Divyanshu Purohit. Simulation of An Off-Road Vehicle Roll Cage: A Static Analysis, Rustamji Institute Of Technology, Tekanpur, India. Applications (IJERA) ISSN: 2248-9622: Vol. 2, Issue 4, July-August 2012, pp.126-128
- [6] Practical Finite Element Analysis by Nitin. S Gokhale, Sanjay. S Deshpande, Sanjeev. V Bedekar, Anand.N Thite.
- [7] The Final Element Method, Linear Static and Dynamic Finite Element Analysis by Thomas J. R. Hughes.

BIOGRAPHIES



Mr. Vedant M. Kulkarni
Mechanical Engineer
vedant.kulkarni01@gmail.com



Mr. Rahul R. Patil
Mechanical Engineer
rahulpatil7835@gmail.com



Mr. Shubham D. Sagar
Mechanical Engineer
shubhamsagar119@gmail.com



Mr. Mihir M. More
Mechanical Engineer
mihir.more02@gmail.com