Design and Frontal Crash Analysis of FSAE BAJA Roll Cage

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ABSTRACT:- In this work, a chassis frame (UGO M15A model) with emphasis on FSAE application was developed. Computer Aided Engineering (CAE) tools such as SOLIDWORKS CAD, SOLIDWORKS Simulation, Autodesk force effect and Autodesk INVENTOR Professionals was utilized in the course of design. The design and analysis of the UGO M15A Chassis frame was conducted with a parametric approach adopted from Prof. Peter Wright of the famous text (F1 Technology), which was performed in a systematic and systemic manner. Every progression of design was assessed and interpreted in detail in this dissertation. The primary goal of increasing the torsional rigidity and stiffness to be above 2000N-m/deg. was achieved from our Finite Element Analysis (FEA) also achieving a weight of 56kg keeping the mounting points for the suspension and engine in mind, never neglecting ease of access, assembly and maintenance. This will help to facilitate easier suspension tuning and also to resist bending and torsional deflection. The project complied with all of the templates and envelopes required by the FSAE 2015 rules. The work serves as a guide to developing a high-performance race car for the FSAE competition and will foster the ingenuity of designers by making the proposed indigenous car possible in view of the local content initiatives in Nigeria.

KEYWORDS

Chassis, chassis frame, FSAE, Finite element analysis, FEA, stresses, CATIA.

INTRODUCTION

Formula Society of Automotive Engineers (FSAE) is an annual competition instituted by Society of Automotive Engineers (SAE) to give universities' undergraduates and graduates around the globe the opportunity to conceive, design, construct and compete with the small, formula-style race car. Every race car participating in this competition has to have high performance, be sufficiently durable and reliable to successfully compete in all events. In this competition, race cars are not only tested under dynamic racing conditions, but are also judged based on their design, functionality, marketability and cost. Innovative design, cost-effective construction, as well as highly sound engineering expertise are aptly rewarded. Challenges faced in this series truly test the knowledge, creativity and imagination of every university race team, providing a great opportunity for building engineers to gain practical experience in solving engineering problems.

This project deals with the Analysis of Roll Cage for the Formula Student Car. In a Formula Student Car, the roll cage is one of the main components. It forms the structure or the main frame of the vehicle on which other parts like Engine, Steering, and Transmission are mounted .It must be of adequate strength to protect the driver in the event of a rollover or impact. Crash Analysis have been carried out in Hyper works 13.0 with Radioss as the solver.

DESIGN AND MODELING

1. **Chassis review –**

Automobile Chassis

Automobile chassis usually refers to the lower body of the vehicle including the tires, engine, frame, driveline and suspension. Out of these, the frame provides necessary support to the vehicle components placed on it. Also, the frame should be strong enough to withstand shock, twist, vibrations and other stresses. The different types of chassis frame used in different vehicles includes; Lotus Elise, Backbone chassis frame, ladder chassis, tubular space frame, monocoque.

Attributes of a good chassis frame

With the function of chassis identified, there are attributes which the good chassis has to possess to perform its duties for FSAE race car. These attributes outline the qualitative characteristic of the chassis and provide the foundation for the quantitative assessment on its performance. They guide the design and analysis of the chassis and its subsequent physical test when the chassis is manufactured. Following attributes of chassis are by no mean comprehensive as they are established with specific emphasis on

FSAE application. Nonetheless, these attributes are considered to be fundamental and essential for the chassis to fulfill its duties. They are; Weight, structural strength, structural stiffness, specific structural strength and stiffness, crashworthiness, durability and reliability, ease of manufacture, ease of access, assembly and maintenance.

Load cases of chassis

In order to ensure that the chassis can fulfill its duties for a high-performance race car, analysis has to be performed during the design of the chassis [4]. Thus, it is important to know about loads that the chassis has to withstand during the operation of the race car so that the analysis can be conducted. The four static load case to be considered.
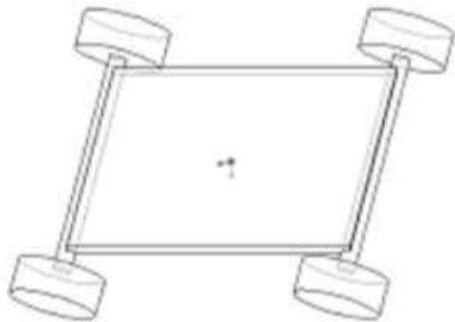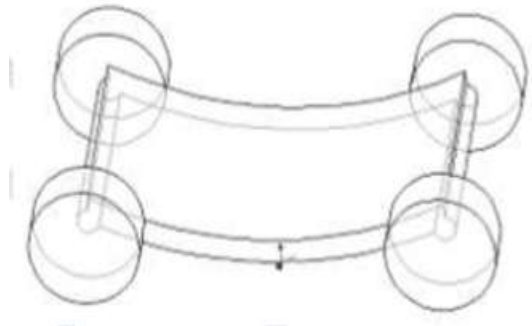

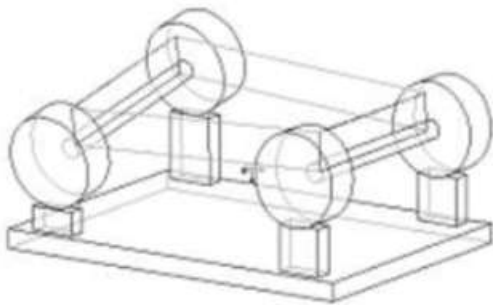**Figure 1.** Horizontal loading

Figure 3. Vertical Bending

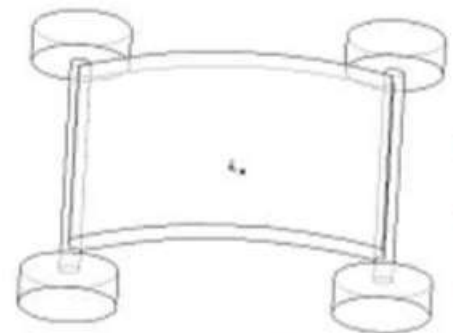

Figure 2. Longitudinal torsion

Figure 4. Lateral Bending

2. Methodology

Frame Type

Space frame chassis has been used widely in university level formula race car. Due to its advantages of easy to be manufactured and easy to be repaired, space frame chassis is the most favorite choice for race car development of newly introduced university level race formula competition.

Material Selection

The Material that is to be used for the chassis is chosen to be 4130 alloy steel extrusion because of its relatively higher strength and wider availability in various cross sections in the market as compared to mild steel extrusions. See Table 1 for the material properties.

Table 1: Material Properties

Name	AISI 4130 Steel
Model type	Linear Elastic
Default failure criterion	Unknown
Yield strength	4.6e+008 N/m^2
Tensile strength	7.31e+008 N/m^2
Elastic modulus	2.05e+011 N/m^2
Poisson's ratio	0.285
Mass density	7850 kg/m^3
Shear modulus	8e+010 N/m^2

Design Requirement

The design requirements of chassis are formed with reference to the attributes of chassis. They are formed with an aim of achieving optimized balance between the attributes. This is not only to optimize the performance of the chassis, but also to better utilize the race team's finite resources. Thus, design requirements are drawn up and categorized with the goal of prioritizing the attributes which are of higher importance towards the performance of the chassis. Prioritization makes sure that the chassis is effectively and efficiently developed with finite resources within the limited amount of allocated design time. These requirements are, Rule requirement, performance rule (structural stiffness and weight), fundamental requirements (structural strength, crashworthiness, durability and reliability), and Auxiliary requirement (ease of manufacture, access, assembly and maintenance).

Computer Aided Engineering (CAE) Tool

SolidWorks CAD and Simulation software (hereafter refer as SolidWorks) is utilized for the design and analysis of the chassis because of its exceptionally powerful capability in the field of design and analysis of engineering products. The one-stop package of comprehensive FEA and all-round design capability make it an ideal tool for the race team to be used to develop components of the race car and thus the chassis. As SolidWorks is also the exclusive tool for the race team to be used as and when it needs, this CAE tool is dominantly used for many projects of the race team, which also include this project.

Space Frame Principle

In theory, spaceframe is a truss-like structure that is formed through assembling extrusions in a three-dimensional space. In this structure, every structural element is straight and each is only stressed axially in either tension or compression. All loads enter and leave the spaceframe only via intersections of extrusions. The use of either pin or rigidly linked joints does not affect the structural stiffness and strength of the spaceframe. Spaceframe principle is a methodology of construction that is derived from the spaceframe. This principle sets the standard for the development of the tubular spaceframe chassis and brings about the important concept of triangulation.
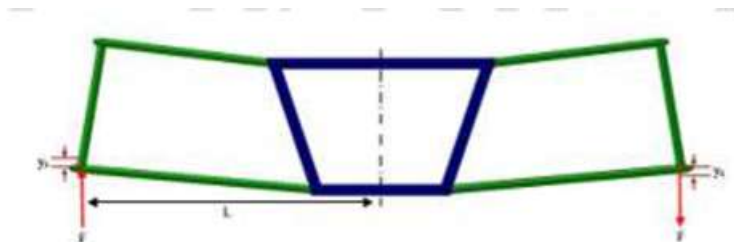
Structural Torsional Stiffness

Figure 5. Deformation due to applied torque

Torsional stiffness is the resistance of an elastic body to deform by an applied torque along a given degree of freedom.

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KT = T/θ   (1)

Where, KT = Structural torsional stiffness, T = FL; F = Force applied, L = Width of measurement

θ = tan^-1((y1 – y2)/ 2L)   (2)

θ = Angular deflection, y1 = Left vertical displacement, y2= Right vertical displacement

Design Approach

The concept developed by Peter Wright for a successful completion of a race car was studied and utilized in developing a systematic approach for the design work. It is important to note that, every aspect of designing, manufacturing, testing and racing a FSAE car involves many technologies that contribute to the success of a given example, racing against similar but different examples. Likes a tree in a forest, the sum of those contributions (e.g. each cell, leaf, and twig) determines how that individual entity develops and whether it succeeds.

Then, utilizing knowledge learnt, experience gained, data generated, models created and the above concept of Prof. Peter Wright, the design and analysis of the chassis frame was carried out in a systematic and systemic manner as outlined in the work chart.
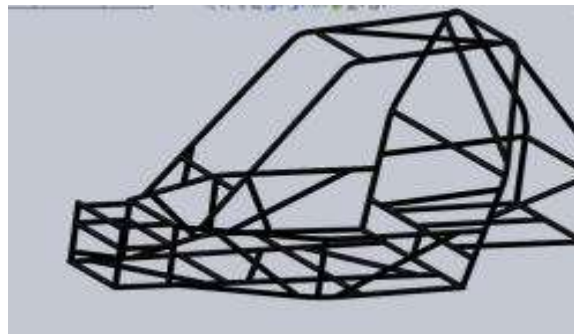
The design chassis model is shown below,

Figure 6. Designed Chasse

Geometry Cleanup

The mid-surface of the roll cage is extracted from the given CAD model. Since the roll cage is symmetrical in design, the roll cage is split in two halves along the X – Direction using the Surface trim option. One half is
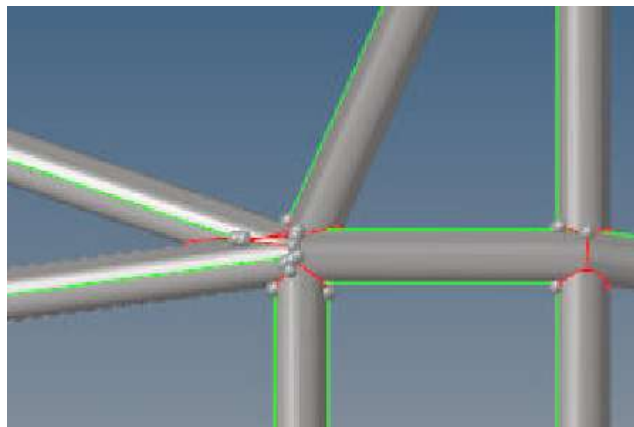

Figure 7. Distorted Joint

moved to the newly created component and the geometry cleanup is done. The joints are trimmed and extended using the extend option, now the intersecting surface are again trimmed and deleted ensuring the joint is a hallow joint.
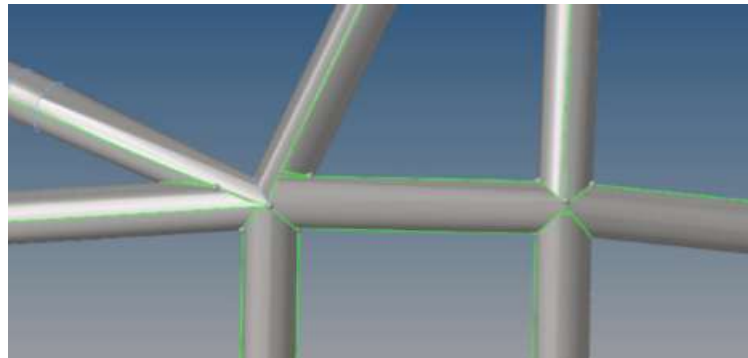

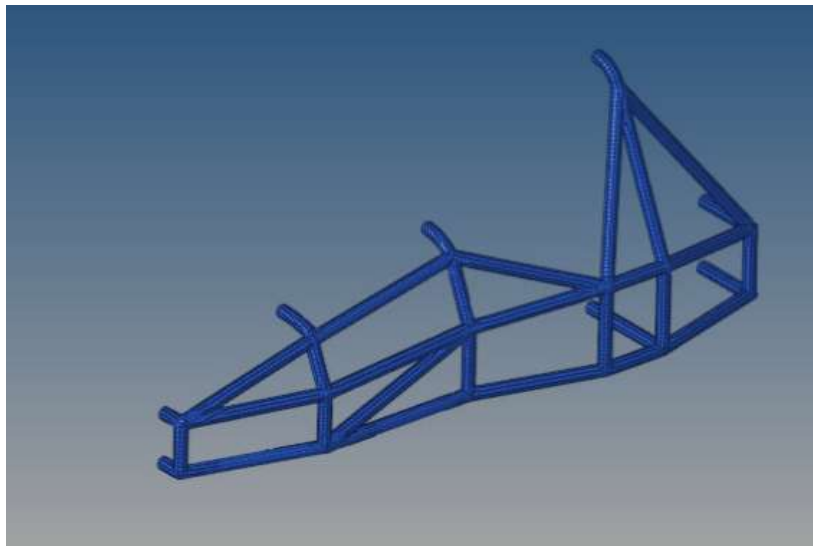
Figure 8. Repaired hallow joint

Meshing

Figure 9. One half of the geometry fully meshed

The meshing is carried out in the repaired geometry. The mesh type is selected as Mixed to ensure the model has the better mesh flow. Since the tria elements are stiffer than the quad elements they are reduced to the maximum without compromising the mesh flow.
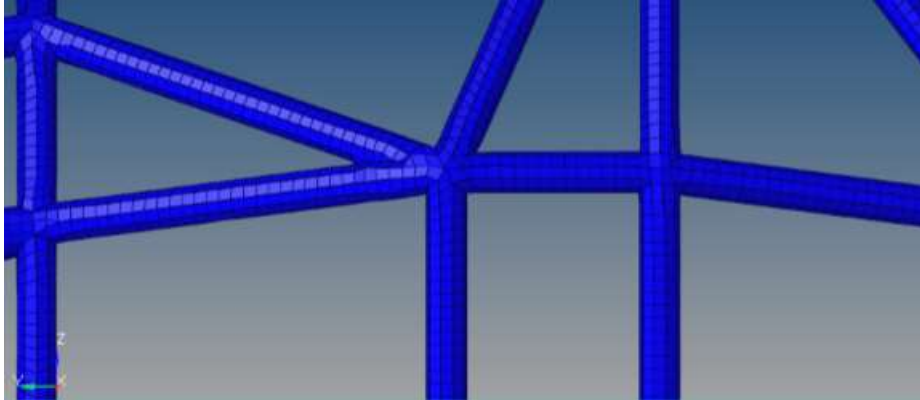
Figure 10. Meshing

Table 2. Element Quality parameter

Sr. No.	Parameter	Value
1	Warpage	15
2	Aspect	5
3	Skew	60
4	Chord Dev.	0.1
5	Cell Squish	0.5
6	Length	6
7	Min. Length	4
8	Max. Length	8
9	Jacobian	0.7
10	Equia. Skew	0.6
11	Area skew	0.6
12	Taper	0.5 Deg
13	Tria Min angle	20 Deg
14	Tria Max angle	120 Deg
15	Quad Max angle	45 Deg
16	Quad min angle	135 Deg

When the element passes these quality criteria the elements are duplicated and reflected to the other half. Now the full model is meshed.

Property Card

The thickness of the roll cage is defined in the property card as 2.5mm.The property card is selected as P1Shell.

Table 3. Property card chart

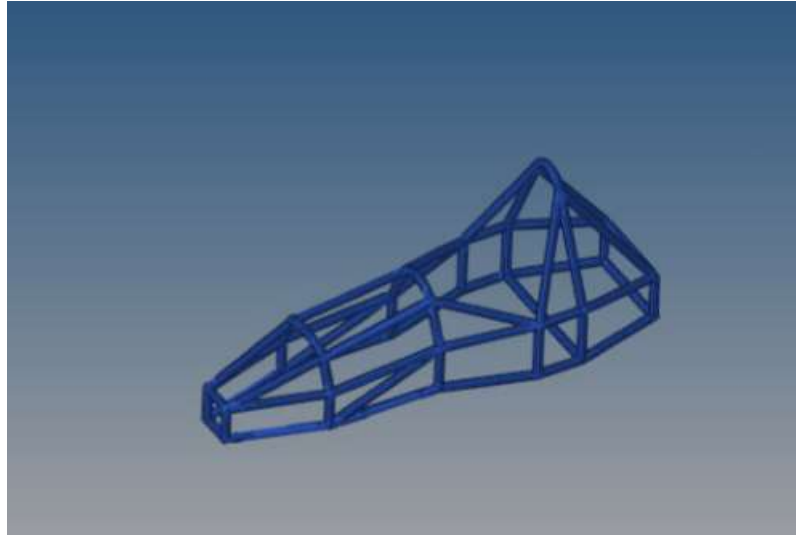| Parameter	Value
Ishell	24
Ismstr	2
Ish3l	2
N	5
Ithick	1
Iplas	1

Figure 11. Fully meshed geometry

Material Card

The material for the model is defined in the material card. The unit system used is Kg KN mm ms. The material defined to the model is Steel 4013. The material card used here is M2 PLAS JOHNS ZERIL considering the material to be Elastic – Plastic

Table 4. Material card chart

Sr. No.	Parameter	Value
1	Density	0.78e-6
2	Young's Modulus	210
3	Poisson ratio	0.29
4	Plastic yield stress (a)	0.70
5	Plastic hardening (b)	0.23
6	Hardening Parameter (n)	0.21
7	Plasticity maximum stress	0.75

Contact card

The model is defined with a Type – 7 contact so that it has self-contact in the event of impact. The contact parameters are listed below.

Table 5. Contact card chart

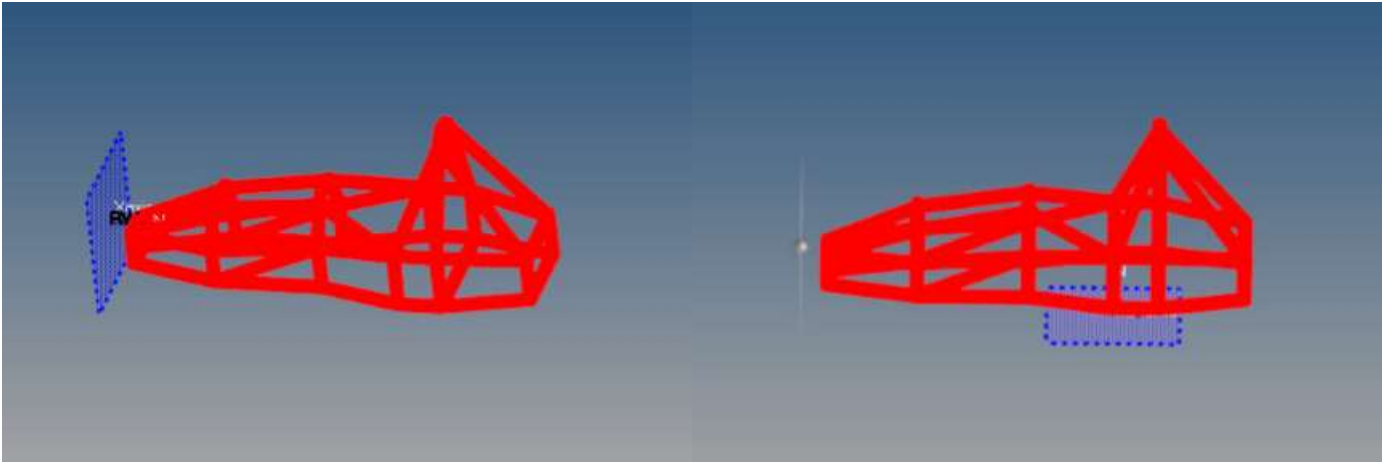| Sr. No.	Parameter	Value
1	Istf	4
2	Igap	3
3	Idel	2
4	Gapmin	0.5
5	Iacti	6
6	Iform	2

Figure 12. Master nodes are in blue and slave nodes are in red.

Load collector

The initial velocity of 16.66mm/ms is added to the roll cage in the positive Y – Direction using INVEL card in BC manager. The initial velocity is added to every node of the Roll cage.

Rigid wall

Two Rigid walls are created using the Rwall card in the front of the roll cage at the distance of 50mm against positive Y – direction and at the bottom at the distance of 10mm along positive z - direction. The rigid walls are created such that it acts as the master node and all the nodes in the roll cage acts the slave node
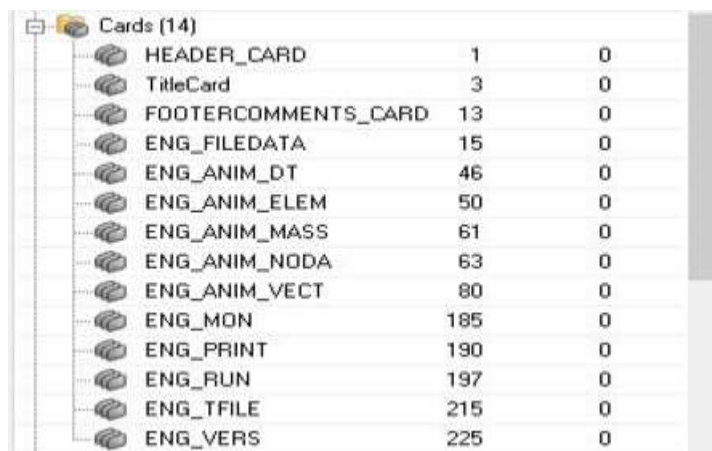
The master nodes are indicated in blue and the slave nodes are indicated in red.

Output Block

The Output Block is created in order request default result parameters like displacement, velocity etc.

Control Card

The control cards are defined in order to optimize the simulation. Basic cards that are defined are ENG_Run, ANIM_DT, ENG_Tfile and other required result cards are also requested.

Figure 13. Required result cards requested.

Now the simulation is made to run the Radioss Solver.

 Post Processing

Now the output file is examined. The animation file is loaded in the HyperView and the results like Plastic strain, Von mises stress are observer visually.

Then the graph is studied in Hypergraph by loading the T0 file. The Internal energy, Kinetic energy and the Total energy is plotted. The Total energy remains constant and the Internal energy increases while the Kinetic energy drops during the impact.
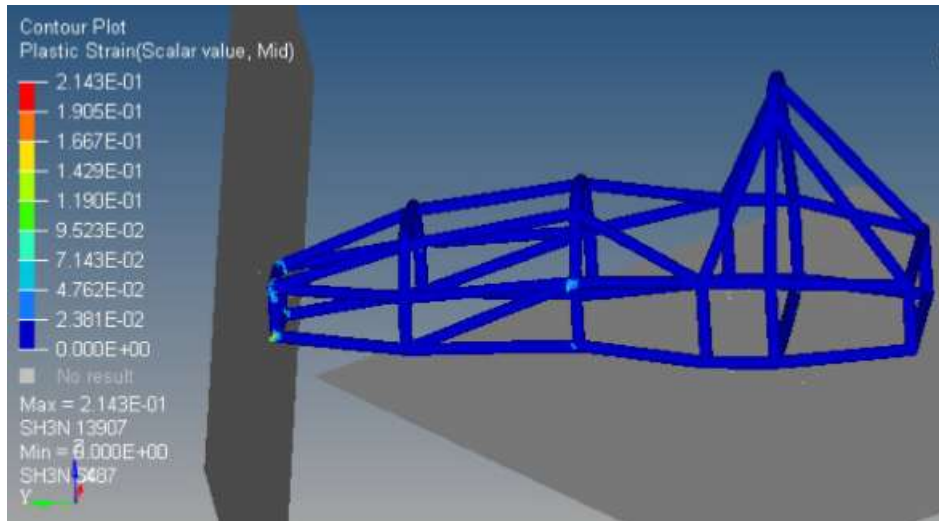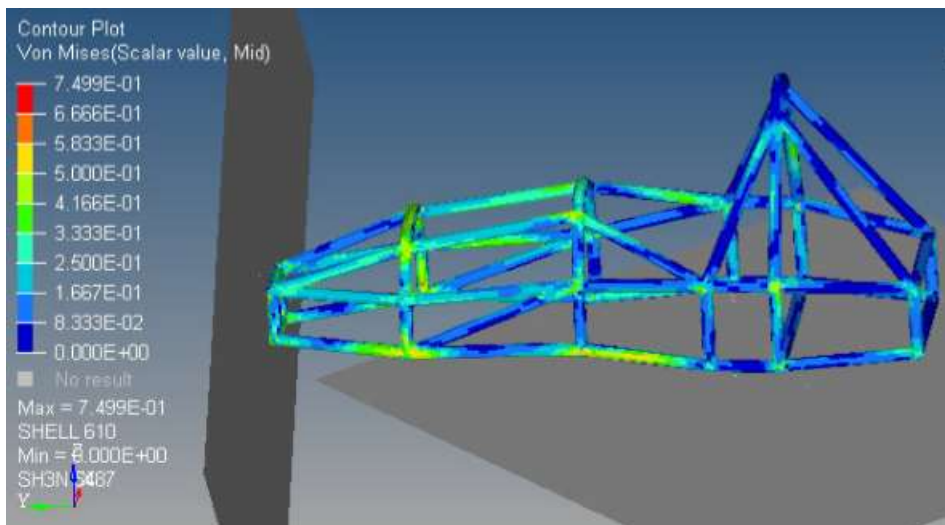

Figure 14. Plastic strain is observed.

Figure 15. Von misses stresses.

Result

The maximum Von Mises stress is 0.749 KN/mm2

Deformation = 0.214mm Factor of safety 0.750/0.749 = 1,

Which indicates the design is safe.

isotropic structural steel as design material [4]. Figure 1 is showing the design of this mono leaf spring model.
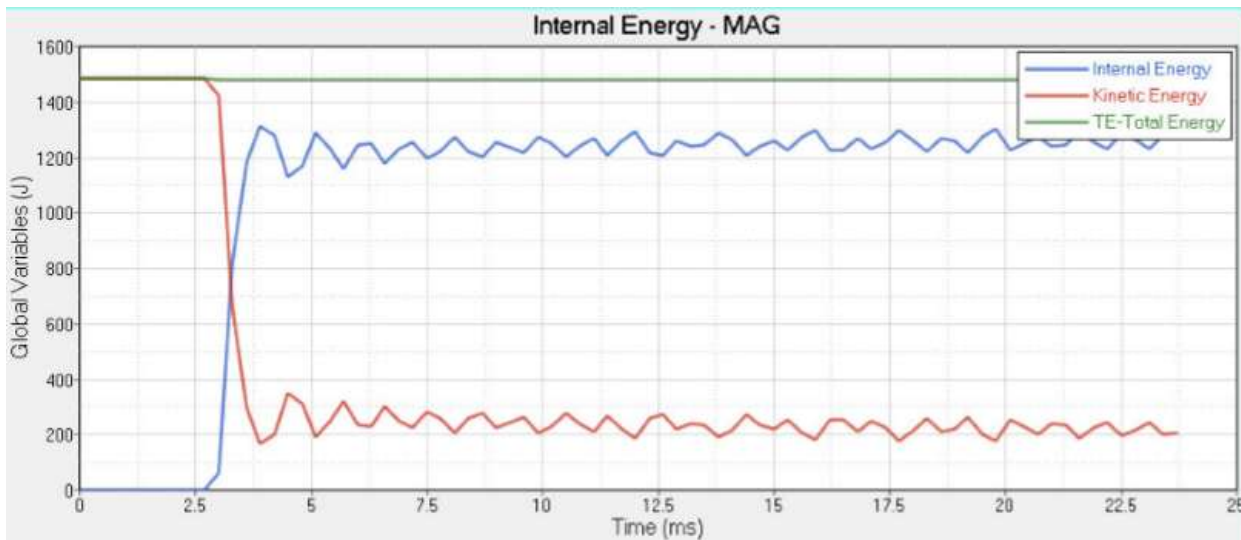

Figure 16. Energy Graph

Factor of safety obtained for the chassis,

Table 6. Factor of safety

Corner	Factor of Safe
Front left	2.1
Front right	2.0
Rear left	1.9
Rear right	1.9

The conceived chassis meets the fundamental requirement. Then the conceived chassis frame is now termed UGO M15A chassis. The factor of safety of UGO M15A chassis is more than one for all scenarios. Finally, with the investigation and enhancement completed, the design and analysis of the chassis is accomplished.

Symmetry of structural torsional stiffness of chassis

There is 0% difference between the structural torsional stiffness of both scenarios. This indicates that chassis is symmetrical and asymmetry of the engine has little influence on the chassis construction. Structural torsional stiffness is almost the same in both scenarios. This also implies that a stable platform is highly possible for the suspension of the race car.
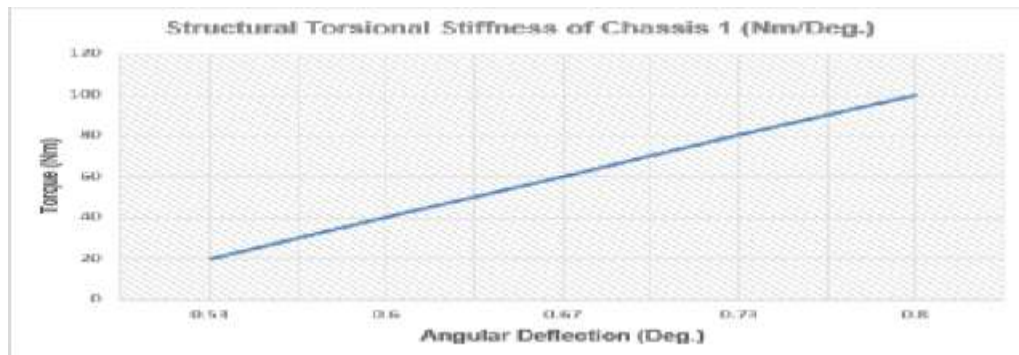

Figure 17. Structural torsional stiffness of the chassis in clockwise torque
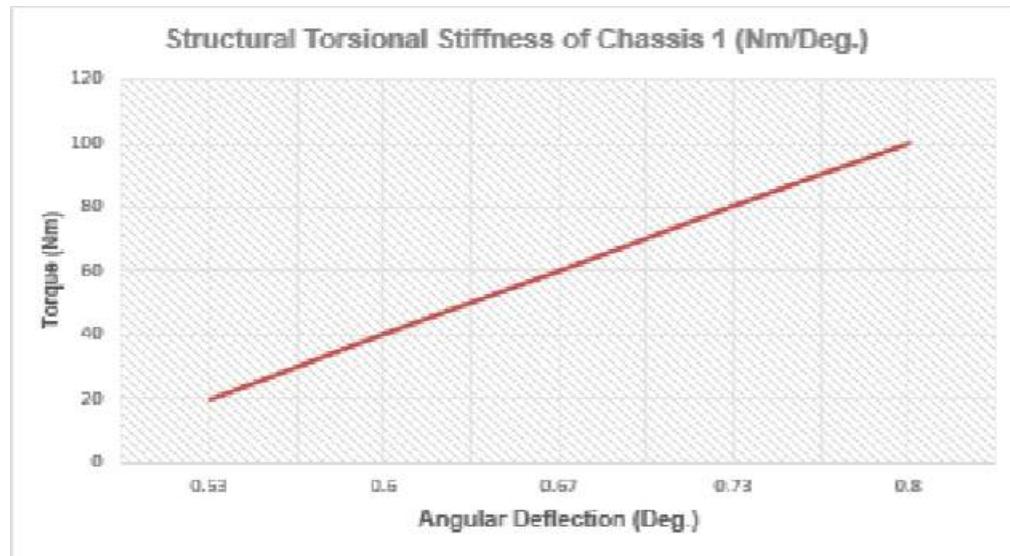
Figure 18. Structural torsional stiffness of the chassis in anti-clockwise torque

CONCLUSION

Through the execution of the proposed top-down development methodology, a chassis model named UGO M15A frame was created. The proposed methodology tackles the design challenge through three major phases; they are shape of chassis, orientation of brace and cross section of structural element. With detailed and in-depth parametric investigation, each aspect of the chassis model is thoroughly investigated, analyzed and designed. During the final phase of the design and analysis of the chassis, multiple investigations are performed in order to more utterly understand the characteristics of the chassis model. One important feature that the proposed systematic and systemic approach has demonstrated is its design flexibility and versatility. In the project, the chassis was developed with the aim of achieving the highest possible specific structural torsional stiffness. Nevertheless, such design requirement is not obligatory.

NOMENCLATURE

σ_{max} **Maximum bending stress**

L   **Eye-to-eye length of leaf spring**

b   **Width of leaf spring**

t   **Thickness of leaf spring**

p   **A constant for simply supported beam**

p   **Pitch of helical spring**

W   **Applied load**

N   **Number of leafs**

FEA   **Finite element analysis**

μ   **Poisson's ratio**

ρ   **Density of material**

E   **Young's modulus**

h   Height of helical spring

d   Wire diameter of helical spring

D   Inner coil diameter of helical spring

n   Number of coils in helical spring

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