# Design and Analysis of a Tubular Space Frame Chassis for FSAE Application

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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.**

***IndexTerms*—Chassis; chassis frame; FSAE; Finite element analysis.**

## I. 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.

## II. Chassis Review

### *Automobile Chassis*

Automobile chassis usually refers to the lower body of the vehicle including the tires, engine, frame, driveline and suspension [1]. 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. *(See Fig 1 - 4)*

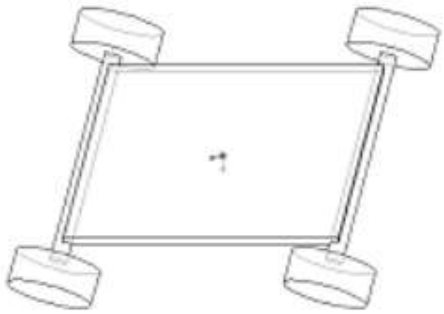


Fig. 1 Horizontal loading [1]

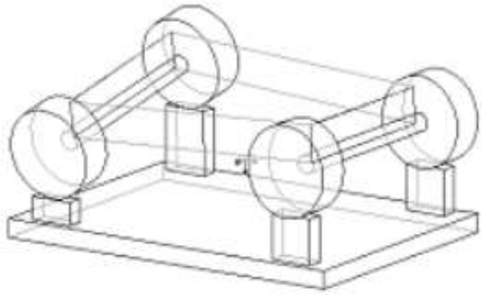


Fig. 2 Longitudinal torsion [1]

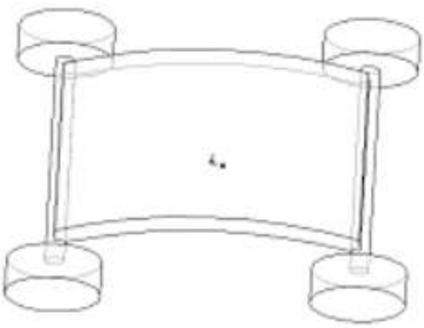


Fig. 3 Lateral Bending [1]

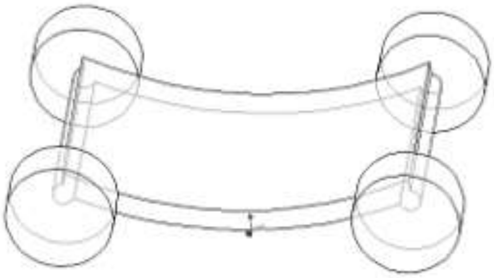


Fig. 4 Vertical Bending [1]

## III. METHODOLOGY

*Frame Type*

Space frame chassis has been used widely in university level formula race car [1]. 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 Isotropic** |
| 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 [8], 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*

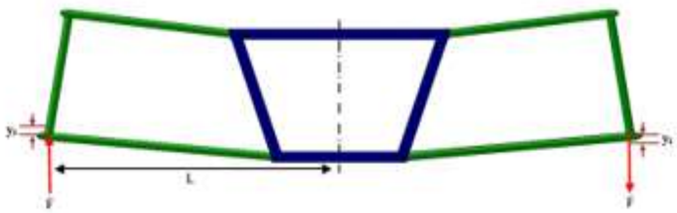
SolidWorks CAD and Simulation software (hereafter refer as SolidWorks) is utilized for the design and analysis of the chassis because of its exceptionally powerful capability in the field of design and analysis of engineering products. The one-stop package of comprehensive FEA and all-round design capability 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 [2]. 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 [7]. 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*

Torsional stiffness is the resistance of an elastic body to deform by an applied torque along a given degree of freedom [6].



$$KT = T/\theta \qquad (1)$$

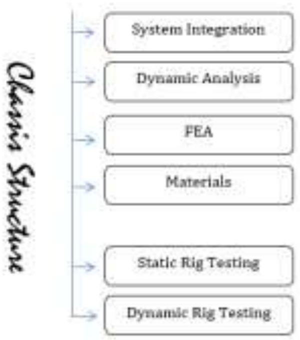
Where, $K_T$ = Structural torsional stiffness, T = FL; F = Force applied, L = Width of measurement

$\theta = Tan^{-1}\left[\frac{(y1+y2)}{2L}\right]$, θ = Angular deflection, $y_1$ = Left vertical displacement, $y_2$= 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[3].

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 shown below.



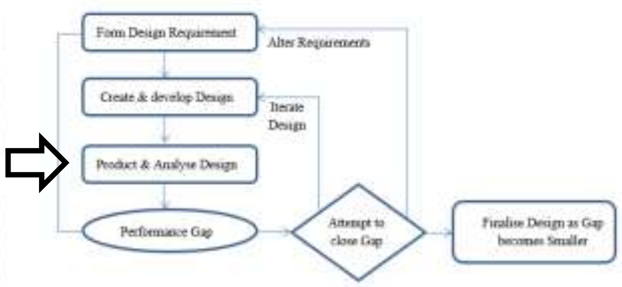




Fig. 5 Chassis structure by Prof. Wright Fig. 6 Work chart of the design and analysis of the chassis

*Chassis Model*

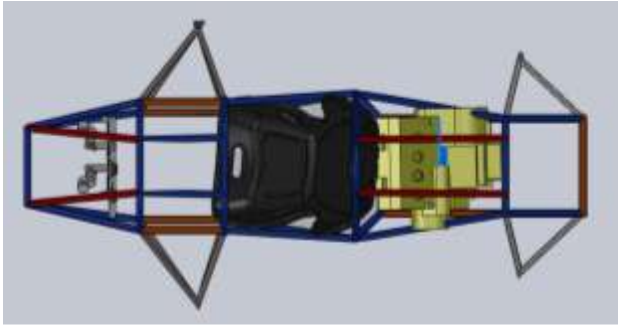


Fig. 7 Chassis model with engine and suspension Model Incorporated for more realistic representation

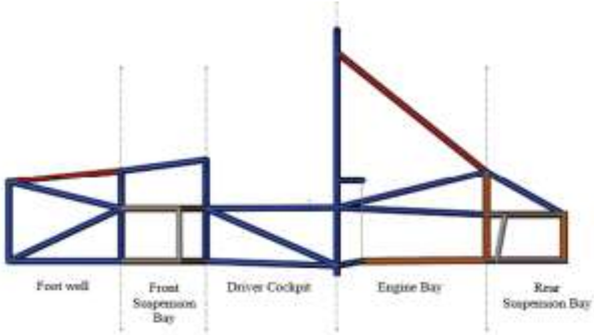



Fig. 8 Division of chassis into bays

The initial chassis model, also termed chassis 1, is compartmentalized into five bays, namely (see fig. 8);

## I. RESULTS AND ANALYSIS

Chassis 1 is analyzed for structural torsional stiffness. The obtained stiffness is utilized together with the weight of chassis 1 to produce the specific structural torsional stiffness. These three measures provide an understanding on the performance of chassis 1 in fulfilling the performance and fundamental requirement of the chassis. For each case, all conceived Chassis was analyzed for auxiliary, rule and driver ergonomics requirement with the use of the models

*Symmetry of Structural Torsional Stiffness of Chassis 1*

Chassis 1 is analyzed for both scenarios of clockwise and counter-clockwise when it is analyzed for structural torsional stiffness. This is to investigate the symmetry of the structural torsional stiffness of chassis 1. (See Fig 9 to 10)

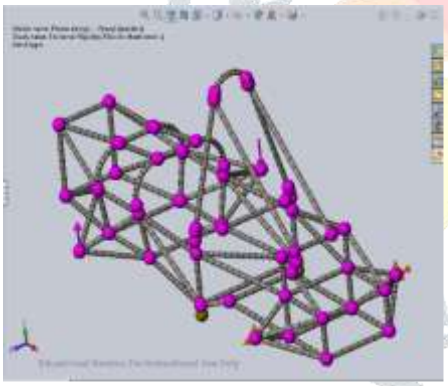


Fig. 9 Clockwise scenario

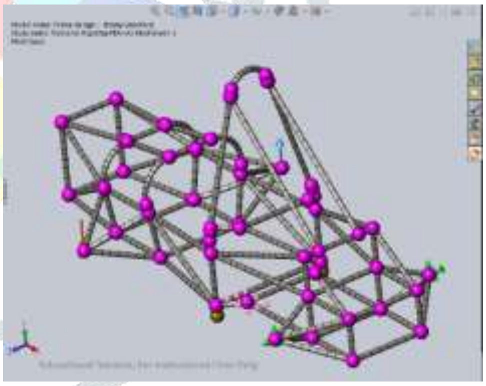


Fig. 10 Counter clockwise scenario

There is 0% difference between the structural torsional stiffness of both scenarios*(See Fig. 11 to 12)*. This indicates that chassis 1 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.

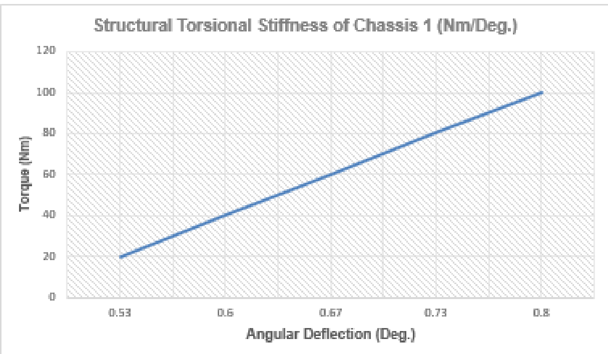



**Fig. 11** Structural torsional stiffness of the chassis 1 (clockwise torque)

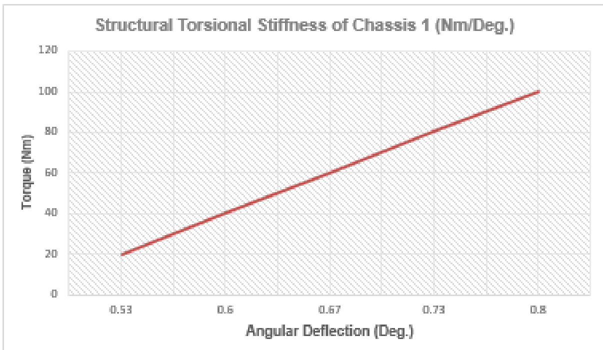



**Fig. 12 Structural torsional stiffness of the chassis 1 (counter-clockwise torque)**

*Shape of Chassis Frame*

Within the specified wheelbase of the race car, the length, height and width of foot well bay is conceived.

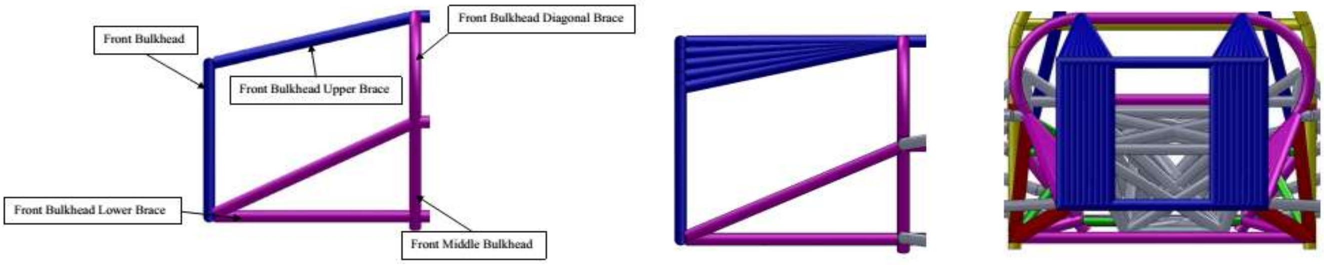



Fig. 13 Variation of length, width and height of foot well

*Orientaion of the cross braces*

**Fig. 14 From left to right, side driver cockpit (side view) and lower driver cockpit (plan view)**

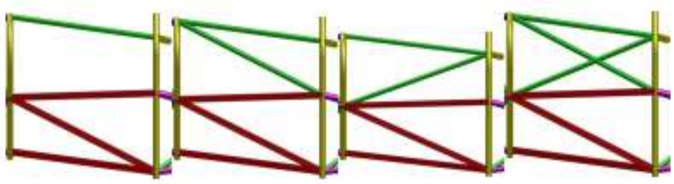


**Fig. 15 From left to right, longitudinal brace, longitudinal & "\" brace, longitudinal & "/" brace and longitudinal & cross brace, each inserted to side driver cockpit in alternating sequence.**

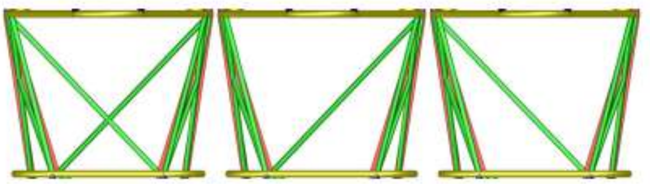


**Fig. 16 From left to right, cross brace, "/" brace, and "\" brace, each inserted to lower driver cockpit in alternating sequence**

*Summary of the conceived Chassis Model*

Table 2: Summary of conceived chassis model

| S/N | Chassis Variation | Weight of Chassis (Kg) | TS of Chassis (Nm/Deg.) | Specific STS of Chassis (Nm/Deg./Kg) | Characteristics of Chassis Model |
|---|---|---|---|---|---|
| 1. | Chassis 1 | 51.20 | 1169.00 | 22.83 | Basic Model |
| 2. | Chassis 2 | 51.40 | 1168.84 | 22.74 | Lengthened Foot Well |
| 3. | Chassis 3 | 51.40 | 1168.84 | 22.74 | Height of FBH |
| 4. | Chassis 4 | 51.32 | 1195.24 | 23.29 | Width of FBH |
| 5. | Chassis 5 | 53.29 | 2993.83 | 56.18 | Side Driver cockpit |
| 6. | Chassis 6 | 53.71 | 3032.47 | 56.46 | Lower Driver cockpit |

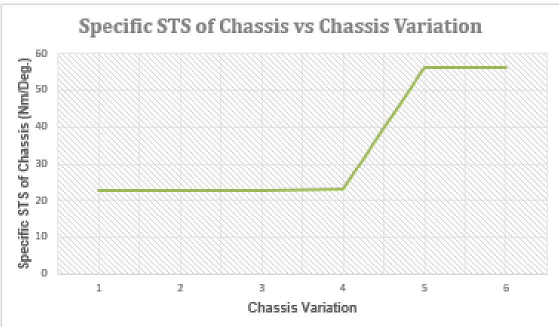



Fig. 17 STS of all conceived chassis models

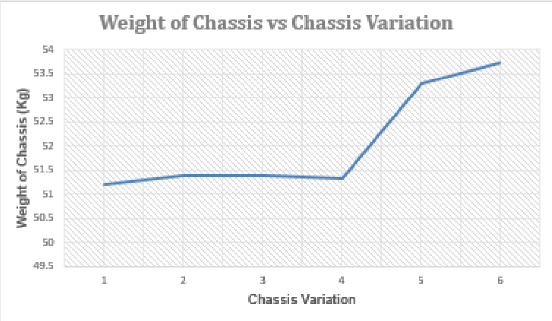



**Fig. 18** Weight of all conceived chassis models

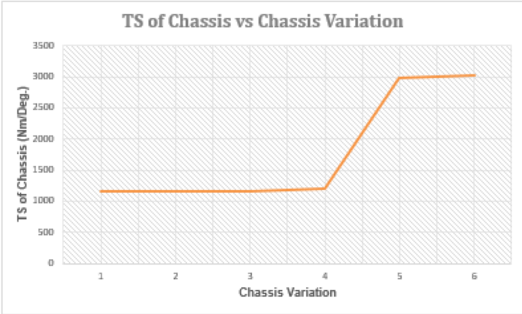



**Fig. 19** Torsional stiffness of all conceived chassis models

The elements that contribute the most to the stiffening and strengthening of the conceived (UGO M15A) chassis model are (See table 2);

- Side drivers Cockpit
- Lower Driver Cockpit

Although these elements stiffen and strengthen the UGO M15A chassis to a tremendous extend, they are responsible for introducing weight to the conceived chassis.

*Investigation on fulfilment of fundamental requirement*

In order to fulfil the fundamental requirement, the factors of safety of the conceived chassis in all scenarios have to be at least one *(See fig. 20 to 23)*

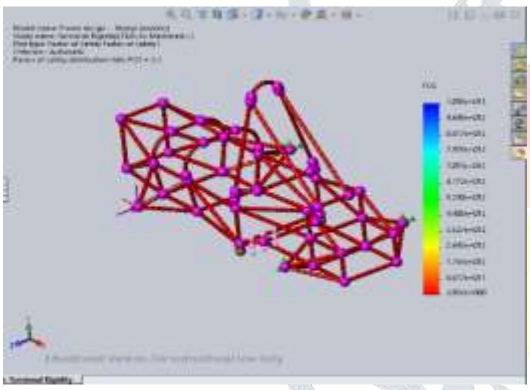


Fig. 20 Load application to Front left corner

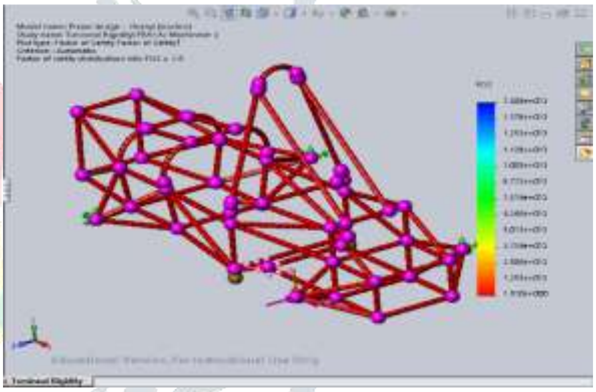


Fig. 21 Load application to Front Right corner

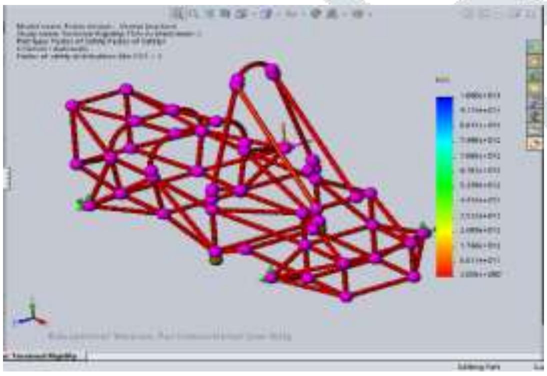


Fig. 22 Load application to Rear left corner

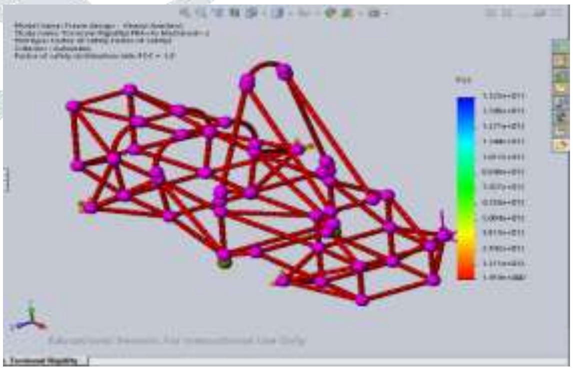


Fig. 23 Load application to Rear right corner

Table 3: Safety factor of UGO M15A chassis in all scenarios

| Corner | Factor of Safety (FOS) |
|---|---|
| Front Left | 2.1 |
| Front Right | 2.0 |
| Rear Left | 1.9 |
| Rear Right | 1.9 |

The result of analysis is shown in Table 3 above. 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

## II. 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.

Finally, the tasks of the project have been successfully completed. The development of the chassis follows a top-down approach, in which all parameters that influence the performance of the chassis are categorized into major and minor clusters and tackled in a systematic and systemic manner.

## III. ACKNOWLEDGMENT

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