DESIGN AND ANALYSIS OF A TWO-WHEELER FRAME

A PROJECT REPORT

Submitted by

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Under the guidance of

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In

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BONAFIDE CERTIFICATE

Certified that this project COMPARING THE DESIGN AND ANALYSIS OF CHASSIS is the Bonafide work of **MOHAN RAJ (180021601068), SUHAIL DIAUDDIN SYED (180021601093) and SAJJAD SAKEER HUSSAIN (180021601077)** who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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VIVA-VOCE EXAMINATION

The viva-voce examination of the project work titled **DESIGN AND ANALYSIS OF A TWO-WHEELER FRAME** submitted by *MOHAN RAJ (RRN: 180021601068), SUHAIL DIAUDDIN SYED (RRN: 180021601093) and SAJJAD SAKEER HUSSAIN (RRN: 180021601077).*

Is held on

INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

A motorcycle frame is a non-standard structural component of a motorcycle linking various components of the vehicle systems and providing the vehicle rigidity and strength while running on different road conditions. This study is aimed to design a frame for a two-wheeler single-seater electric scooter, by considering the strength, safety, and optimum performance of the vehicle. The study has been carried out with a two-step approach. The steps includes validating the frame design i.e., stress calculation using analytical and numerical. This study also includes optimizing frame structure, load characteristics, metallurgical and mechanical properties of the scooter frame members, identifying critical stress areas, and material improvement through vibrational analysis by identifying the different mode shapes and Natural frequency of the structure.

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1. INTRODUCTION

Automotive chassis is the main carriage systems of a vehicle. The chassis truly sets the overall style of the two-wheeler. The frame serves as a skeleton upon which parts like gearbox and engine are mounted. It can be made of steel, aluminum or an alloy. It is essential that the frame should not buckle on uneven road surfaces and that any distortions which may occur should not be transmitted to the body components. The frame must therefore be torsion resistant.

Over the years designers have been repeatedly criticized for their seeming reluctance to depart from the diamond-pattern frame inherited from the pedal cycle. However, since the earliest motorcycles were pushbikes with small low-powered engines attached at various places that was the logical frame type to adopt, particularly so long as pedal assistance was required. Until the general adoption of rear springing several decades later, this diamond ancestry was discernible in most frame designs. This was hardly surprising as the frame's depth suited the tall single-cylinder engines that were popular for so long. In any case the motorcycle, like the pedal cycle, was after all a single-track vehicle in which the use of an inclined steering head was a convenient way to provide the front-wheel trail necessary for automatic straight-line stability.

The geometry should mainly concentrate on aerodynamics, comfort and good design so that it should be attractive. Generally, motorcycles frames are designed to make power transfer from rider to wheels as efficient as possible so that it should be pleasant driving through the wet and dry roads.

A tubular frame is most commonly used on budget-friendly motorcycles. It mimics the look of a bicycle chassis. Here, the frame acts as the bed for the components. Tubular designs are more convenient because of its large chunk of material is removed, while its torsional and lateral stiffness of the vehicle is maintained.

2. LITERATURE REVIEW

Mr. Abhijeet R. Raut and *Dr. A.D. Shirbhate,* in the year 2017, in their literature "Design and Analysis of Two Wheeler Composite Chassis Frame" [1], reviewed the investigations that have been made in the design and analysis of various automotive parts with the application of composites material. The weight reduction greatly affects the fuel efficiency of the vehicle, working with the use of strong design and simulation tools like CATIA, Hyper-Mesh and ANSYS optimization of existing chassis is done. The optimization process consists of CAD model generation of existing chassis in CATIA, and its analysis using Hyper-Mesh and ANSYS. From their project, they mainly focused on its design and analysis in composite material and thereby reducing the overall weight of the vehicle with increasing its fuel efficiency.

Afaque Umer et al. in the year 2018 in their paper about "Strength And Stiffness Optimization Of Diamond Frame Using Corrugated Tube" **[2],** have made a review of the structural design and quasi-static vertical load analysis of the bicycle frame are presented using finite element analysis. By introducing corrugated tubes into the main triangle with different sets of combinations and the numerical result thus obtained was compared against the standard tubular bicycle frame. The structural analysis for the frame was carried out using ANSYS. The 3D model of the bicycle frame was done in SOLIDWORKS software using the weldment feature and each model was then imported into ANSYS and the static structural code was used for conducting the vertical test. A vertical load was applied at the seat post tube keeping the front and rear end tubes fixed in all the cases. A finite element model of a standard diamond frame was created to simulate the behavior under static vertical loading. For increasing the strength and effectiveness of the frame, corrugated tubes were introduced into the main frame replacing the conventional tubular structure. Six different models were formed as a result of combinations of the top tube, seat tube and down tube. The overall efficiency and performance depend solely on the weight and frame structure.

M Palanivendhan etal. in the year 2020 made a review on the topic "Design and development of hybrid chassis for two-wheeler motorcycle" [3], were able to design a new hybrid chassis of a two-wheeler for high-speed stability and agility. A static analysis calculates the effects of steady loads and forces on a structure. The static analysis includes steady inertia loads and time-varying loads that can be approximated to equivalent loads in a static condition. The static analysis comprises the strains, stresses, Forces and displacements in structures or components caused by the load. The designing and analysis of the different types of bike chassis were done using the solid works software to prove that a hybrid chassis (a combination of both perimeter and trellis frame) has combined effects of the two frames to have a good balance in both straight-line stability and cornering agility. As these frames are analyzed for their structural integrity in the ANSYS software stress, strain and displacement values as the result of given load conditions for each chassis. As a result of combining both the parameters and characteristics of the perimeter and trellis frame, vibrations can be reduced and both stability and agility are achieved.

Sasidhar Gurugubelli etal. in the year 2018 conducted a review on **‘**’Design and Fabrication of Electric motor Bike Frame‘’ [4], had decided to design the frame in such a way that it could resist all the forces acting on the chassis. To achieve this they worked mostly with the SOLIDWORKS for the design followed by the analysis. The motorcycle frame was analyzed under the conditions for generation of stress, and static displacement at critical locations. The static analysis was performed using the SOLIDWORKS design tool. In this study, they conclude with various analysis tests theoretically as well as experimentally that their low carbon steel bike frame can stand a load without deflection and the material can be shock resistant and it can support two to three persons riding without any failure. This design will support smooth riding and absorb fewer amounts of vibrations and sudden impacts.

Scott Openshaw & Erin Taylor in 2006 published the book “Ergonomics and Design - A Reference Guide” [5], continue to develop products that respond to not only the issues that confront office workers every day, but the size and shape of the person working, the work that is being done, the most common positions, and with attention to universal design concerns. While there are many different methods of ergonomic research and theory used to develop products that solve common workplace problems, we hope this reference helps to clarify some of the concepts and methodologies used in our process. It is the goal to provide a better understanding of how the science of Ergonomics is used to make products work more comfortably, efficiently, and effectively. Many of the items included in this reference can help engineers, designers, and others to create products and spaces that will be more ergonomic for the user and increase user comfort. Others can use this tool for general information and guidelines on ergonomics and product design.

Chien-Cheng Lin etal. in 2017 study, **“**Structural analysis and optimization of bicycle frame designs” [6], attempted to verify the stress and displacement response of several types of bicycle frames using a wireframe model and then analyze the solid structure. The methodology consists first of establishing optimum dimensions for the frames. Optimization design goals are total mass minimize (weight lighter) and design limits von Mises stress (se) \ yield strength (Sy).This article analyzes the stress and optimizes the design of a customized bicycle frame using Pro/ENGINEER digital solid modeling computer-aided design software computer-aided design (CAD), CAE, simulation and testing using finite element analysis (FEA), sensitivity analysis for optimization design, and customized programming interface. Through Pro/ENGINEER-MECHANICA, the results of digital solid modeling software, CAE analysis show that all of the displacement, strain energy, and stress of the bicycle frame made of magnesium alloy materials without adding Al2O3 as the reinforcement phase are higher than those of the bicycle frame made of aluminum alloy.

G Pruthvi Raju etal. in 2017, in their paper “Design and Structural Analysis of a Motor Bike Frame” [7], developing a structural modeling, using finite element analyze and the optimization of the bike frame for robust design. Static analysis was carried out for finding the stress/strain results. Shape optimization technique is used for performing optimization cause measurable reduction in weight of bike frame. By the FEA analysis results, the bike frame is suggested to be remodeled based on the Shape optimization results. The structure of bike frame was modeled in CATIA V5 R19 software and analysis was performed using ANSYS17 Workbench software. Analysis was tried to simulate real condition by notice to all of effective forces on bike frame on two different materials namely Aluminum alloy 6061 & Structural steel. The analysis results are observed the equivalent stress in aluminum alloy bike frame to be 2.5381 MPa and steel to be 2.5681 MPa. Total deformation in Aluminum alloy to be 0.091107 mm and in steel to be 0.032267 mm – Equivalent elastic strain in Aluminum alloy to be 4.3651e-5 mm and in steel to be 1.5941e-5 mm, so Aluminum alloy is the best replacement material in place of steel for present generation bike frames.

Sarath P et al. in "Stress Analysis of Bicycle Frame using Different Materials by FEA" [8], in 2021 study that deals with the use of a finite element analysis to study the comparative behavior for a standard bicycle frame under a range of measured cases using four different materials such as Steel, Aluminum 6061 T6, Titanium grade 9 and Carbon Fiber. The methodology consists of stress acting within the bicycle are analyzed with respect of frame performance relating to static strength related to load applied. In this study static structural analysis of the bicycle frame is conducted under different load conditions such as static start-up, steady state pedaling, vertical impact, horizontal impact and rear wheel braking in four different materials using ANSYS. The modeling of the bicycle frame is done using CATIA V5 and the analysis is carried out in ANSYS 16.0. A comparative study was made for the total deformation and equivalent (von-Mises) stress in the members of materials for all load cases with the help of ANSYS 16.0. After the analysis on four materials, Carbon fiber has a less chance of deformation than other three materials used. Aluminum 6061 T6 happens to be the most deformed material. Aluminum 6061 T6 is the most deformed material for rear wheel braking loading case with a deformation of 0.52604 mm. In the case of Equivalent (von-Mises) stress Carbon fiber has the maximum equivalent stress distribution as compared to the other three materials used.

Vignesh et al. in 2019 paper, "Design and Analysis of Frame of an Electric" [9], studied optimum design for an electric bike was modeled and analyzed for stress and failure rate for commercial purpose. Frame is backbone of the bike; it supports and holds the whole load. The main objective of the paper was to design and fabricate a light weight still strong, safe, and economical than the conventional ones. The material used is of AISI standard. The analysis comprised of static simulations and torsional analysis for sudden impacts of all the components in the frame. The methodology section depicts a flowchart based on how the design and analysis of the frame was done, based on the requirement of the customer. The collection of data consists of several factors such as availability, machine ability, cost, reliability, feasibility and ergonomics. The total length, height and weight were also taken into considerations. Instead of the material AISI 4130 various materials can be used such as carbon fiber and titanium. The carbon fiber and titanium alloy restrict the design as it costly but it is compared to be much stronger than the material we have used. So, depending upon the requirement the efficient one can be chosen. Due to the choosing of AISI 4130, the loading conditions have been restricted, so if any other stronger material has been chosen the loading conditions can be expanded.

Derek Covilla in 2014 study, “Parametric finite element analysis of bicycle frame geometries” [10], has outlined a FE model using beam elements to represent a standard road bicycle frame. The model simulates two standard loading conditions to understand the vertical compliance and lateral stiffness characteristics of 82 existing bicycle-frames from the bicycle geometry project and compare these characteristics to an optimized solution in these conditions. Perhaps unsurprisingly, smaller frames (490mm seat tube) behave the most favorably in terms of both vertical compliance and lateral stiffness, while the shorter top tube length (525mm) and larger head tube angle (74.5°) results in a laterally stiffer frame which corresponds with findings from literature. The optimized values show a considerable improvement over the best of the existing frames, with a 13% increase in vertical displacement and 15% decrease in lateral displacement when compared to the best of the analyzed frames. The model has been developed to allow for further develop to include more detailed tube geometry, further analysis of more frame geometries, alternative materials, and analysis of other structural characteristics. The optimized values show a considerable improvement over the best of the existing frames, with a 13% increase in vertical displacement and 15% decrease in lateral displacement when compared to the best of the analyzed frames. The model has been developed to allow for further develop to include more detailed tube geometry, further analysis of more frame geometries, alternative materials, and analysis of other structural characteristics.

Need for design and analysis study experiment:

Despite the continuously evolving technology and innovations, the electric two-wheelers face certain shortcomings that need to be eliminated to improve the overall performance of the vehicle. The prime concern where more efforts need to be put in the weight and size of the systems and components, with a view of increasing range, speed, payload and grade ability of the vehicle. In recent days the popularity of single seater bike is gaining more interest among the populous in many cities. Many single seater EV scooter start-ups have been initiated in India, likewise our design proposal considers ergonomics, stiffness, long run and rigidity for a sustaining design over existing product in market.

2.1 OBJECTIVES

- To design a chassis for single seater EV scooter by considering ergonomic seating conditions for the rider.
- To choose material which has higher strength and elasticity to handle dynamic stress, on the other hand density of the material should be less than the existing or commonly used material to reduce weight of the vehicle.
- To verify the design through analytical and numerical solutions for determining the tube diameter for the chassis.
- To find the natural frequency of the vehicle in order to avoid resonance.
- The design should also have an easy access for dismantling crucial components (battery).

3. METHODOLOGY

3.1 CHASIS AND ITS TYPES

3.1.1 Backbone Frame

This one is one of the most basic and economical types of motorcycle frames. As the name suggests, this one resembles a spine. However, it is not a complete skeleton. Instead, it keeps different motorcycle parts in place.

In this design, the amount of steel used is lesser than other motorcycle frames. Thus, it makes the construction of this type of frame very economical. In addition, the engine bolts onto the backbone frame in this design. Generally, the engine hangs off the backbone frame. Therefore, it is neither cradled nor contributes as a stressed member.

The backbone type of motorcycle frame is very economical to produce. However, it lacks excellent strength or torsional rigidity. Therefore, it is suitable mainly for low-cost budget motorcycles with a low-capacity engine.

3.1.2 Single Cradle Frame

This frame design is a fundamental type, simple, and cost-effective. There is only one down-tube in this design. Therefore, this type looks more like the frame of a bicycle. It includes steel tubes of various sizes and strength capacities welded together. It forms an assembly that holds together various motorcycle components. Manufacturers often refer to these motorcycle frames as single cradle frames because they use single down-tube frames.

3.1.3 Monocoque Motorcycle Frame

Furthermore, cars typically use monocoque type frames. Manufacturers build them in highly robotized and automated manufacturing units. Generally, these are more expensive to make unless you have a massive production scale.

However, some extreme-performance motorcycles require the entire skeletal structure made of a single, super-stiff piece of metal. Hence, manufacturers term it as a monocoque motorcycle frame. However, manufacturers don't make such frames very commonly. Besides, they use it mainly for hyper bikes or motorcycles with extreme power. Such motorcycles demand unconditional torsional rigidity and lightweight construction.

Furthermore, some hyper bikes make use of this type of motorcycle frame. They have complex construction and a high degree of precision. Such structures regularly use exotic materials such as carbon fibre and magnesium. Thus, they are costly as compared to other standard frame types.

3.1.4 Double Cradle Motorcycle Frame

Manufacturers also call it a double-down-tube chassis frame. A single cradle frame has just one steel tube going down to support the engine. However, a double-cradle frame has two tubes going down to support the engine. A double-cradle frame has a significant advantage over single cradle frames in strength and rigidity. However, they don't cost very high compared to single cradle frames. In addition, the double-cradle frame can handle the forces well during a high lean angle. It provides heavy braking much better than a single-cradle frame. Indian manufacturers use this variety of frames in large quantities. This frame type offers strength and rigidity. However, it is still not the best suited for performance-oriented bikes.

3.2 MATERIAL SELECTION:

The material is an essential quality of the structure. The frame's rigidity, cost, and capability, all these qualities depend upon its material. Conventionally, manufacturers use steel for budget-oriented motorcycles such as commuter bikes & mopeds. These frames make use of bending tubes together to suit a specific purpose/design.

Table 3. 1 Mechanical Properties for Chassis Materials

Sl. No	Material properties	ERW- 2	AISI 4130	ERW - 1
1	*Poison's ratio*	*0.33*	*0.33*	*0.28*
2	*Yield strength (MPa)*	*240*	*460*	*160*
3	*Elongation (%)*	*22*	*15*	*25*
4	*Tensile strength (MPa)*	*380*	*650*	*310*

Table 3. 2 ERW 2 – Physical Properties

ERW 2 - Physical properties		
Thermal conductivity	*50*	*(W/m·K)*
Density	*7800*	*Kg/m3*
Specific heat	*510*	*(J/Kg·K)*
Linear thermal expansion(°C)	*10*	*(10^{-6}/K)*

Table 3. 3 AISI 4130 – Physical Properties

AISI 4130 - Physical properties		
Thermal conductivity	*25*	*(W/m·K)*
Density	*7700*	*Kg/m3*
Specific heat	*460*	*(J/Kg·K)*
Linear thermal expansion(°C)	*10*	*(10^{-6}/K)*

Table 3. 4 ERW 1 – Physical Properties

ERW 1 - Physical properties		
Thermal conductivity	*50*	*(W/m·K)*
Density	*7882*	*Kg/m3*
Specific heat	*510*	*(J/Kg·K)*
Linear thermal expansion(°C)	*10*	*(10^{-6}/K)*

The above materials are selected on basis of cost and market availability. ERW-2 and ERW-1 are most commonly used automotive material, while on the other hand AISI 4130 (chromoly) is also used in frame designing and it also contains high chromium ratio. Higher ratio of chromium content helps the material to resist against rust for extended period of time, which makes it unique compare other two materials.

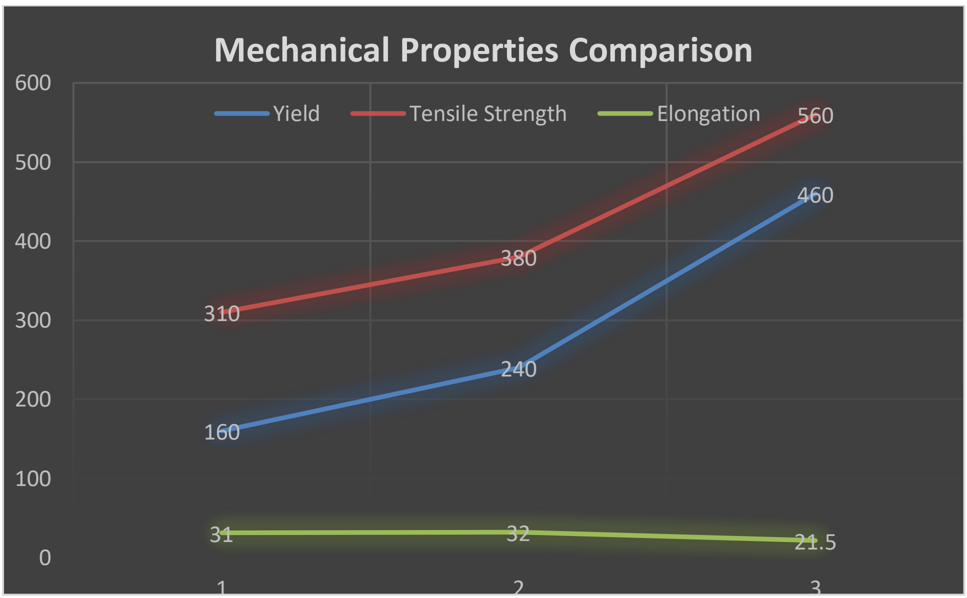

Figure 3. 1 Mechanical Properties Comparison

3.3 ERGONOMICS

The word ergonomics comes from two Greek words:

- ERGO: meaning work
- NOMOS: meaning laws.

Ergonomics is a science focused on the study of human fit, and decreased fatigue and discomfort through product design. Ergonomics applied to office furniture design requires that we take into consideration how the products we design fit the people that are using them. At work, at school, or at home, when products fit the user, the result can be more comfort, higher productivity, and less stress. Ergonomics can be an integral part of design, manufacturing, and use. Knowing how the study of anthropometry, posture, repetitive motion, and workspace design affects the user is critical to a better understanding of ergonomics as they relate to end-user needs.

Ergonomics for rider (considering 95th male percentile):

Anthropometric dimensions for each population are ranked by size and described as percentiles. It is common practice to design for the 5th percentile (5th%) female to the 95th percentile (95th%) male. Conversely, a 95th% male value may represent the largest dimension for which one is designing. The 5th% to 95th% range accommodates approximately 90% of the population. To design for a larger portion of the population, one might use the range from the 1st% female to the 99th% male.

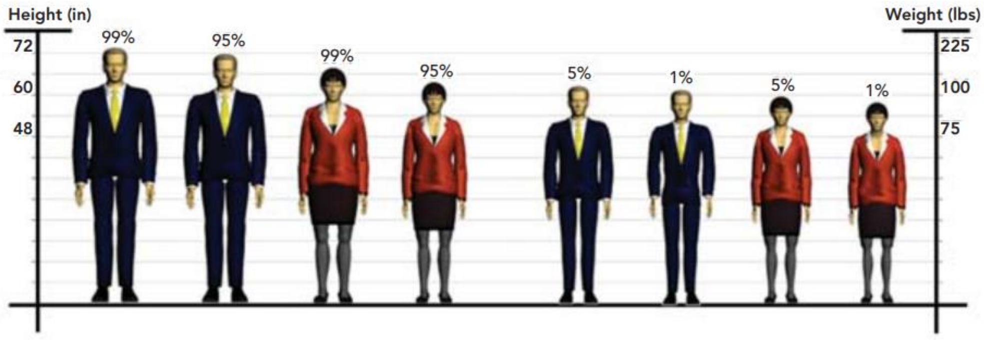

Figure 3. 2 Height-Weight Ergonomics Considerations

The 5th% female value for a particular dimension (e.g., sitting height) usually represents the smallest measurement for design in a population.

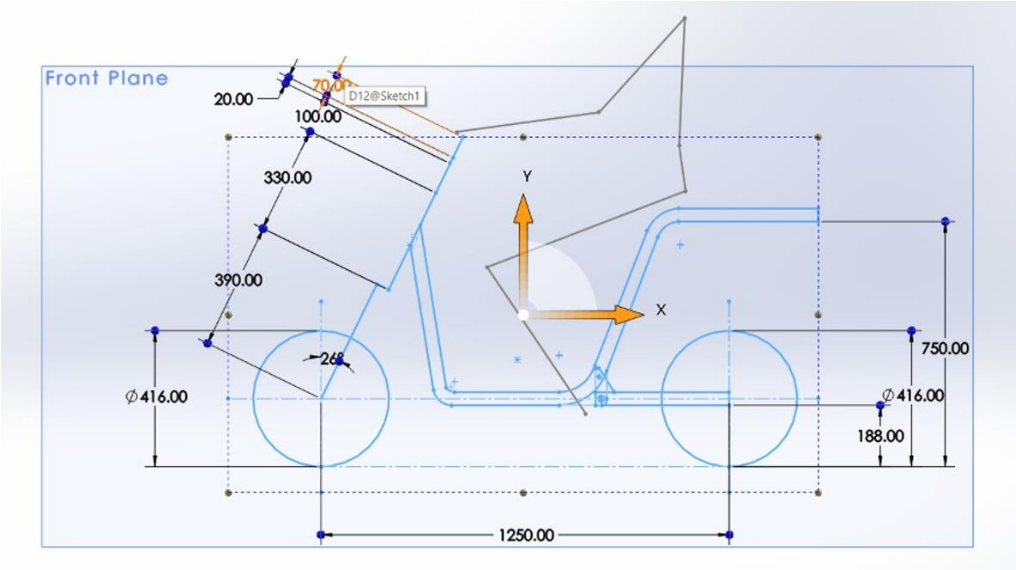

Figure 3. 3 Seating of Handle Bar Distance

Conversely, a 95th% male value may represent the largest dimension for which one is designing. The 5th% to 95th% range accommodates approximately 90% of the population. To design for a larger portion of the population, one might use the range from the 1st% female to the 99th% male.

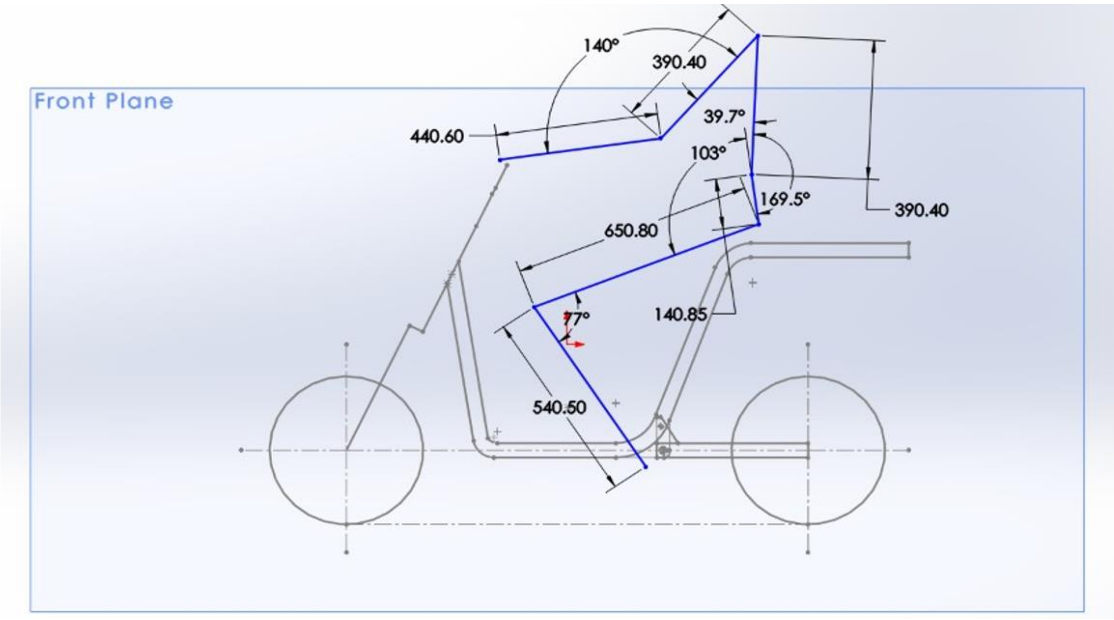

Figure 3. 4 Ergonomics for Seating Poster

3.4 DESIGN AND DEVELOPMENT OF CHASIS

The chassis is the backbone of the moped; it must support all the vehicle sub-assemblies as well as protect the driver. The chassis design is crucial to the success of the project because if the chassis fails, that puts the moped and the driver at tremendous risk. The goal of the frame will be to protect the driver, offer sturdy mounting for all subsystems, maintain all safety rules and regulations, and still be light.

3.4.1 Chassis Structure: Underbone

Underbone, on the other hand, have step-over frames with its engine positioned between the rider’s feet. Unlike conventional motorcycles, underbones lack the frame’s backbone where a motorcycle’s tank usually sits. Instead of a step board that goes through to rest your feet, you still have to swing our leg over it in order to mount the bike. It still has the same foot pegs you would find in standard motorcycles where your feet would be resting as you drive it down. Because of the way its frame and chassis are structured, it lacks the usual storage conveniences that scooters normally bring for your small items and favorite gadgets. The appearance and frame of an underbone is quite different to that of a motorcycle, but the power-train is functionally almost identical. The underbone engine is positioned between the rider's feet but the rear wheel is driven by a regular motorcycle secondary chain drive. Styling considerations only mean that the chain driven nature of the machine tends to be concealed under sheet-metal covers to a greater extent than that of motorcycles.

3.5 DESIGN CONSIDERATIONS

CAD model is the priority to initiate any design concept, so that we can observe its prototype when constructed, how it will behave. Hence 3-D modeling tool used was SOLIDWORKS 2020. Keeping in mind the bends as much they can be given to avoid weld spots by using a continuous member rather than putting up weld spots all around so that the weight can be kept lower, which is an essential point for E-BIKE. Manufacturability is utmost important i.e.; we need to keep in mind that simpler fabricating processes shall be used for an accurate design.

Figure 3. 5 Initial Under-bone Design

The design in Figure 3.6 is upgraded by increasing the tube diameters, varying the thickness and introducing gusset in critical regions and sharp bends. The tube diameters are designed according to the analytical calculation.

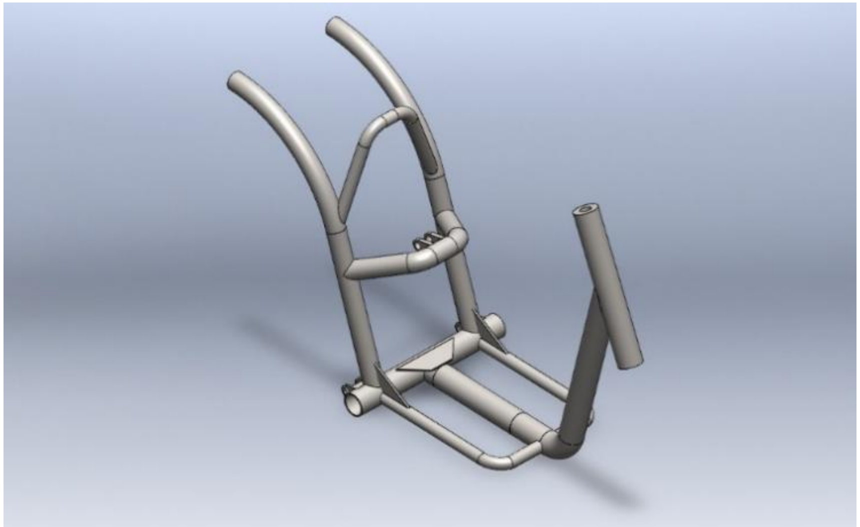

Figure 3. 6 Final Chassis Design

The Figure 3.7 Rear Arm Design is designed to facilitate both battery and horizontal suspension, since single seater bike has small wheelbase, its necessary to have a compact base.

Figure 3. 7 Rear Arm Design

The Figure 3.8 design is specially developed providing suspension point in horizontal fashion giving more comfort for the rider. This configuration of rear swing arm assembly increases the space to accommodate battery below the suspension.

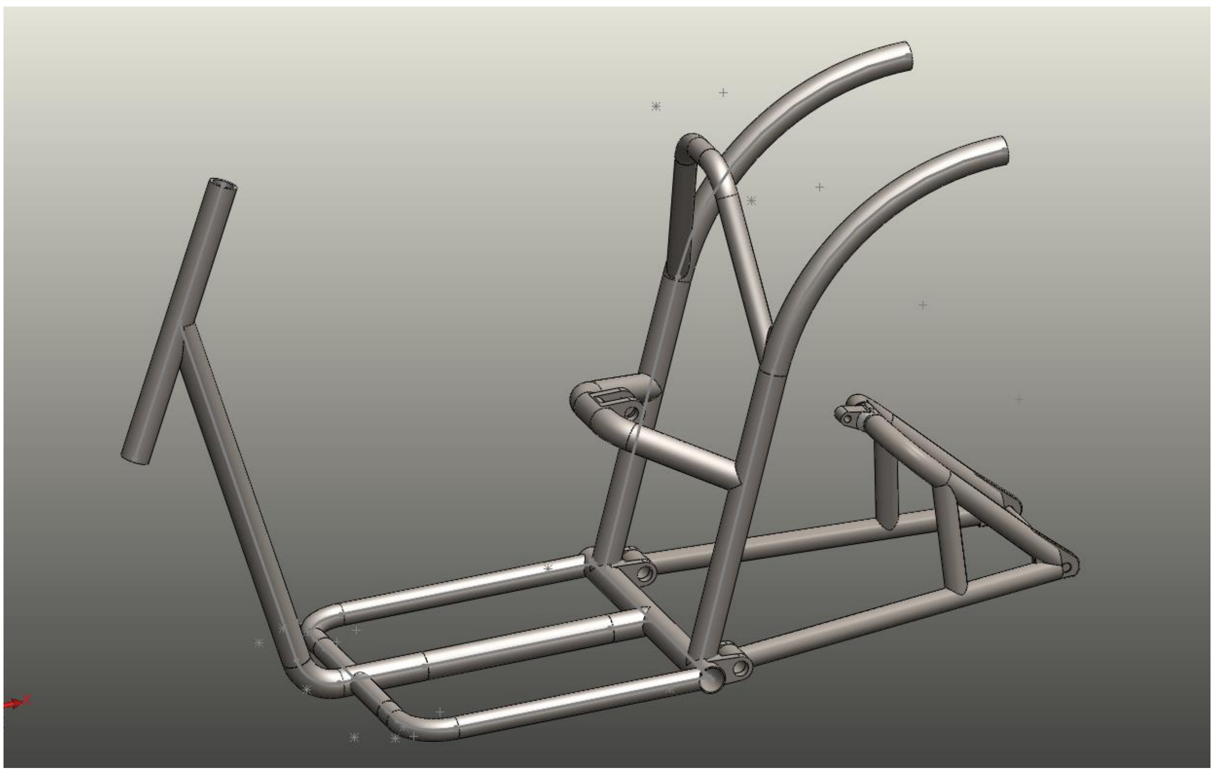

Figure 3. 8 Entire Chassis Assembly

The Figure 3.9 is a preview to showcase a single seater e-scooter designed chassis. The above model is developed using SOLIDWORKS 2022.

Figure 3. 9 Surface Model Isometric view

4. RESULT AND DISCUSSION

4.1 STEERING GEOMENTRY CALCULATIONS

Rake angle - 22*

Trail (a) - 84.04mm.

Wheelbase (p) – 1150mm.

FRONT NORMAL TRAIL

$a_n = a \cos \theta$

$= 77.92$mm.

REAR NORMAL TRAIL

$b_n = (p + a) \cos\theta$

$= 1144.18$mm.

RATIO OF FRONT AND REAR NORMAL TRAIL

$R_b = a_n/b_n$

$= 6.8\%$

4.2 BENDING STRESS CALCULATION (selected tube diameters)

- Outer diameter = 50.80;
- Thickness **=** 2.80

$$M_A = F \times perpendicular\ distance$$

$$= 465000\ Nm.m$$

$$\boldsymbol{\sigma_1} = \frac{\mathbf{32 \times M_A \times 50.80}}{\boldsymbol{\Pi(D_o{}^4 - D_i{}^4)}}$$

$$\sigma_1 = 178.15\text{MPa}$$

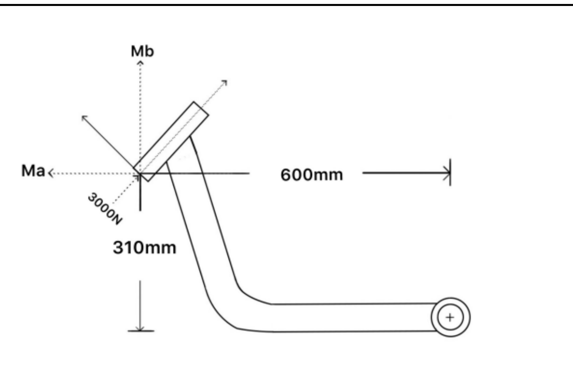

Figure 4. 1 Main-tube Diagram

$$\sigma_2 = \frac{32 \times M_B \times 50.80}{\Pi\left(D_o{}^4 - D_i{}^4\right)}$$

$$\sigma_2 = 344.809 \text{ MPa}$$

Maximum principle stress:

$$\sigma = \frac{\sigma_2 + \sigma_1}{2} \pm \sqrt{\left(\frac{\sigma_2 - \sigma_1}{2}\right)^2 + \tau^2}$$

σ_{MAX} =344.809 MPa σ_{MIN} = 178.15 MPa

4.3 MATERIALS SELECTED

- ***Chromoly AISI 4130***

  σ allowable = Ultimate tensile strength / F.O.S

  σ allowable = 350 MPa

- ***ERW – 2 (mild steel)***

  σ allowable = Ultimate tensile strength / F.O.S

  σ allowable = 200 MPa

Since the bending stress for O.D (50.80) and wall thickness (2.8) is less than the Ultimate tensile stress in both the materials, the design is safe to proceed. F.O.S - 2 is considered in loading condition

Load transfer to the vehicle during braking:

$$(\Delta w) = \frac{mg'h}{l}$$

m = GVW of the vehicle

g' = rate of deceleration

h =height of centre of gravity

l =wheelbase

μ = adhesion b/w tire to ground

$d_s = \text{stopping distance}$

$$g' = \left(\frac{-a}{g}\right)$$

Where, -a → deceleration = $\dfrac{finall_V - intiall_V}{2d_s}$

$g' = 0.800ms^{-2}$

$$d_s = \frac{v^2}{2\mu g}$$

$d_s = 78.04m$

$$(\Delta w) = \frac{mg'h}{l}$$

$(\Delta w) = 491N\ or\ 50.136\ Kg$

- Here the total weight acting on the front fork during braking is

$$(\Delta w) + total\ weight\ of\ the\ vehicle$$

4.4 NUMERICAL SOLUTION

Mopeds are powered by electric motors; to extract maximum acceleration from this motor a lightweight chassis is necessary. At the same time the chassis must undergo the rigors of Indian roads. To analyze a structure that will undergo such loads, finite element analysis (FEA) is often a viable solution. FEA breaks the structure into smaller elements and analyzes each element as a body and can calculate the stress, deflection and other reactions of any structure. A Transient FEA will be the main simulation done to optimize the weight and strength of the mopeds Chassis. From here forward a few assumptions have been made to aid design and analysis.

MESHING:

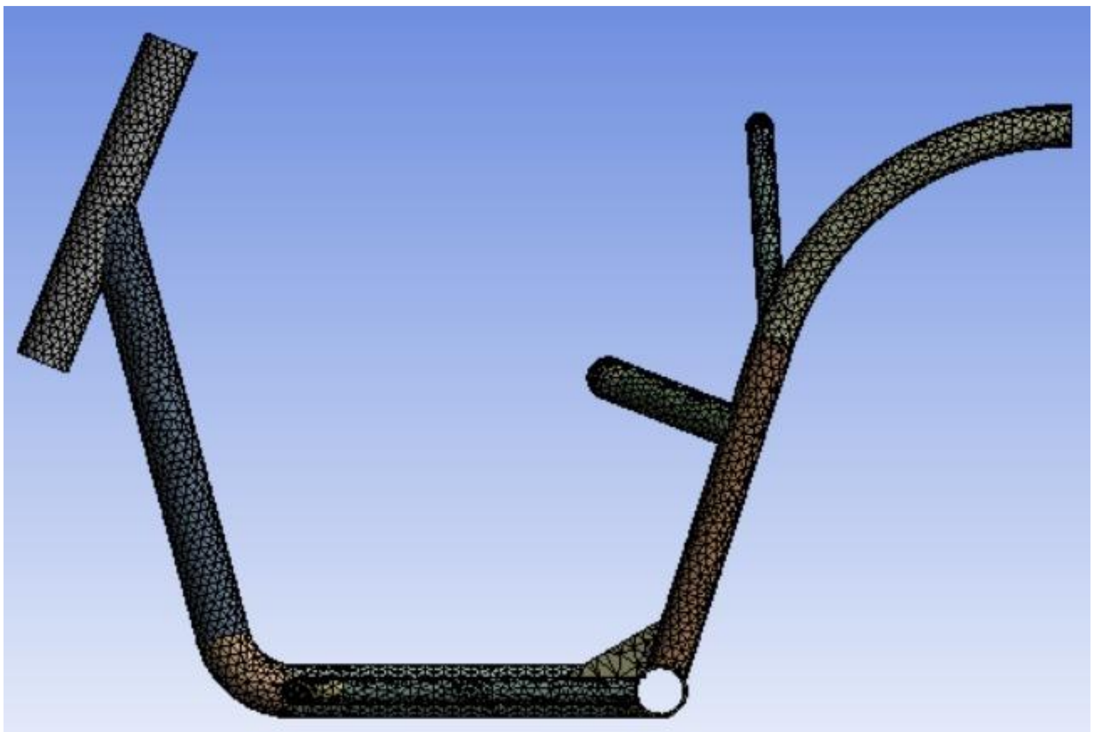

Figure 4. 2 Meshing

Meshing is one of the most important steps in performing an accurate simulation using FEA. A mesh is made up of elements which contain nodes (coordinate locations in space that can vary by element type) that represent the shape of the geometry. Meshing is the process of turning irregular shapes into more recognizable volumes called "elements". A good mesh has a quality criterion that fits basic needs such as element quality and aspect ratio. By understanding geometry and using controls to get the best mesh possible which, leads to a better product design. The mesh quality has been improved to increase mesh density in edges, curves and in flat surface larger elements are created.

MESH REFINEMENT:

Mesh refinement is a series of process to improve accuracy of results. Here in Table 4: Mesh refinement is done by decreasing the element size for each iteration and total deformation values are noted accordingly. There is gradual increase in deformation values as the number of nodes increases; this is because of increase in element density within a particular cross section of area.

No. of Nodes	Total deformation
18913	1.3654
32557	1.4232
52771	1.4587
82931	1.4631
83033	1.4647

Table 4. 1 Mesh Refinement

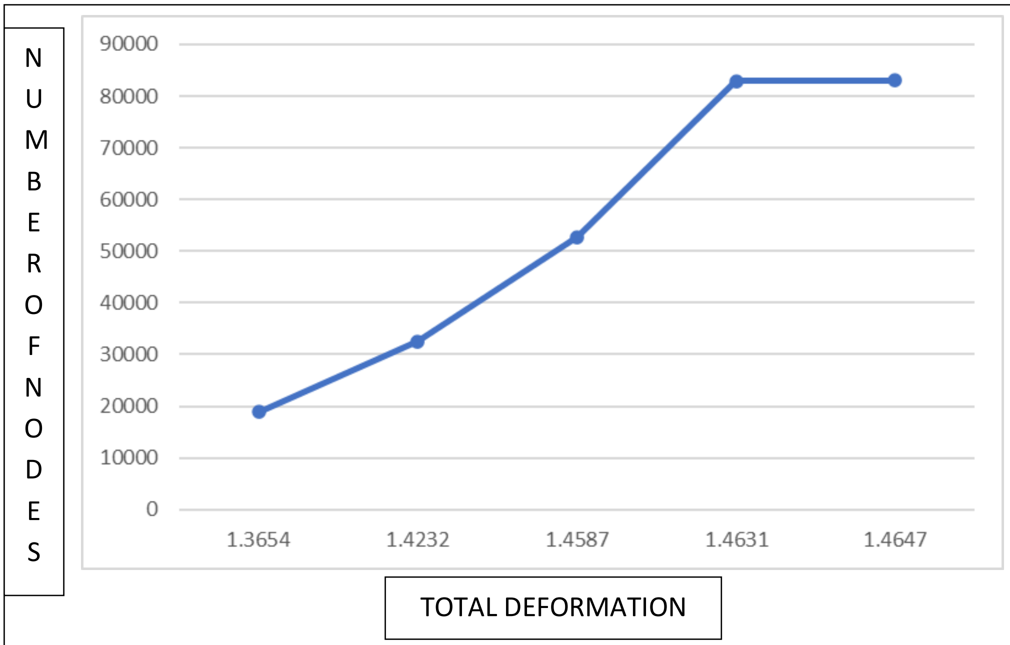

Figure 4. 3 Graph for Mesh Refinement

Figure 4.3 gives a graphical representation of number of nodes vs. total deformation of Underbone chassis. The iteration is stopped after fifth trial, as we can infer values beyond fifth trial will result the same deformation values. Highest deformation value is 1.4647mm. Model can easily withstand load beyond these deformations, so the design is safe to proceed.

FINITE ELEMENT ANALYSIS: (AISI 4130)

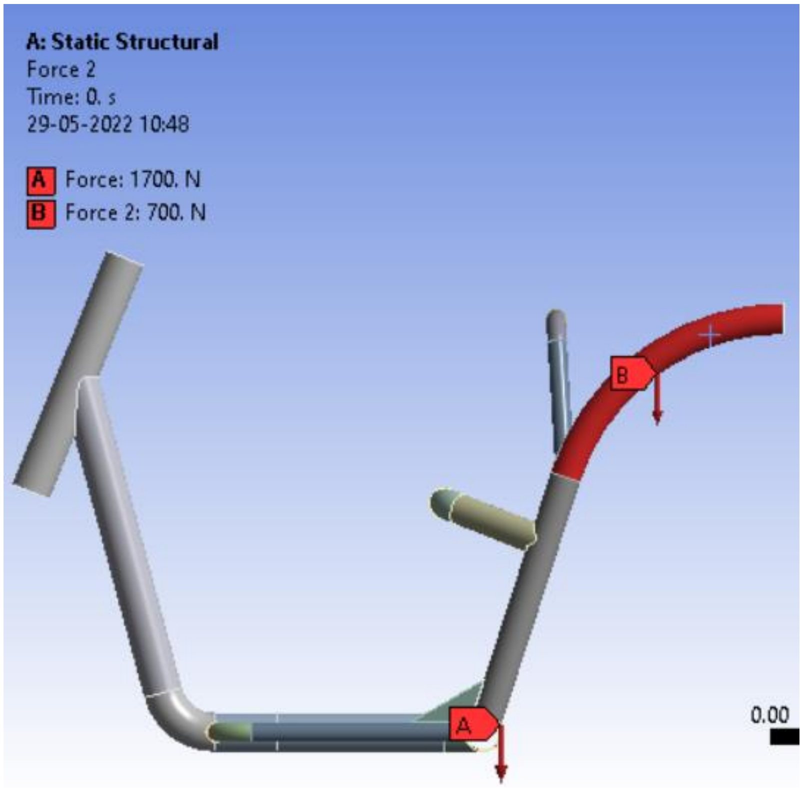

Figure 4. 4 Loading Condition for AISI 4130

In an analysis model, the loading conditions are the mechanical forces and thermal loading which act on the object or part. The boundary conditions are the environmental factors influencing the behavior of the object or part under normal use a place on a structure where either the external force or the displacement are known at the start of the analysis.

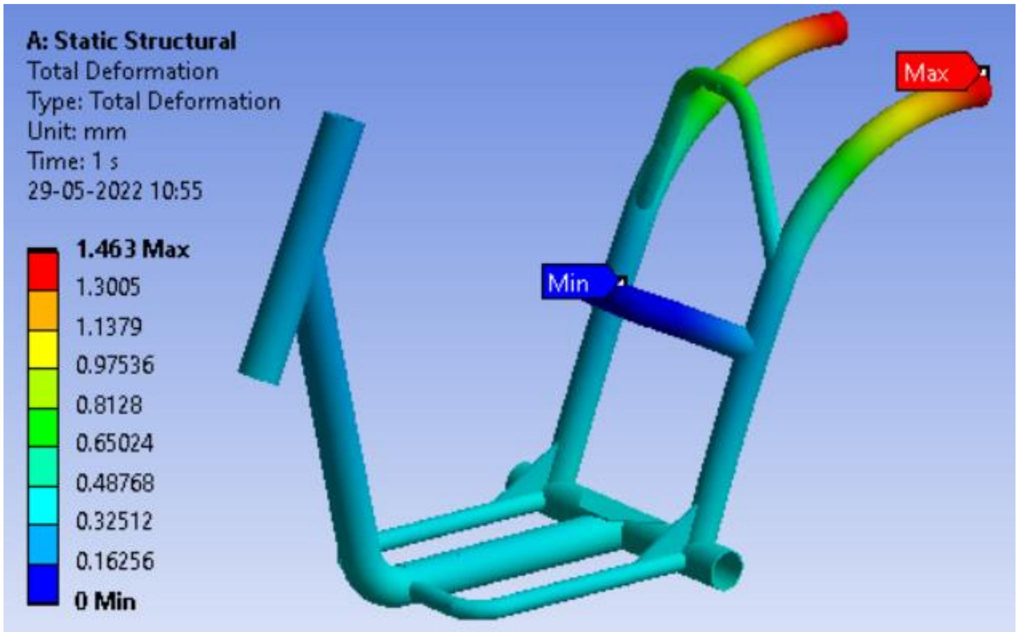

Figure 4. 5 Total Deformation AISI 4130

Total deformation is the deformation option that you can see all the deformation results related to your model, in three coordinates(X, Y, and Z). Directional: In directional deformation, you can select a coordinate (X, Y, or Z) to see the deformation result of your physical model in this direction.The maximum , minimum and average value for total deformation are 1.463mm,0mm & 0.4262mm respectively.

Table 4. 2 Deformation Results AISI 4130

Tabular Data				
S.NO.	Time	Minimum [mm]	Maximum [mm]	Average [mm]
1.	1	0	1.463	0.4262

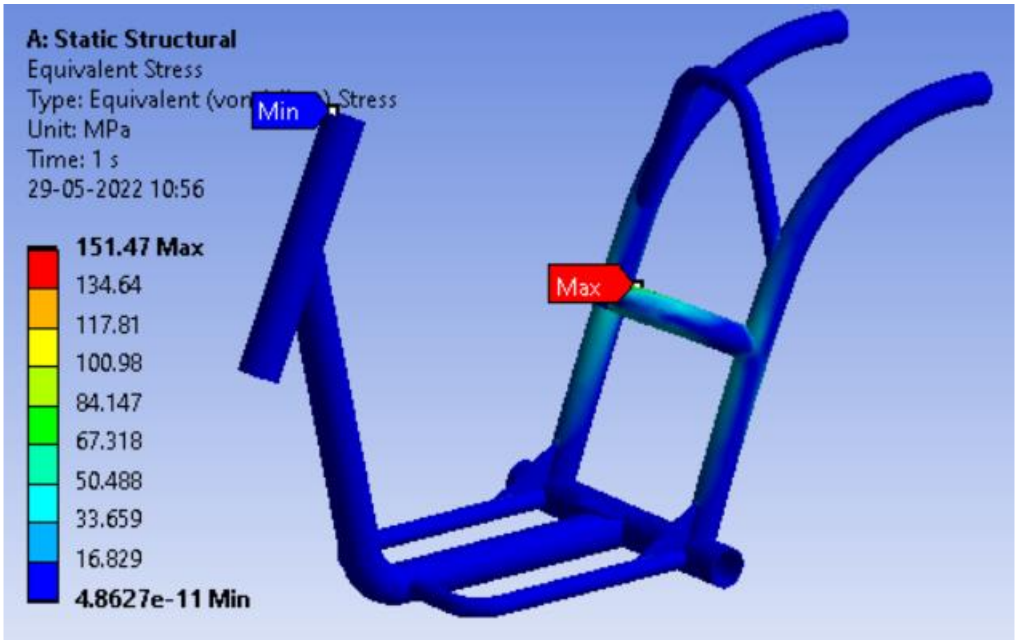

Figure 4. 6 Equivalent Stress AISI 4130

Equivalent Stress, also called distortion energy theory or von-Mises theory states that maximum equivalent stress at stress elements on material or part must be smaller from the yield strength of that used material. Maximum equivalent stress theory applies to ductile materials.The maximum, minimum and average values for Equivalent Stresses are 151.47MPa, 4.8527e^{-11}MPa& 6.52MPa respectively.

Table 4. 3 Von-Mises Results AISI 4130

Tabular Data				
S.NO.	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	1	4.8627 e^{-011}	151.47	6.52

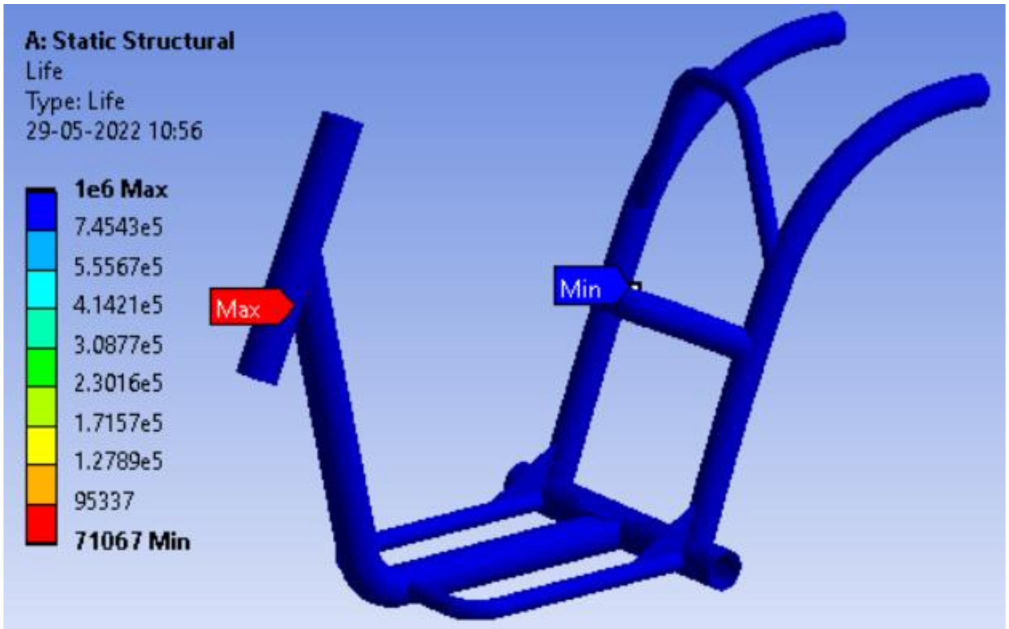

Figure 4. 7 Life Calculation AISI 4130

Fatigue or Life is a contour plot of the fatigue damage at a given design life. Fatigue damage is defined as the design life divided by the available life. It is based on a counting variable representative of the stress states and of their evolution versus time in order to identify and extract multi-axial cycles.The maximum, minimum and average value for Fatigue Damage or Life are 71067, $1e^{+}6$& 9.9735 $e^{+}5$respectively.

Table 4. 4 Life Calculation Results

Tabular Data				
S.NO.	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	1	71067	1.e^{006}	9.9735 e^{005}

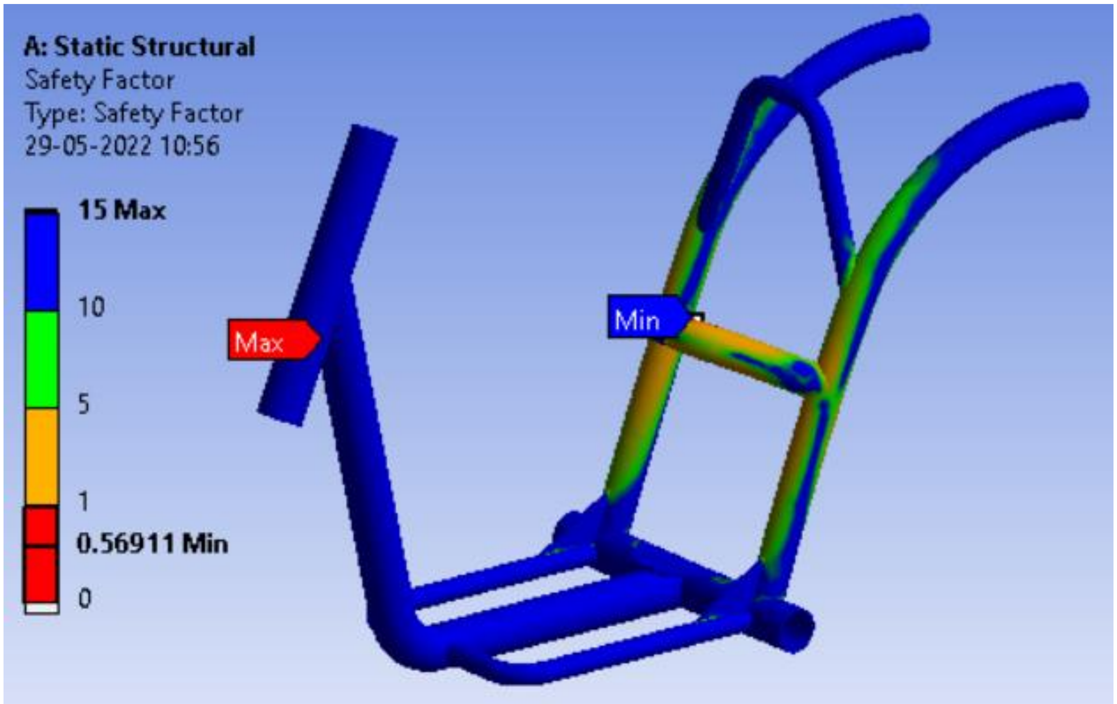

Figure 4. 8 Safety Factor AISI 4130

The Safety Factor is the ratio of the stress at which failure occurs to the stress that actually occurs in the part. So a SF of 15 means that the loads causing the stress could be increased by a factor of 15 before failure occurs.The maximum , minimum and average value for Safety Factor are 15,0.56911 & 12.727 respectively.

Table 4. 5 Tabulated Results for Chromoly

Tabular Data				
S.NO.	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	1	0.56911	15	12.727

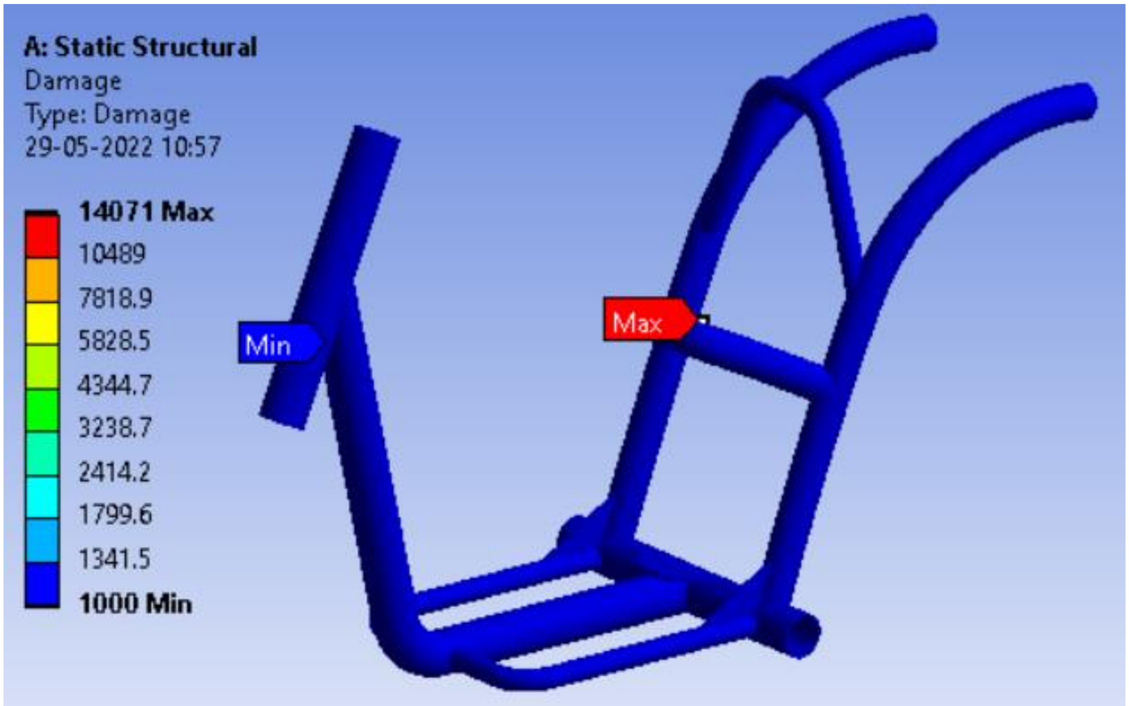

Figure 4. 9 Results for Damage AISI 4130

Damage satisfying the selected initiation criteria, further loading will degrade the material. The damage evolution law determines how the material degrades..The maximum, minimum and average values for Safety Factor are 14071, 1000 & 4344 respectively.

4.4.1 IMPACT ANALYSIS ON STATIC STRUCTURE

Chromoly (AISI 4130)-

For chassis and swing arm AISI 4130 steel is used. Chassis and Swing arm is being completely designed in Solid Works and imported to ANSYS 2021 R2 software for performing various analysis on it. In order to plot the maximum stress developed in different points of the model, structural analysis is performed.

Design geometry is uploaded into ANSYS and constrained to specific conditions to get the best probable results.

Following are the outcome of the Static structural analysis.

1. **Equivalent stress**
2. **Total Deformation**

After getting the results, stress concentration points are being strengthened to get the maximum stress very much under the permissible level of the material. Design iterations is being performed many timed to get the most optimized design. Design optimization is validated by comparing the developed stress with the material property. Developed stress is maintained well under the ultimate strength of the material.

For the vehicle structure the following tests are performed,

1. **Frontal Impact Analysis**
2. **Rear Impact test**

4.4.1.1 Frontal Impact test: For the frontal impact the whole chassis is analyzed by applying the maximum force at the loading points to get the most accurate deformation and maximum stress developed in it.

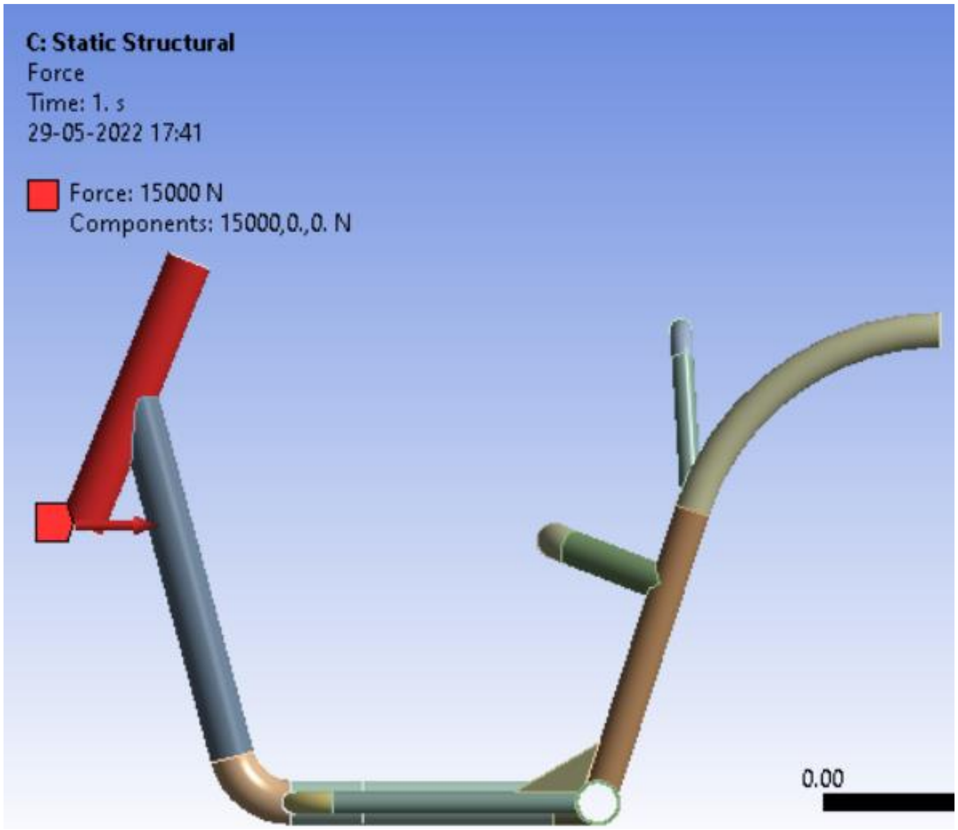

Figure 4. 10 Impact Loading Condition

Frontal impact mainly targets the core region of the front end.

Above chassis is applied with the following constrains

- Swing arm and suspension pointing points are constrained as fixed support.
- Force is applied at the front end exactly on the bottom surface of the cone.

Impacting force entirely tries to deform the chassis at the welded cone region of the chassis. So different diameter-thickness variations have been tested for withstanding the applied impacting force. So, after several iterations proper tube diameters are selected.

Equivalent stress at the chassis is obtained as 3750 MPa, it occurs at main tube of chassis. Other than the suspension point other regions of the chassis is very much safer and developed stress almost negligible when compared to the material property.

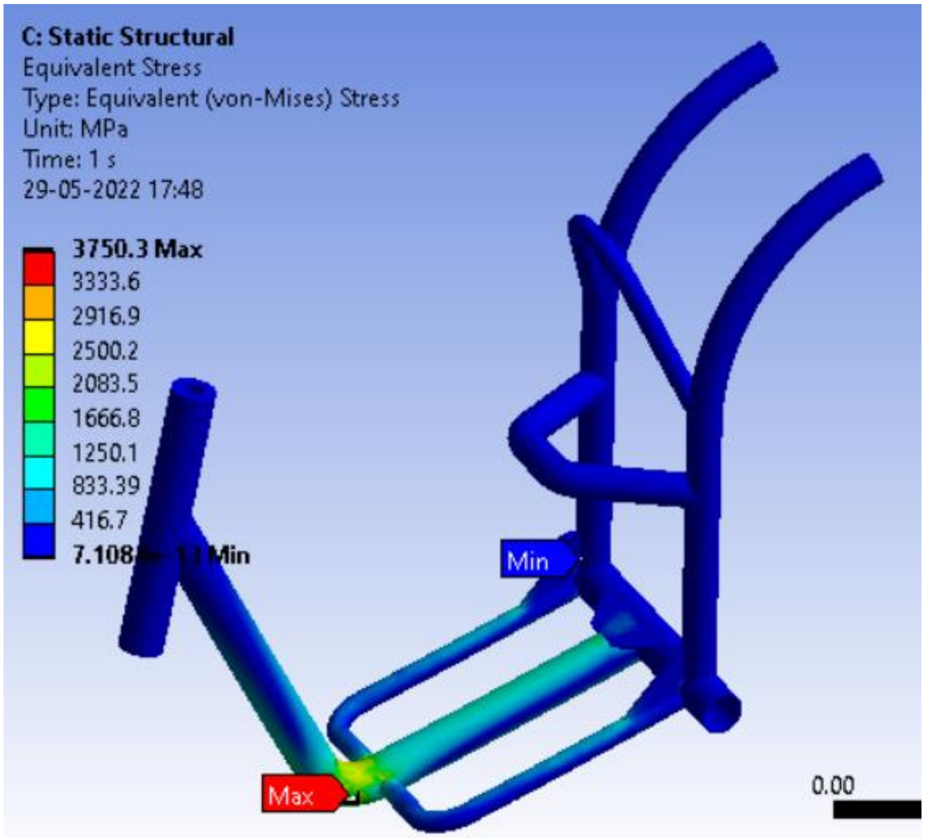

Figure 4. 11 Impact Total Deformation

In swing arm the stress is 7.108 MPa. It infers that after applying the maximum force of 15000N at the rear end will not affect the structural rigidity of the chassis. Also, will never contribute for any bending in the chassis.

FOS = 2

Gross weight = 150 Kg's

Applied force (with FOS) = 15000N

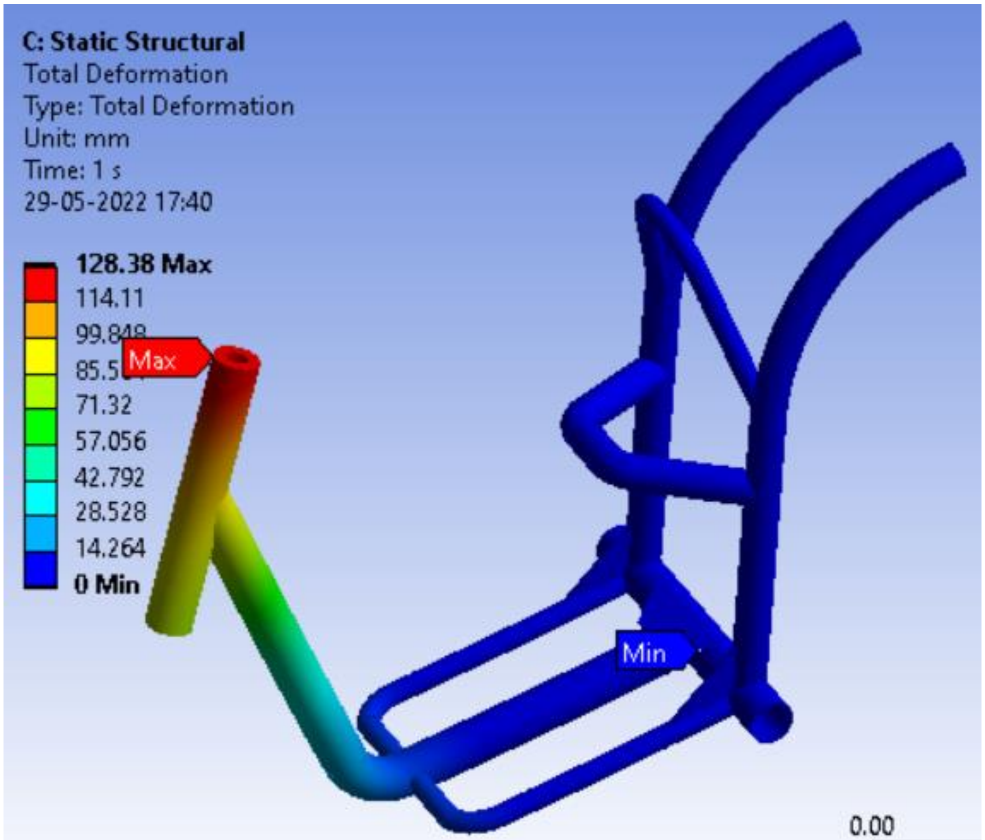

Figure 4. 12 Impact Total Deformation

In most of the points the stress level is very low. Analysis infers that the design will sustain the maximum frontal impact of 15000N. Total deformation is 128mm at front fork which will be safe for the driver during the impact.

***4.4.1.2 Rear Impact test*:** For the rear impact test the swing arm is analyzed for total deformation and equivalent stress. For swing arm the main deforming force is acting on the axle bolt of the Hub motor. So that the swing arm mounting point is given as the fixed support and force is applied on the axle mounting point of the swing arm.

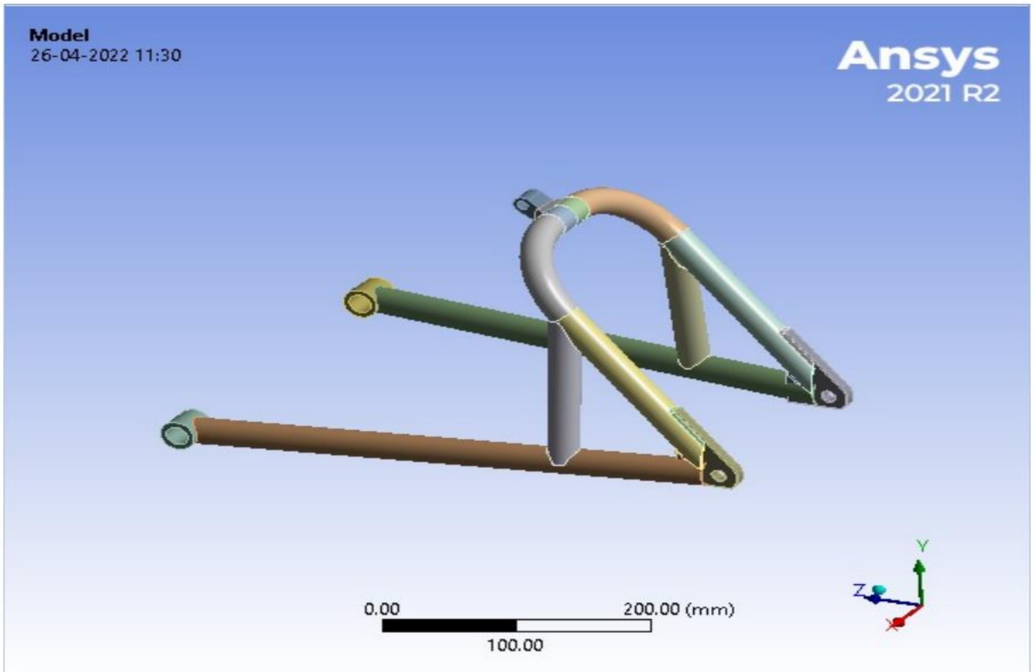

Figure 4. 13 Impact Total Deformation

Force applied on the swing arm at axle point is considered as 70% of the vehicle weight with Factor of Safety.

FOS considered for design is 2.

- Gross weight = 150 kg's
- Design weight = 105 kg's
- Design stress(1050*2) = 2100 N

Thus at the axle point the force acting is considered as 2100N.

These are the two constrains for swing arm. After applying the constraints the model is finely meshed. Then the Maximum stress test and Total deformation analysis is performed on the swing arm. Due to the fine mesh accurate results are obtained.

4.5 ANALYSIS

After the analysis it is observed that the maximum deformation in rear end is 0.198mm, which is nothing in reality to impact the rigidity of the swing arm structure.

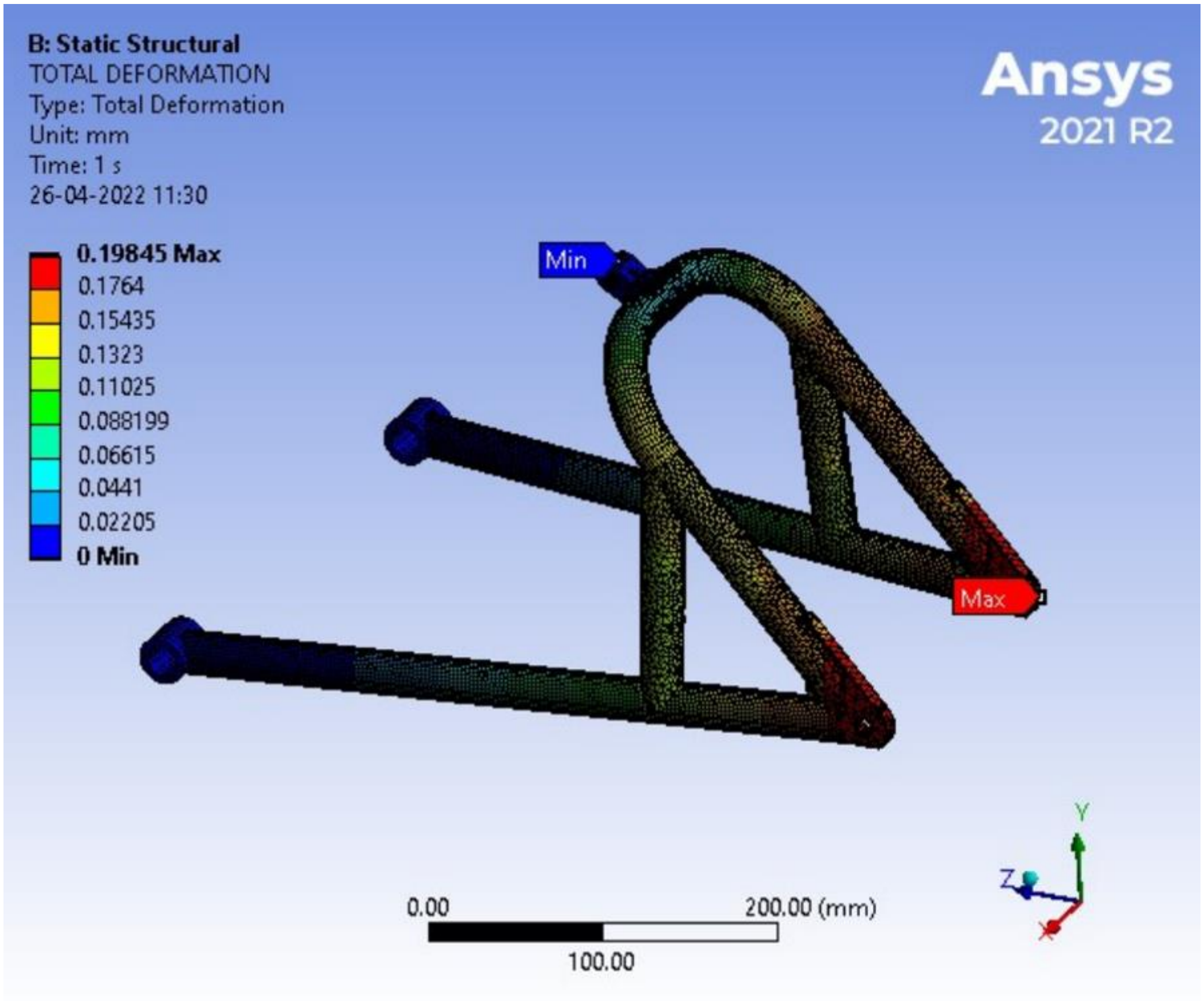

Figure 4. 14 Total Deformation Results

That too obtained maximum deformation is at the axle point. This deformation will occur on situations when purely 2100N is applied at the rear end. As we are using the rear suspension only minimal impact will be there at the rear end. Thus, the design is very much safe at the rear end.

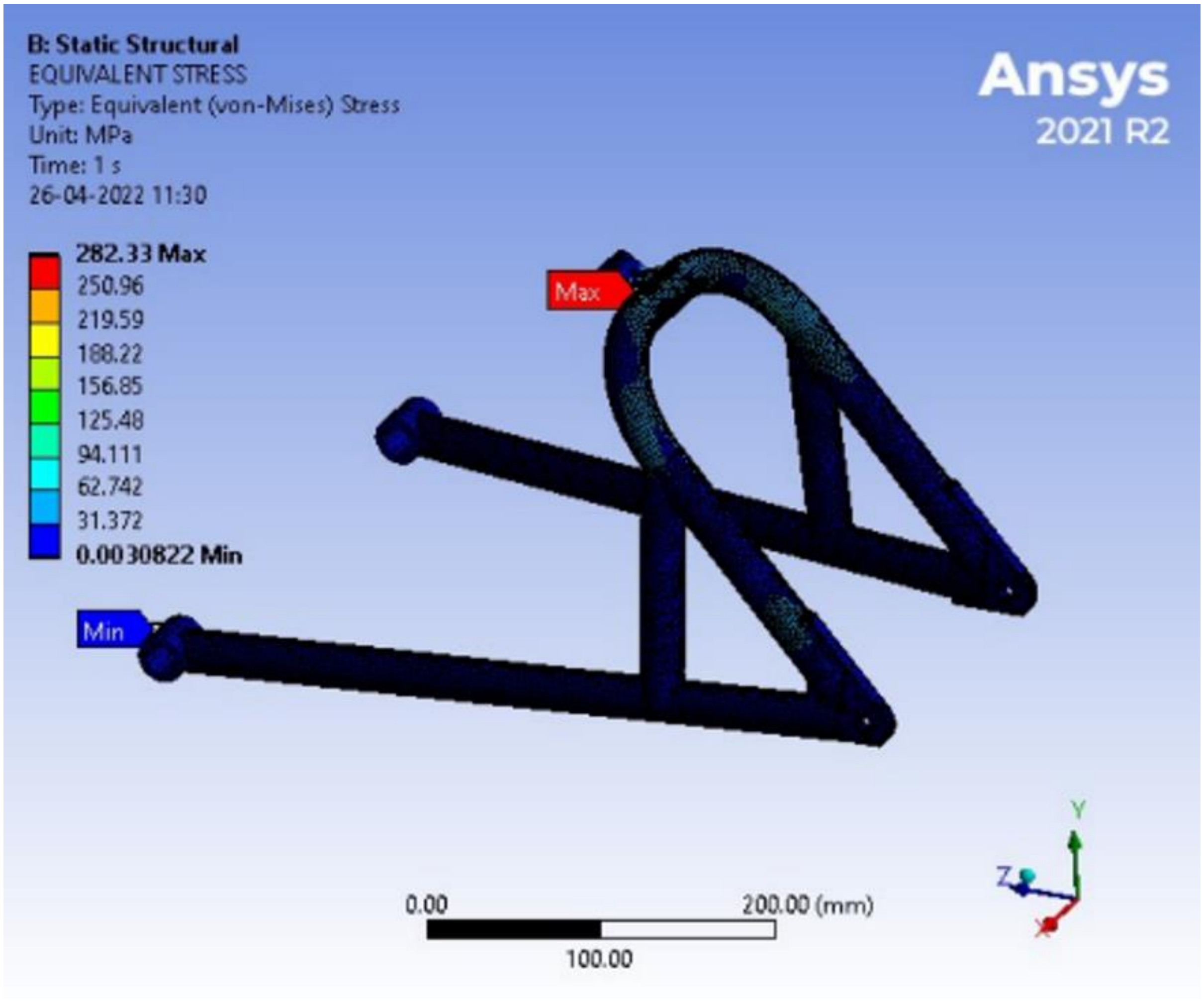

Figure 4. 15 Equivalent Stress Results

Maximum stress at the rear end is obtained as 282.33MPa. This is much below the ultimate strength of the material. As the average stress in the swing arm is 16.24 MPa, it infers that by applying the impact on swing arm will almost have no effect on stressing the swing arm.

4.5.1 Modal analysis for AISI4130:

Modal analysis is the fundamental dynamic analysis type, providing natural frequency at which the chassis will resonate. Model analysis allows us to predict key charecteristics of proposed designs in frequency domain.

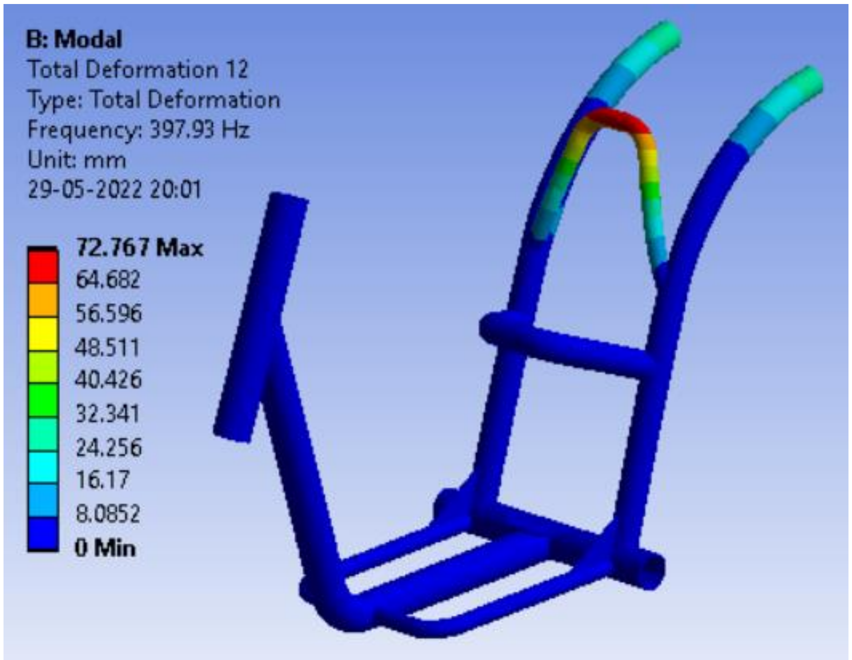

Figure 4. 16 Modal Analysis

In Figure 4.16 Modal analysis is carried out for AISI 4130 material in the underbone chassis. The results show movement of different parts of the structure under dynamic loading condition.

Table 4. 6 Tabular Data for Various Model Natural Frequencies

S. No.	Mode	Frequency [Hz]
1.	1	26.168
2.	2	27.042
3.	3	110.25
4.	4	122.43
5.	5	137.97
6.	6	164.61
7.	7	170.31
8.	8	176.1
9.	9	337.8
10.	10	346.34
11.	11	397.93

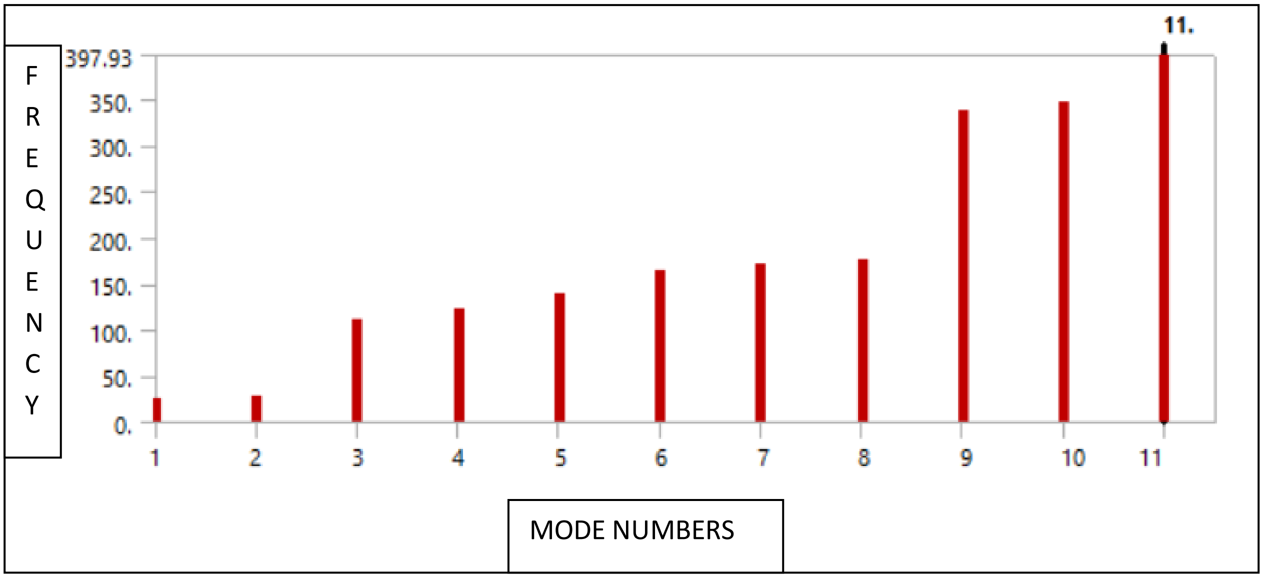

Figure 4. 17 Graph for Natural Frequency

Figure 4.17 shows graphical representation of natural frequency for different mode shapes. We can infer that mode shape '11' has the highest frequency of 397.93 Hz.

4.5.2 Finite Element Analysis (ERW - 2) –

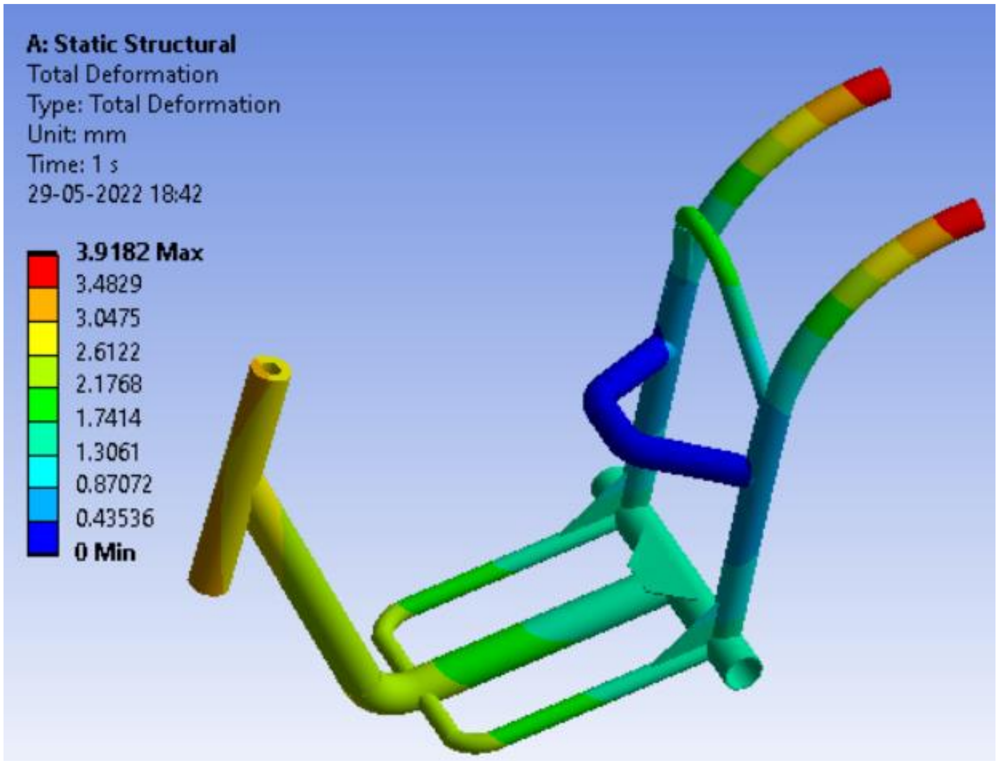

Figure 4. 18 Total Deformation ERW -2

Total deformation is the deformation option that you can see all the deformation results related to your model, in three coordinates(X, Y, and Z). Directional: In directional deformation, you can select a coordinate (X, Y, or Z) to see the deformation result of your physical model in this direction.The maximum , minimum and average value for total deformation are 3.9182mm,0mm & 1.6415mm respectively.

Table 4. 7 Results for Total Deformation (ERW -2)

Tabular Data				
S.NO.	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1	1.	0	3.9182	1.6415

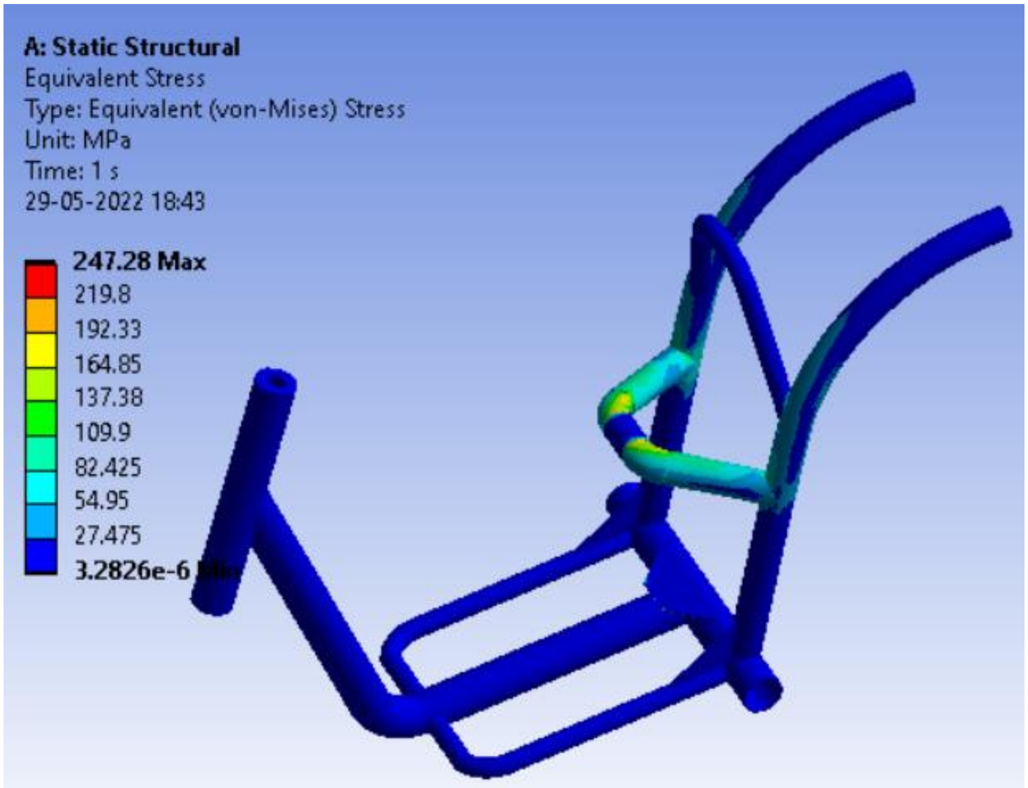

Figure 4. 19 Equivalent Stress ERW -2

Equivalent Stress, also called distortion energy theory or von-Mises theory states that maximum equivalent stress at stress elements on material or part must be smaller from the yield strength of that used material. Maximum equivalent stress theory applies to ductile materials.The maximum, minimum and average value for eequivalent stress are 247.28MPa, 3.2826e^{-6}MPa& 11.977MPa respectively.

Table 4. 8 Results for Deformation ERW -2

Tabular Data				
S.NO.	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	1.	3.2826 e^{-006}	247.28	11.977

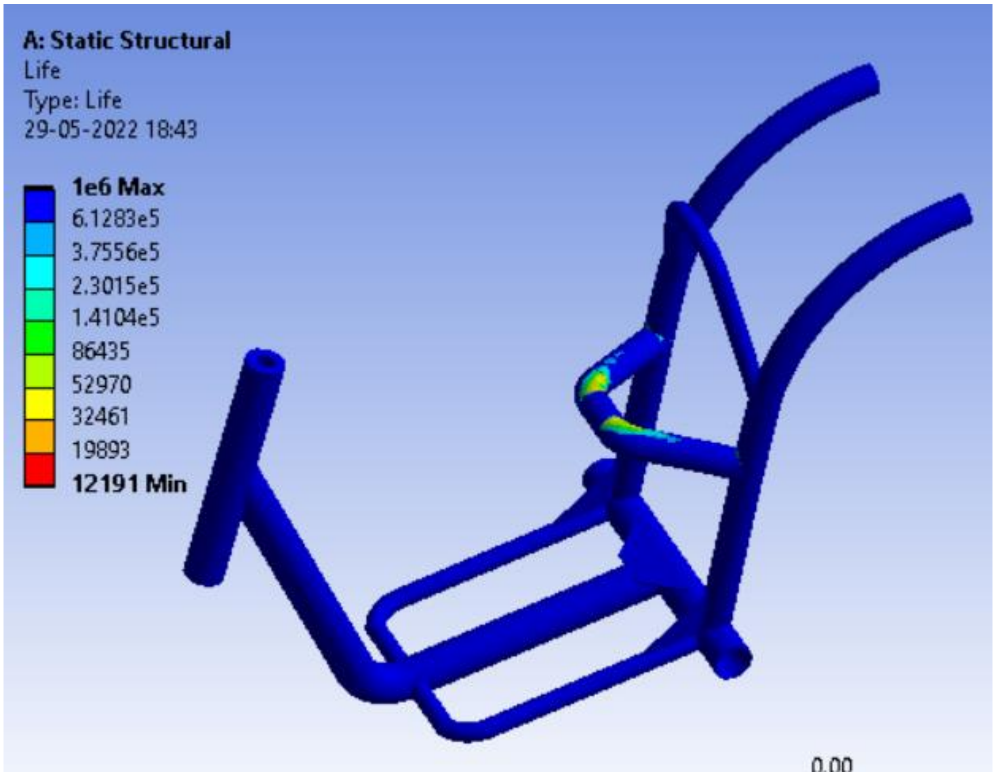

Figure 4. 20 Life for ERW -2

Fatigue or Life is a contour plot of the fatigue damage at a given design life. Fatigue damage is defined as the design life divided by the available life. It is based on a counting variable representative of the stress states and of their evolution versus time in order to identify and extract multi-axial cycles.The maximum, minimum and average value for Fatigue or Life are 12191,1 $e^{+}6$& 9.89$e^{+}5$respectively.

Table 4. 9 Results for Life (ERW -2)

Tabular Data				
S.NO.	Time [s]	Minimum	Maximum	Average
1	1.	12191	1. e^{006}	9.89 e^{005}

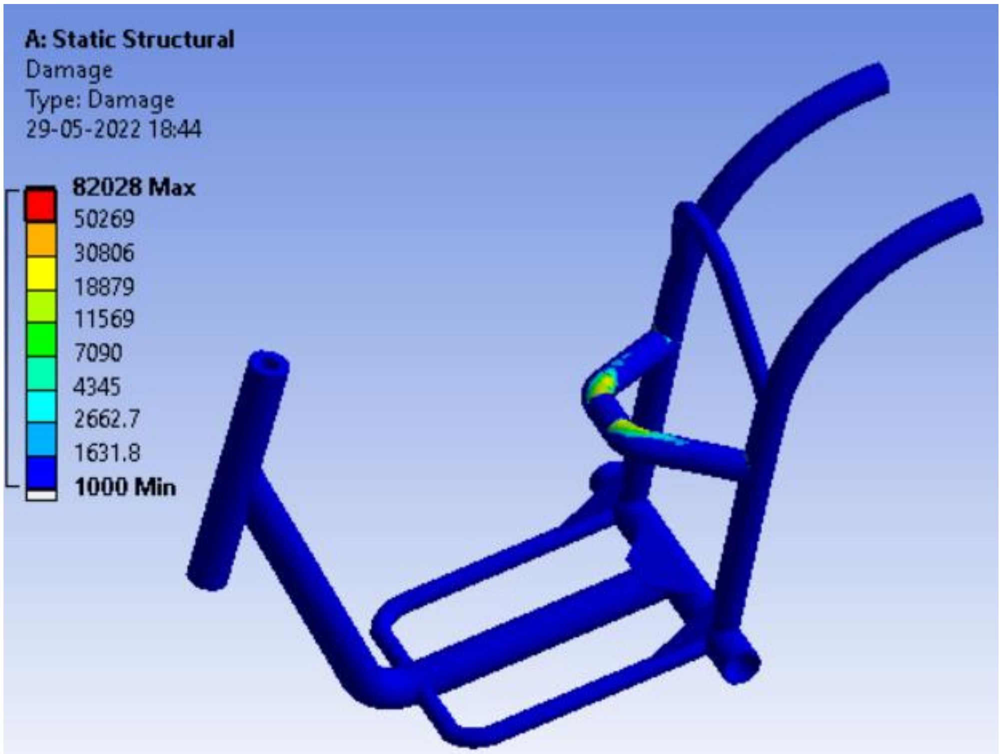

Figure 4. 21 Damage for ERW -2

Damage satisfying the selected initiation criteria, further loading will degrade the material. The damage evolution law determines how the material degrades..The maximum, minimum and average value for Safety Factor are 82028,1000 & 1102 respectively.

Table 4. 10 Results for Damage (ERW -2)

Tabular Data				
S.NO.	Time [s]	Minimum	Maximum	Average
1	1.	1000	82028	1102

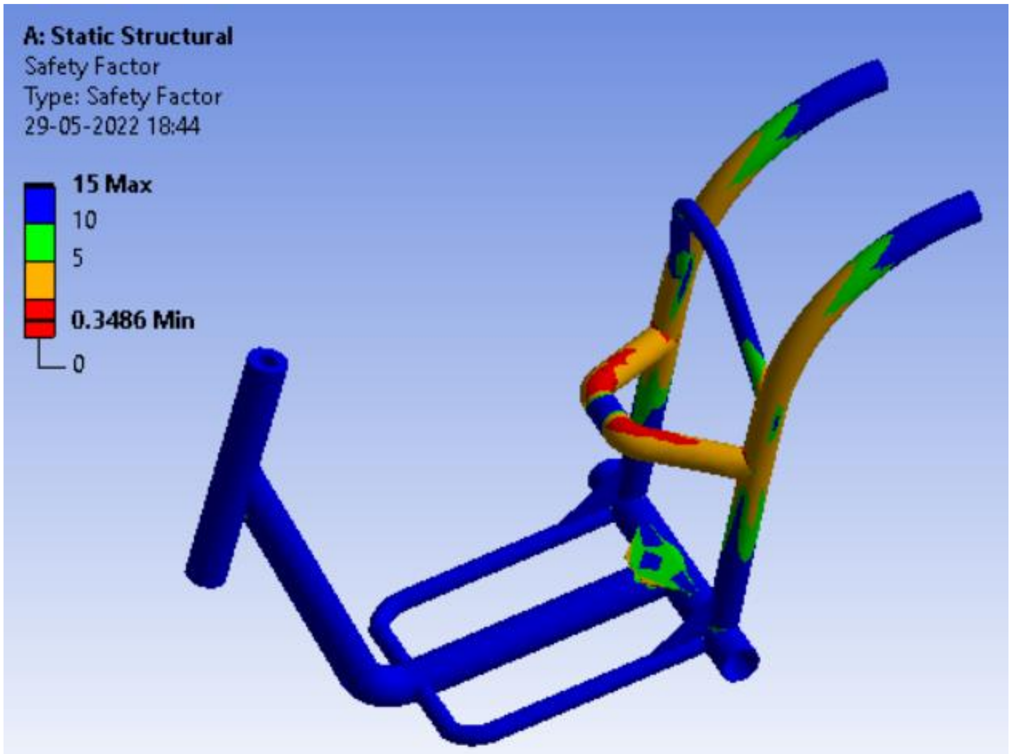

Figure 4. 22 Safety Factor (ERW -2)

The Safety Factor is the ratio of the stress at which failure occurs to the stress that actually occurs in the part. So a SF of 15 means that the loads causing the stress could be increased by a factor of 15 before failure occurs.The maximum , minimum and average value for Safety Factor are 15,0.3486 & 11.686 respectively.

Table 4. 11 Results for Safety Factor (ERW-2)

Tabular Data				
S.NO.	Time [s]	Minimum	Maximum	Average
1	1	0.3486	15	11.686

4.5.3 Impact Analysis On Static Structure:

ERW 2-

For chassis and swing arm ERW 2 steel is used. Chassis and Swing arm is being completely designed in Solid Works and imported to ANSYS 2021 R2 software for performing various analysis on it. In order to plot the maximum stress developed in different points of the model, structural analysis is performed.

Design geometry is uploaded into ANSYS and constrained to specific conditions to get the best probable results.

Following are the outcome of the Static structural analysis.

1. **Total Deformation**
2. **Equivalent stress**

After getting the results, stress concentration points are being strengthened to get the maximum stress very much under the permissible level of the material. Design iterations is being performed many timed to get the most optimized design. Design optimization is validated by comparing the developed stress with the material property. Developed stress is maintained well under the ultimate strength of the material.

For the vehicle structure the following tests are performed,

1. **Frontal Impact Analysis**
2. **Rear Impact test**

4.5.3.1 Frontal Impact Test:

For the frontal impact the whole chassis is analyzed by applying the maximum force at the loading points to get the most accurate deformation and maximum stress developed in it.

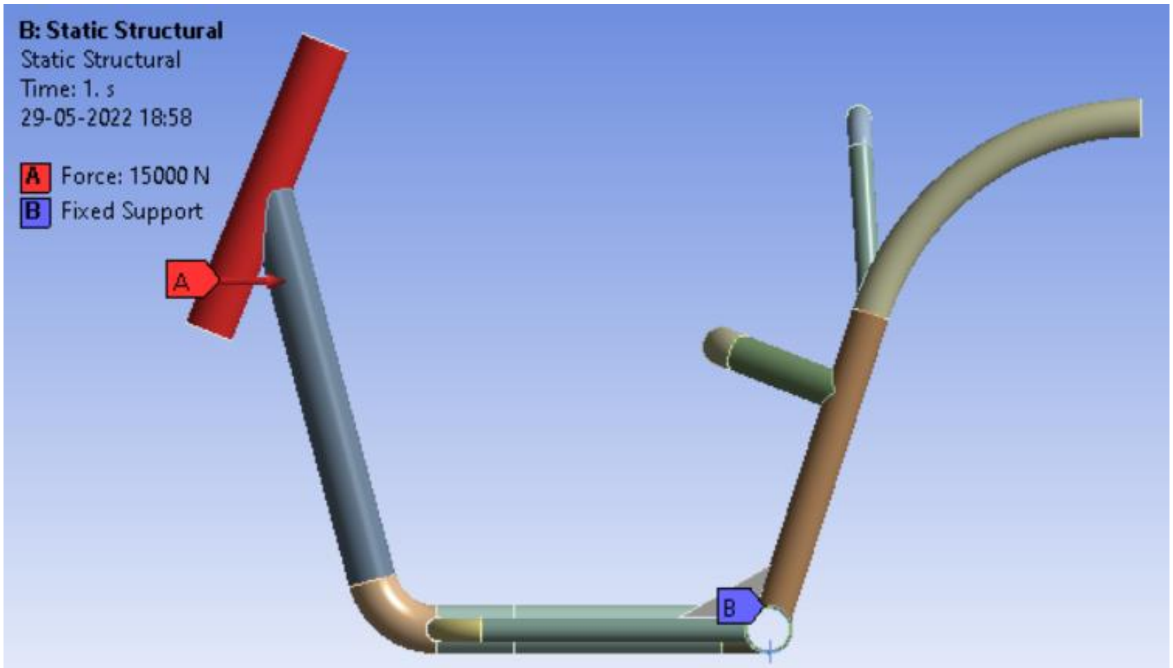

Figure 4. 23 Loading Condition for Impact Test

Frontal impact mainly targets the core region of the front end.

Above chassis is applied with the following constrains

- Swing arm and suspension pointing points are constrained as fixed support.
- Force is applied at the front end exactly on the bottom surface of the cone.

Impacting force entirely tries to deform the chassis at the welded cone region of the chassis. Different diameter-thickness variations have been tested for withstanding the applied impacting force. So, after several iterations proper tube diameters are selected.

Equivalent stress at the chassis is obtained as 3700 MPa, it occurs at main tube of chassis. Other than other regions of the chassis is very much safer and developed stress almost negligible when compared to the material property.

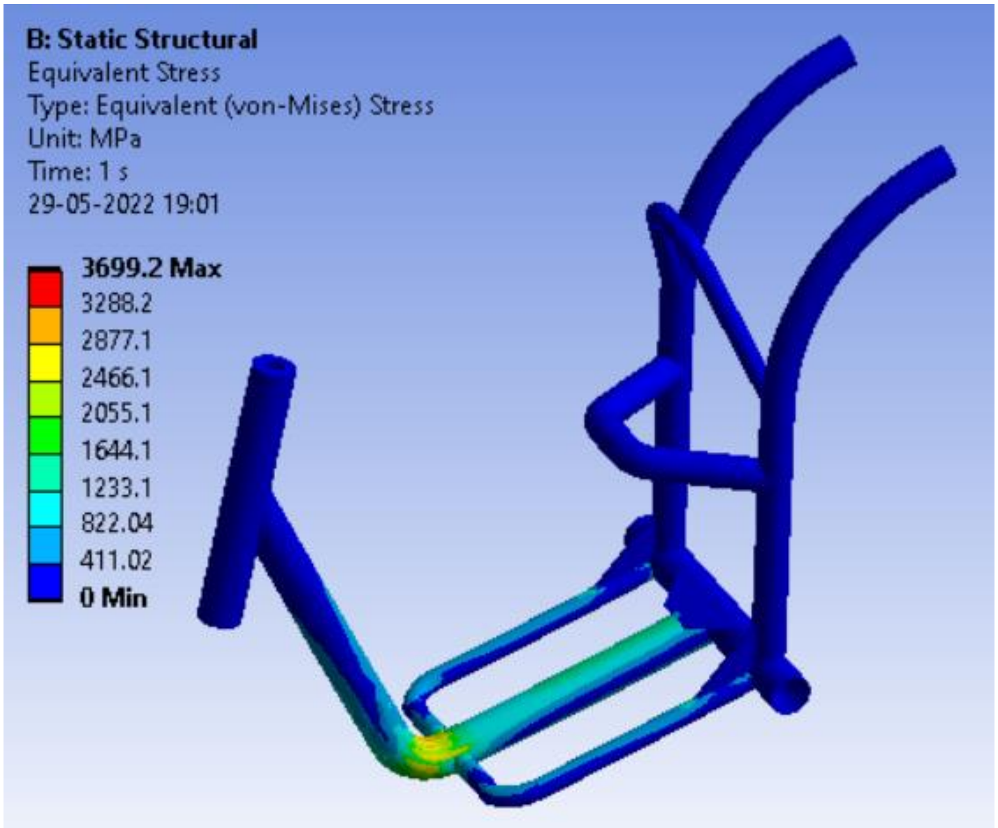

Figure 4. 24 Impact Stress (ERW -2)

In swing arm the stress is 0 MPa. It infers that after applying the maximum force of 15000N at the front end will not affect the structural rigidity of the chassis; also, will never contribute for any bending in the chassis.

FOS = 2

Gross weight = 150 Kg's

Applied force (with FOS) = 15000N

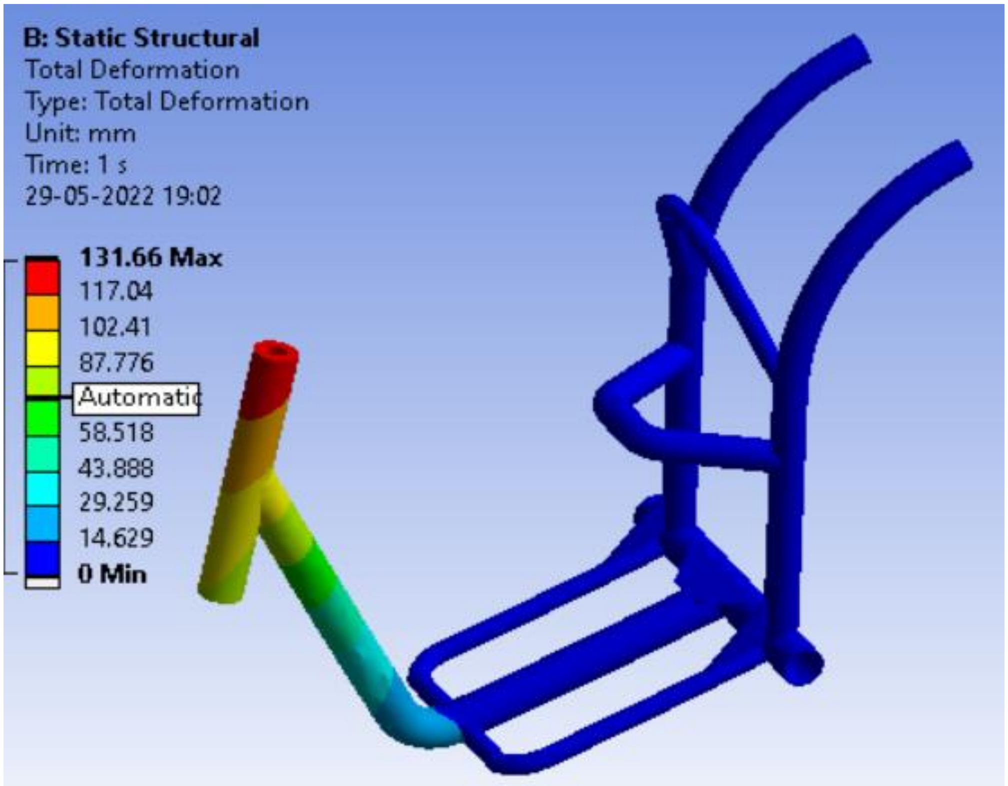

Figure 4. 25 Total Deformation ERW -2

In most of the points the stress level is very low. Analysis infers that the design will sustain the maximum frontal impact of 15000N. Total deformation is 131mm at front fork which will be safe for the driver during the impact, since the formation happens only in the front fork of the vehicle.

4.5.3.2 Modal analysis for ERW 2:

Modal analysis is the fundamental dynamic analysis type, providing natural frequency at which the chassis will resonate. Model analysis allows us to predict key charecteristics of proposed designs in frequency domain**.**

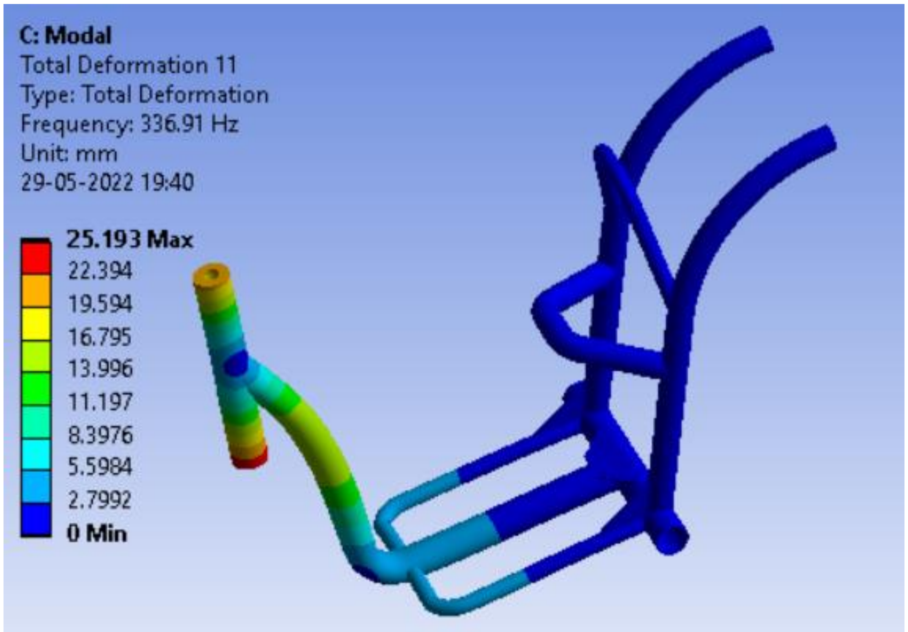

Figure 4. 26 Modal Analysis (ERW – 2)

In Figure 4.25 Modal analysis is carried out for ERW 2 material in the underbone chassis. The results show movement of different parts of the structure under dynamic loading condition.

Table 4. 12 Results for Modal Analysis (ERW -2)

S.NO.	Mode	Frequency [Hz]
1	1.	25.218
2	2.	26.122
3	3.	106.82
4	4.	118.28
5	5.	131.97
6	6.	154.79
7	7.	163.37
8	8.	164.41
9	9.	328.58
10	10.	336.91

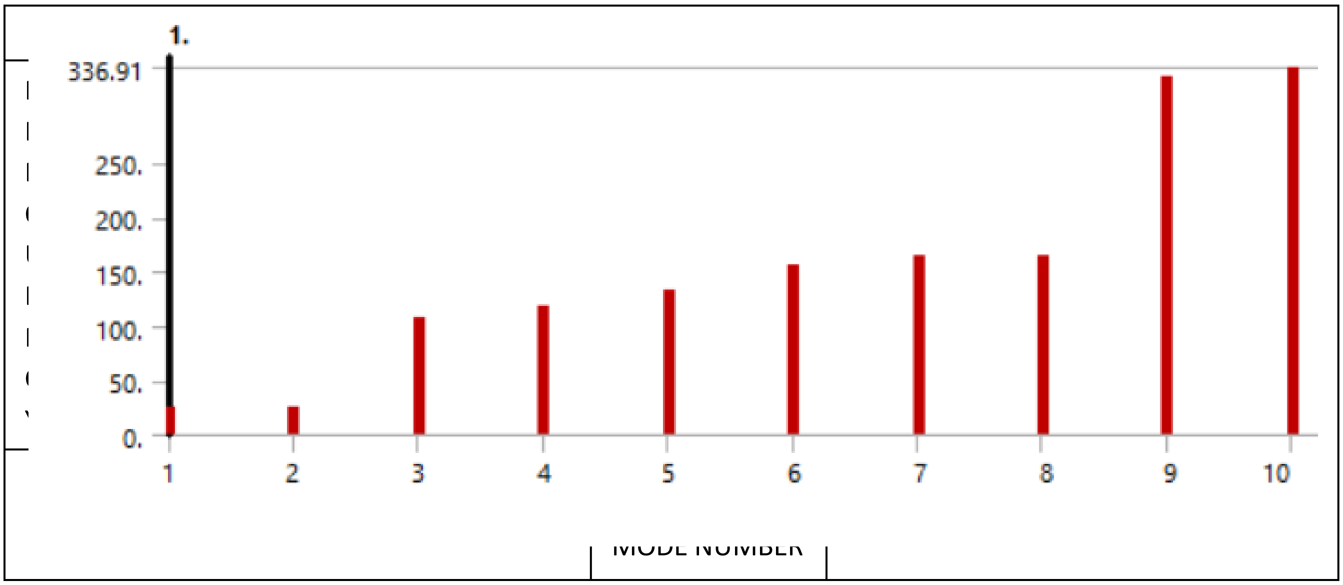

Figure 4. 27 Graph for Natural Frequency

Figure 4.27 shows graphical representation of natural frequency for mode shapes. We can infer that mode shape ‘11’ has the highest frequency of 336.91 Hz.

5. CONCLUSION

From the above analysis of both ERW and AISI 4130 has given results favoring to AISI 4130.

- The design was developed and analyzed by considering ergonomics for 95th male percentile.
- The impact analysis results we can infer that the total deformation in Chromoly (AISI 4130) has less deformation than ERW 2
- Total deformation and equivalent stress in Chromoly (AISI 4130) is less than ERW 2 and also within the yield strength, so the design is safe.
- Natural frequency for both the variants has been found.

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