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Design and Analysis of FSAE Chassis

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Abstract:- The design and analysis of a Formula Student (FSAE) chassis is crucial in ensuring the performance and safety of the vehicle in high-stress racing conditions. This project focuses oncreating an optimised chassis design using CATIA and ANSYS to ensure structural integrity, safety, and performance efficiency. A space frame chassis design was chosen for its balance between light weight and torsional rigidity, which is essential for maintaining vehicle handling and control. The primary analysis includes evaluating the chassis's ability to absorb energy from various loading conditions, such as frontal, side, and rear impacts, and torsional stresses during dynamic driving. Material selection plays a key role, with AISI 4130 chromoly steel chosen over structural steel for its strength-to-weight ratio. The study also integrates Finite Element Analysis (FEA) to assess stress distribution and optimize the design for both strength and weight efficiency. The final chassis design is intended to meet the FSAE competition's stringent safety and performance criteria while maintaining a low overall vehicle mass for improved acceleration and handling. The project further investigates modifications to increase torsional rigidity and optimize frame weight, incorporating both static and dynamic loading scenarios. The results of this project provide critical insights into improving FSAE chassis designs through a combination of simulation, analysis, and real-world testing.

I. INTRODUCTION

One of the most prestigious events for engineering students involves its Formula SAE competition to challenges them to design, analyze, and build a small, high-performance racecar. During the competition, students apply their skills in engineering, teamwork, and problem-solving abilities in a budget-constrained, time-constrained, and manufacturing-ability-constrained environment. A major aspect of FSAE vehicle design is the chassis. It serves as a structural foundation for all other vehicle components and thereby Supports everything.

The AISI 4130 chromoly steel is preferred most often since it provides a high strength-to-weight ratio. This is very important in racing applications wherein each ounce saved is crucial. This steel is also well suited for a racing chassis due to its ability to withstand extreme stresses without adding some unnecessary weight. Its strength and resistance to fatigue make it ideal for FSAE vehicles. However, such costs and accessibility should also be taken into consideration as teams usually have a limited budget; in addition to selecting the materials, the whole process is bound by design principles to optimize the overall geometry of the frame to ensure it will be able to absorb and distribute the loads of thevehicle while performing dynamic operations.

The second most important stage in chassis design is the generation of the 3D model. In thisproject, CATIA is adopted to model the chassis structure. CATIA is a very powerful tool thatallows for precise 3D modelling, making engineers visualise the structure in a world ofpossibility and perform virtual testing before building the physical frame.This makes an error very costly in the manufacturing process andallows the design to be optimized as early as possible. The 3D model is put through a lot ofsimulations that will validate how the chassis will perform in the real world. The mostimportant of these analyses is the Finite Element Analysis - which simulates the vehicle'sresponse to a race, of different forces and stresses.

FEA, run on thesystem ANSYS, would simulate how stress within the chassis would develop, deform, and fail when subjected to torsional forces, bending moments, or impacts.

This would consequently provide critical information about how well a chassis would perform when. Optimization tools such as topology optimization can be applied either by integration in CAD software like CATIA, and material removal from design with no effect on structural integrity or as a separate study, analyzing the global weight distribution of the car. Poorly balanced vehicles negatively affect handling and overall performance. This can be achieved by keeping the centre of gravity lowand ensuring weight is evenly distributed around thechassis for better cornering and stability of the vehicle.

Ultimately, this project aims to design a chassis that meets the standard and competitive criteria of the FSAE.

Competition while also providing informative findings in the process of designing high-performance race car structures. Utilizing advanced design tools and simulations combined with optimization techniques, this project aims to push FSAE boundary limitations to develop concepts that could make race cars faster,safer, and more efficient.

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II. OBJECTIVES

A. Material Selection and Comparison

To evaluate and compare the mechanical properties of AISI 4130 chromoly steel andstructural steel, focusing on tensile strength, yield strength, fatigue resistance, and weight-to-strength ratios. The goal is to determine the more suitable material for FSAE chassis design, considering both performance and manufacturability.

B. Frontal Impact Simulation

To conduct frontal impact simulations in ANSYS to assess the crashworthiness of both AISI 4130 chromoly steel and structural steel. The analysis will focus on the deformation, energy absorption, and safety performance of the chassis during a frontal collision, comparing the two materials' ability to protect the driver while minimizing damage to the vehicle.

C. Impact Simulation (Side and Rear)

To perform side and rear impact simulations in ANSYS to analyze the structural integrity and performance of the chassis under impact conditions from different angles. This will help assess how each material behaves under dynamic impact forces and identify the material offering the best balance of strength, rigidity, and safety.

D. Vibration Analysis

To simulate the chassis under dynamic loads and vibrations to determine how both materials respond to high-frequency vibrations typically encountered in high-speed racing conditions. The objective is to analyze the vibrational characteristics such as natural frequencies, damping ratios, and resonance effects for both AISI 4130 and structural steel to ensure chassis stability and performance during race events.

➢ *Implementation*

- Material Selection and Preparation: The project begins with the selection of materials — AISI 4130 chromoly steel and structural steel. Key properties such as yield strength, tensile strength, and modulus of elasticity are considered for each material. This comparison helps establish which material is better suited for the chassis design based on structural and safety requirements.
- Chassis Design in CAD: The chassis is designed using CAD software like CATIA or SolidWorks, with considerations for mounting points, safety features, and space for engine andsuspension components. Once the design is finalized, it is exported to a compatible format forANSYS simulations.
- Pre-Simulation Setup in ANSYS: The CAD model is imported into ANSYS, where materialsare assigned to the chassis components. Boundary conditions, load applications, and mesh generation are set up for accurate simulations. This step is crucial for ensuring that the physical behaviour of the materials is accurately represented in the simulations.
- Impact Simulation (Frontal, Side, and Rear): Frontal, side and rear impact simulations are conducted to analyze the chassis's energy absorption and deformation behaviour under crash conditions. The results from these simulations help determine which material performs better in terms of safety and structural integrity.
- Vibration Analysis: Dynamic forces and vibrations during racing are simulated to assess thechassis's stability. Modal and damping analyses are performed to ensure that neither material causes the chassis to resonate at critical frequencies, which could lead to instability or structural failure.

III. DESIGN METHODOLOGY

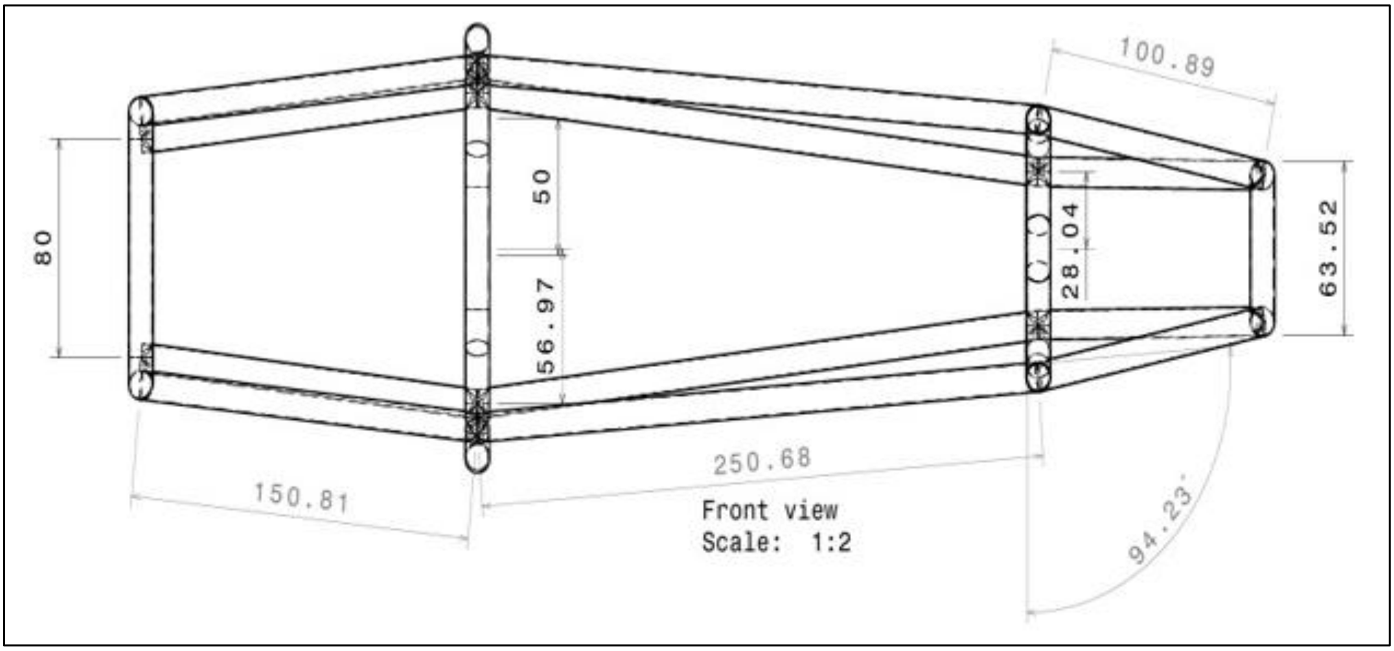

Fig 1: Front View

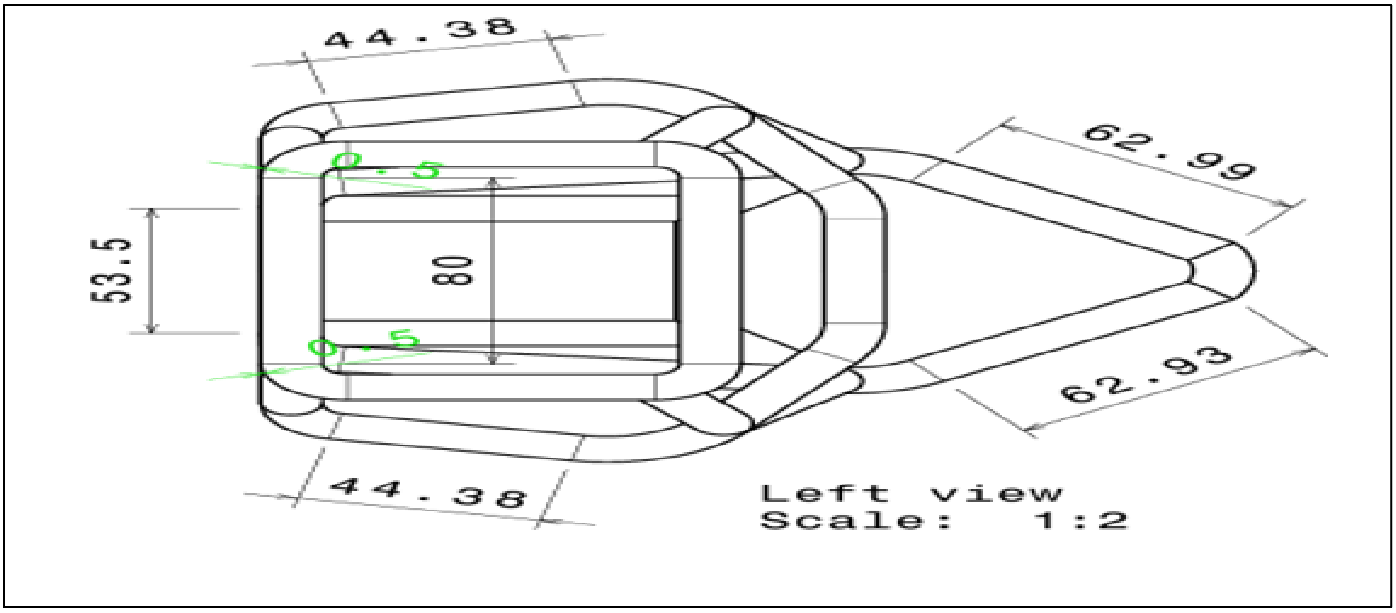

Fig 2: Left View

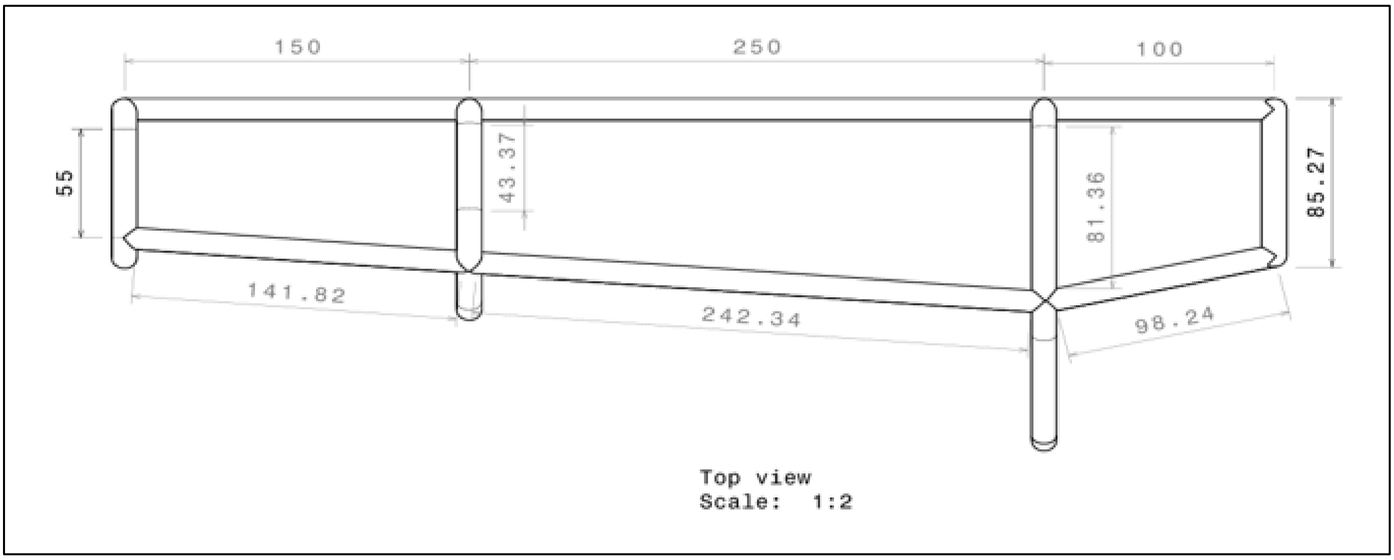

Fig 3: Top View

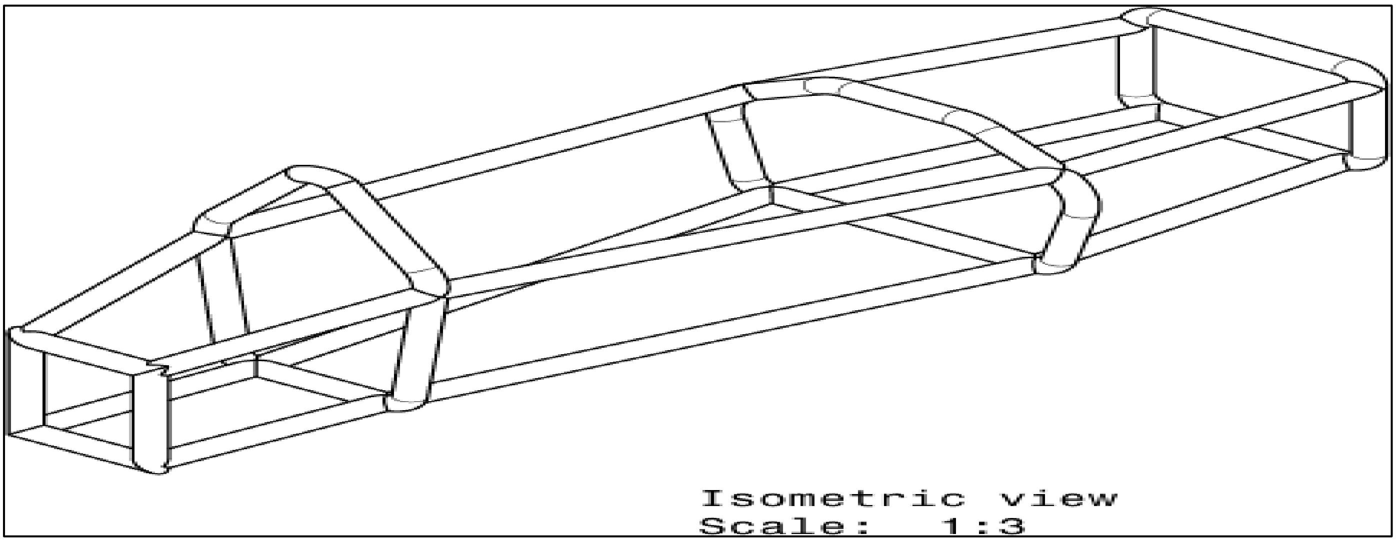

Fig 4: Isometric View

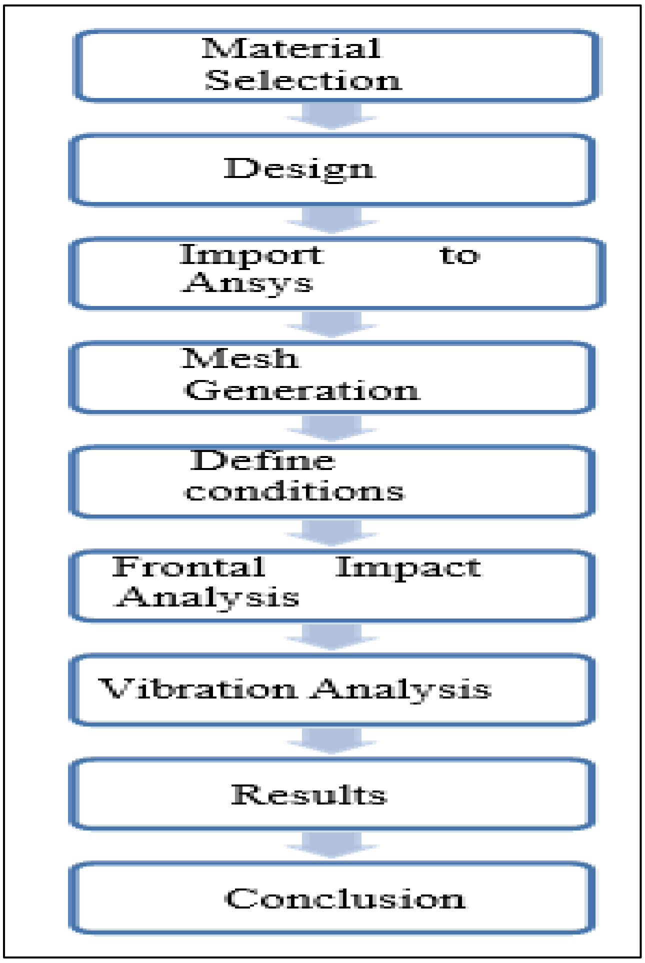

Fig 5: Flow Chart

The design methodology for the FSAE chassis follows a systematic approach to ensure the creation of a safe, lightweight, and high-performance chassis. The methodology involves thefollowing key steps:

- **Material Selection**: The first step involves choosing the appropriate materials for thechassis. Two materials, AISI 4130 chromoly steel and structural steel, are considered due to their differing mechanical properties, such as yield strength, tensile strength, and fatigue resistance. Material selection impacts the overall performance, weight, and safety of the chassis.
- **Preliminary Design & CAD Modeling**: After selecting the material, the chassis is designed using CAD software such as CATIA or SolidWorks. The design takes into account the overall dimensions, suspension mount locations, driver safety, and spacefor other components like the engine and transmission. A preliminary design is generated that is further refined in subsequent steps.
- **Design in CATIA**: The detailed design of the chassis is done in CATIA, where structural integrity, mounting points, and ergonomic considerations are taken into account. CATIA's advanced tools allow for the creation of a precise 3D model that ensures the chassis will fit within the vehicle's design specifications.
- **Simulation Setup in ANSYS**: The CAD model of the chassis is imported into ANSYS for various simulations, including impact, vibration, and stress analysis. The material properties (from Step 1) are assigned to the model, and boundary conditionsand loads are applied to simulate real-world conditions.
- **Impact Analysis**: The chassis undergoes impact simulations such as frontal impact testing, simulating potential crash scenarios. The objective is to analyze how the chassis absorbs and dissipates energy, which is crucial for ensuring driver safety. Theresults from the simulation help in evaluating the effectiveness of the chosen material (AISI 4130 vs structural steel).
- **Vibration Analysis**: Vibration analysis is performed to study the chassis' dynamic behaviour under racing conditions. Modal and damping analyses are conducted to determine the natural frequencies and damping characteristics. This helps identify any critical frequencies that could lead to resonance and potentially cause failure during high-speed racing.

IV. RESULT

The structural integrity of the FSAE chassis was analyzed under three critical conditions: frontal load, impact, and vibrations. The analysis was performed using ANSYS, a powerfulsimulation tool that allowed for a detailed evaluation of stress, deformation, and natural frequencies. Two materials were compared: AISI 4130 chromoly steel and structural steel.

A. Analysis of FSAE Chassis in ANSYS

The structural integrity of the FSAE chassis was analyzed under three critical conditions: frontal load, impact, and vibrations. The analysis was performed using ANSYS, a powerfulsimulation tool that allowed for a detailed evaluation of stress, deformation, and natural frequencies. Two materials were compared: AISI 4130 chromoly steel and structural steel.

B. Frontal Load Analysis

The frontal load analysis simulates a force applied to the front crash structure of the chassisto evaluate its strength and deformation under a standard frontal impact scenario.

➢ *Steps Involved:*

- *Import the CAD Model:*

✓ The chassis model created in CATIA was imported into ANSYS.

- *Define Material Properties:*

✓ Material properties for AISI 4130 chromoly steel and structural steel were defined in ANSYS, including density, Young’s modulus, and yield strength.

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- *Apply Boundary Conditions:*

✓ Fixed supports were applied at the suspension mounting points to replicate theconstraints of the vehicle's chassis.
✓ A frontal load of 2.5 kN was applied to the front of the chassis to simulate impact forces.

- *Meshing:*

✓ A fine mesh was created, focusing on areas such as suspension mounts and critical jointsto ensure accuracy.

- *Run the Simulation:*

✓ Static structural analysis was run to determine the maximum Von-Mises stress and totaldeformation under the applied load.

➢ *Structural Steel*

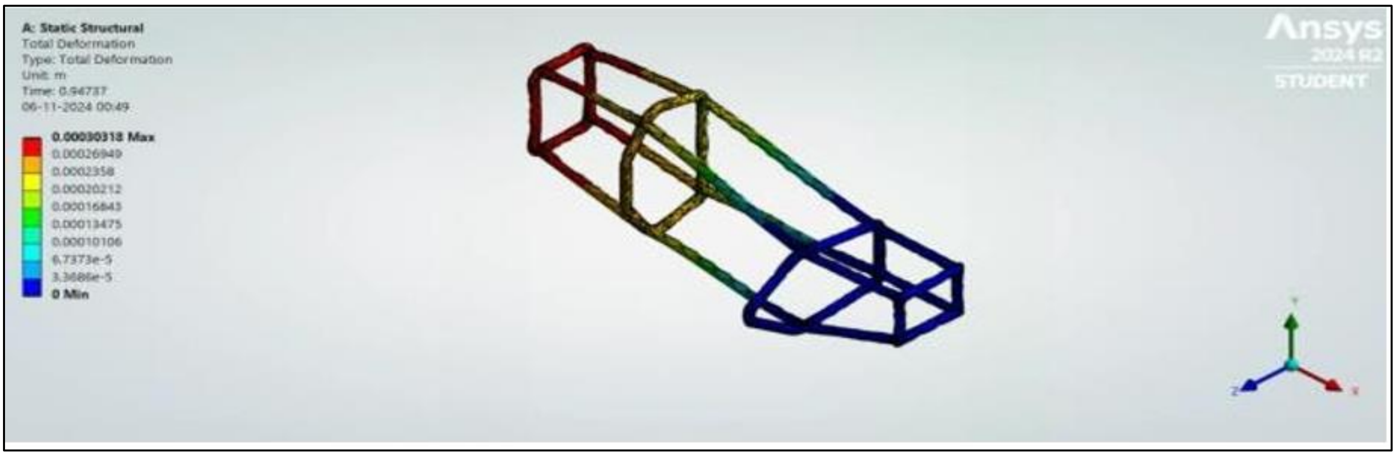

Fig 6: Total Deformation

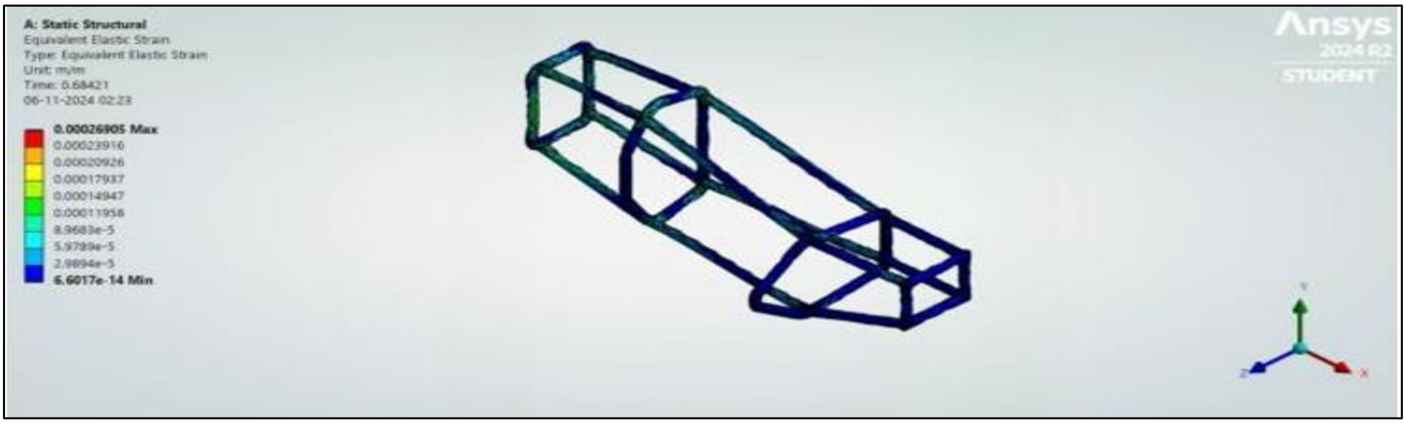

Fig 7: Equivalent Elastic Strain

➢ *AISI 4130*

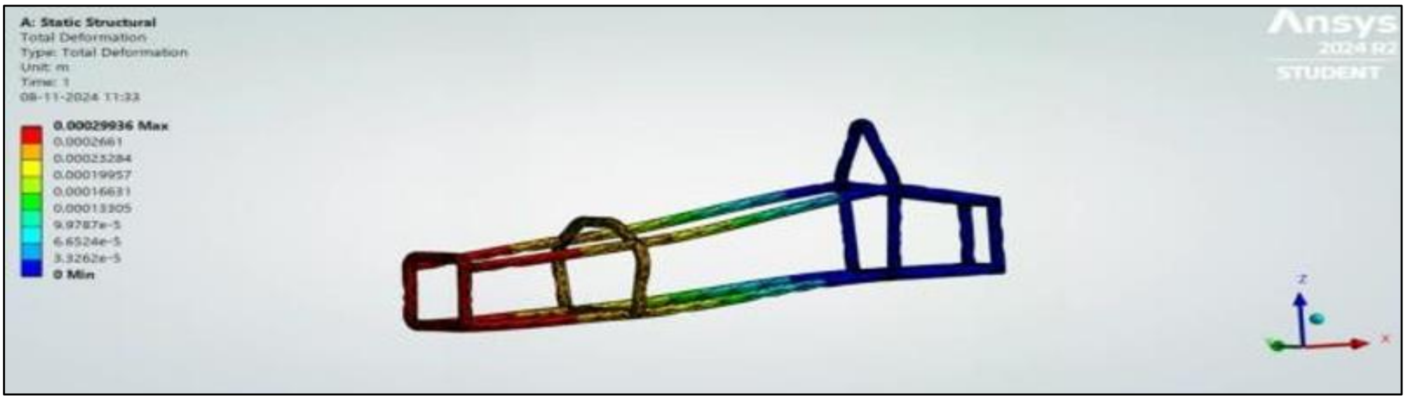

Fig 8: Total Deformation

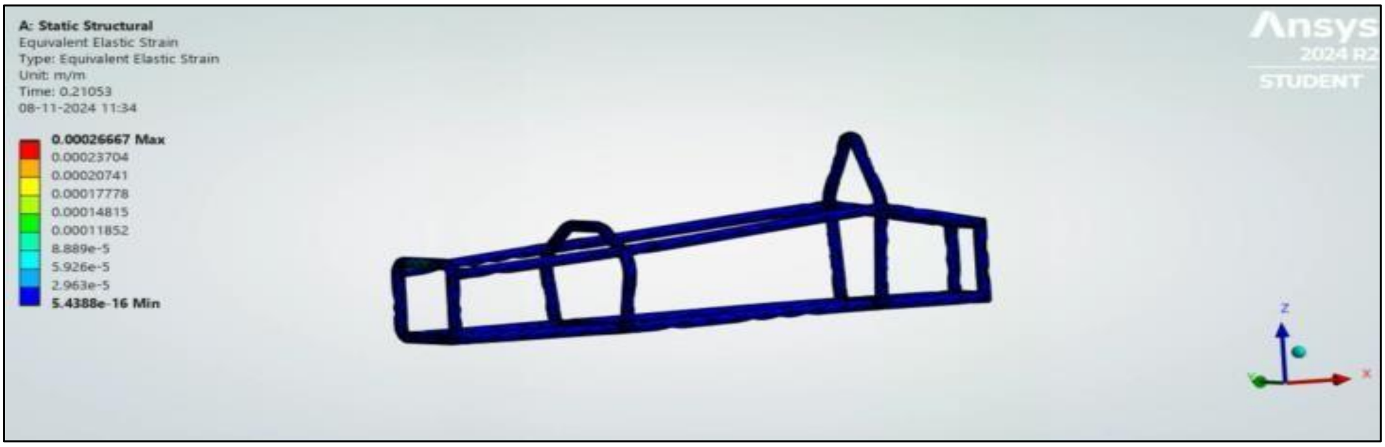

Fig 9: Equivalent Elastic Strain

C. Impact Analysis

The impact analysis simulates a collision scenario to assess how the chassis behaves duringa crash. This test is crucial to ensuring the chassis can withstand high-impact forces without failure.

➢ *Steps Involved:*

- *Prepare Model for Impact Simulation:*

✓ The chassis model was set up for an explicit dynamic analysis in ANSYS.

- *Define Material Properties:*

✓ As with the frontal load analysis, material properties for AISI 4130 chromoly steel and structural steel were defined.

- *Apply Boundary Conditions:*

✓ The chassis was constrained at mounting points.

- *Meshing and Simulation Setup:*

✓ A finer mesh was applied to areas expected to experience the highest stress duringimpact.

✓ The simulation was set to run using explicit dynamic analysis to simulate the crashscenario.

- *Run the Simulation:*

✓ The simulation was run to calculate the stress distribution and total deformation underimpact conditions.

➢ *Structural Steel*

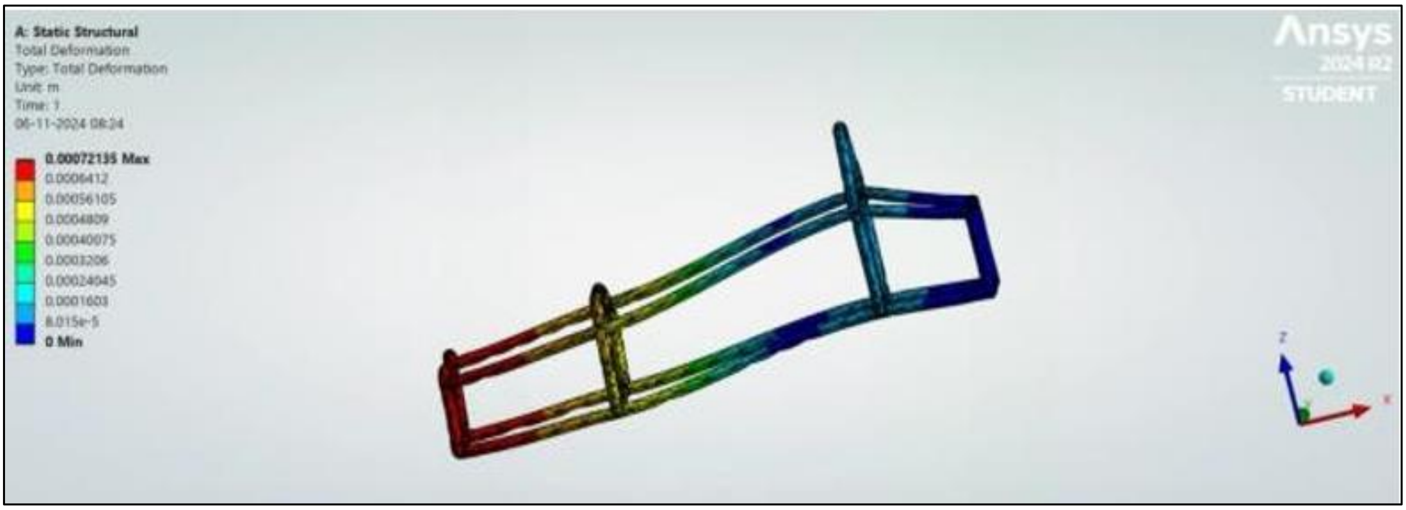

Fig 10: Total Deformation

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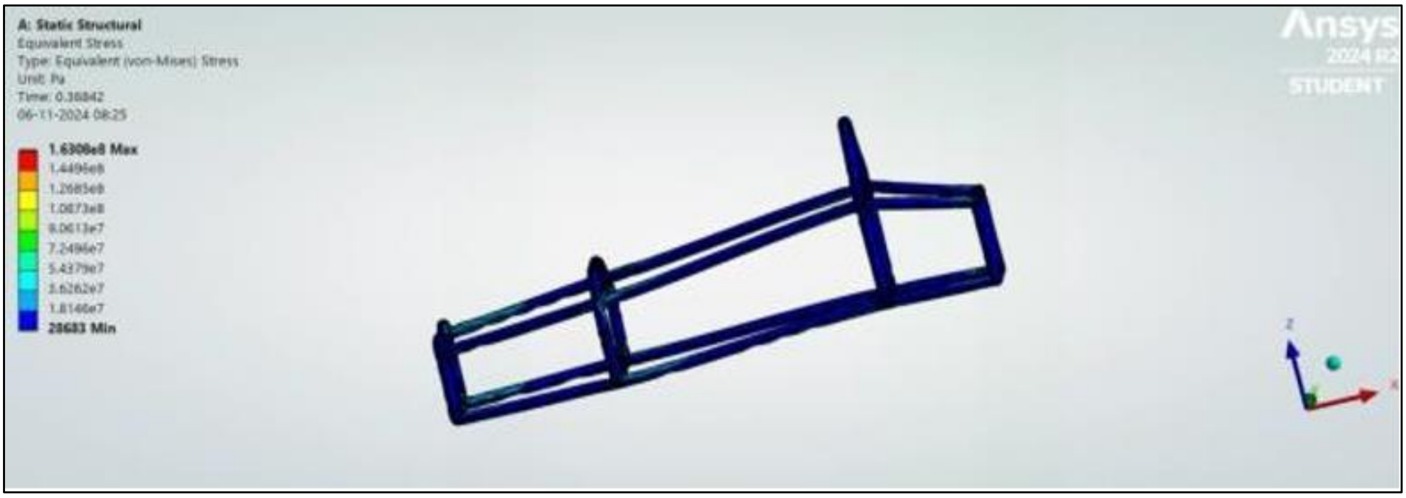


Fig 11: Equivalent Stress

- *AISI 4130*

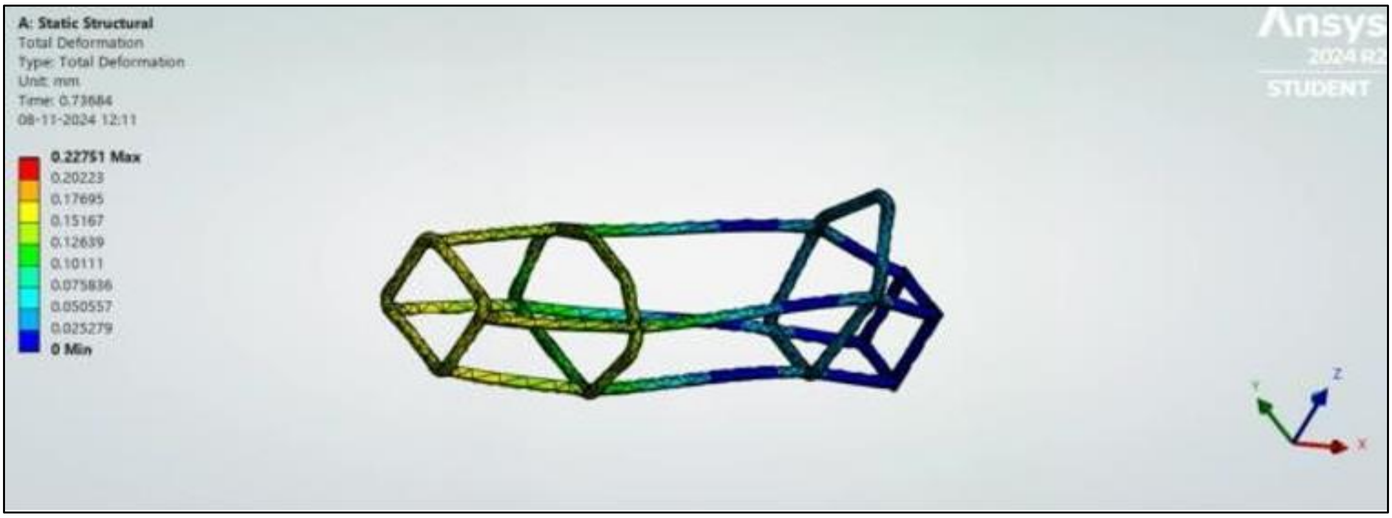


Fig 12: Total Deformation

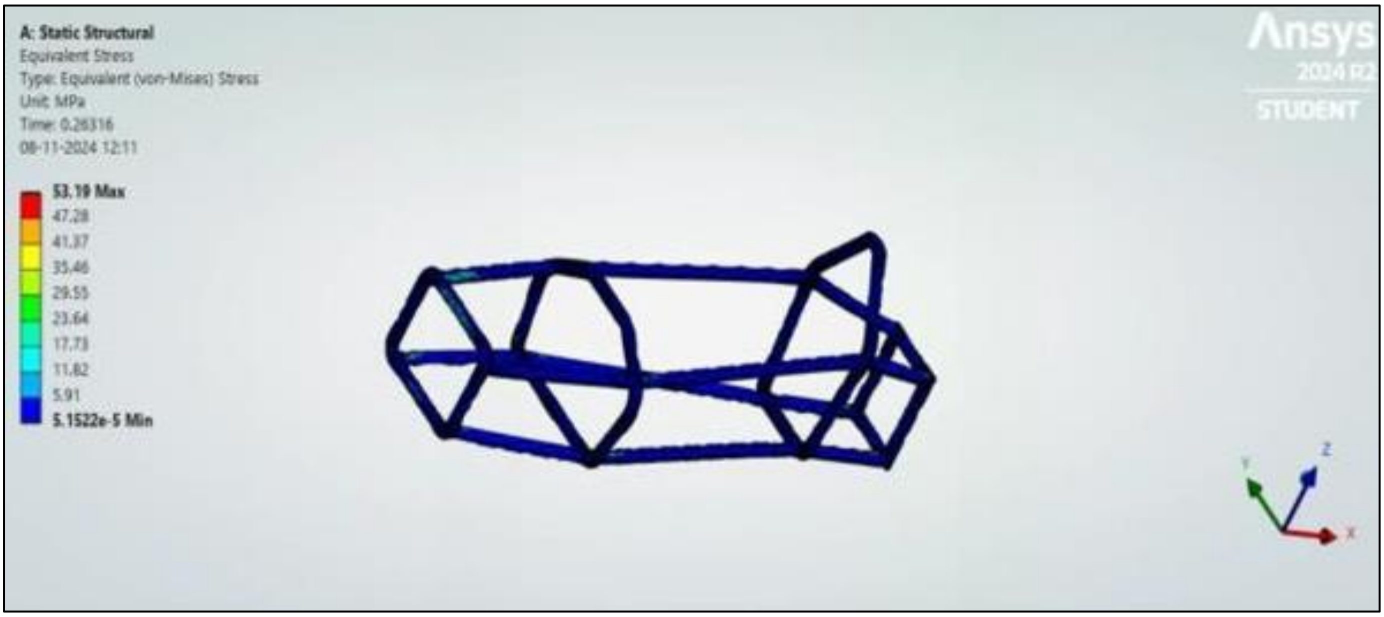


Fig 13: Equivalent Stress

D. Vibration (Modal) Analysis

The vibration analysis was conducted to determine the natural frequencies of the chassis. This is essential for ensuring that the chassis does not resonate with operational vibrations, which could lead to failure or performance degradation.

➢ *Steps Involved:*

- *Prepare Model for Modal Analysis:*

✓ The chassis model was set up in ANSYS for modal analysis to determine the naturalfrequencies.

- *Define Material Properties:*

✓ As with the other analyses, material properties for AISI 4130 chromoly steel andstructural steel were defined.

- *Apply Boundary Conditions:*

✓ The chassis was constrained at the suspension mounting points.

- *Meshing:*

✓ A fine mesh was applied to capture the modal behaviour accurately.

- *Run the Simulation:*

✓ Modal analysis was run to determine the natural frequencies of the chassis.

➢ *Structural Steel*

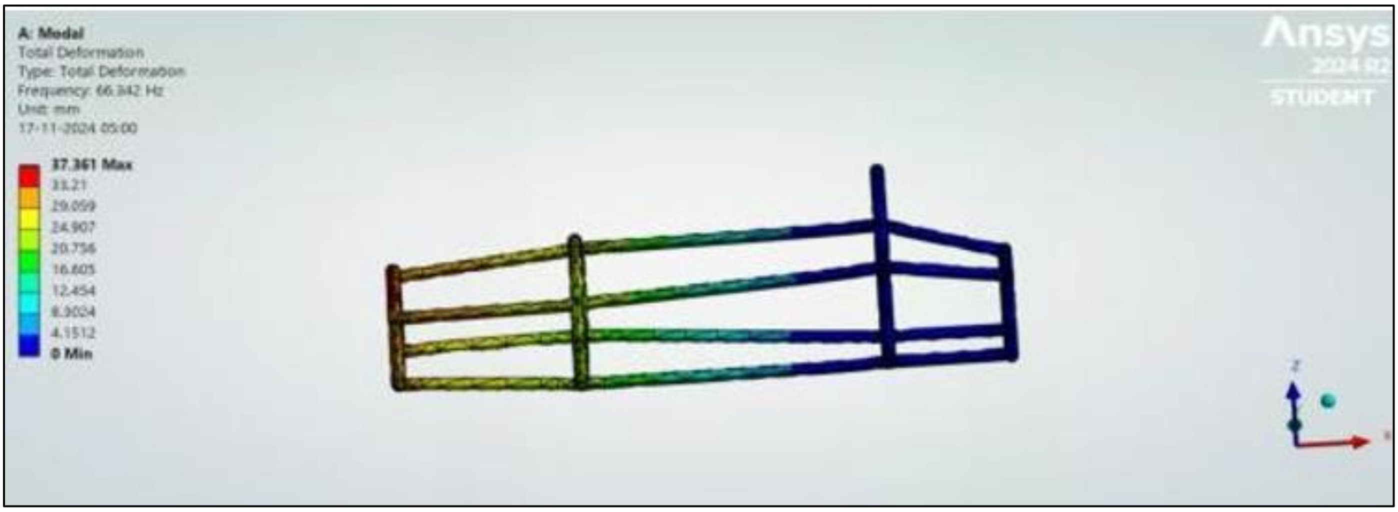
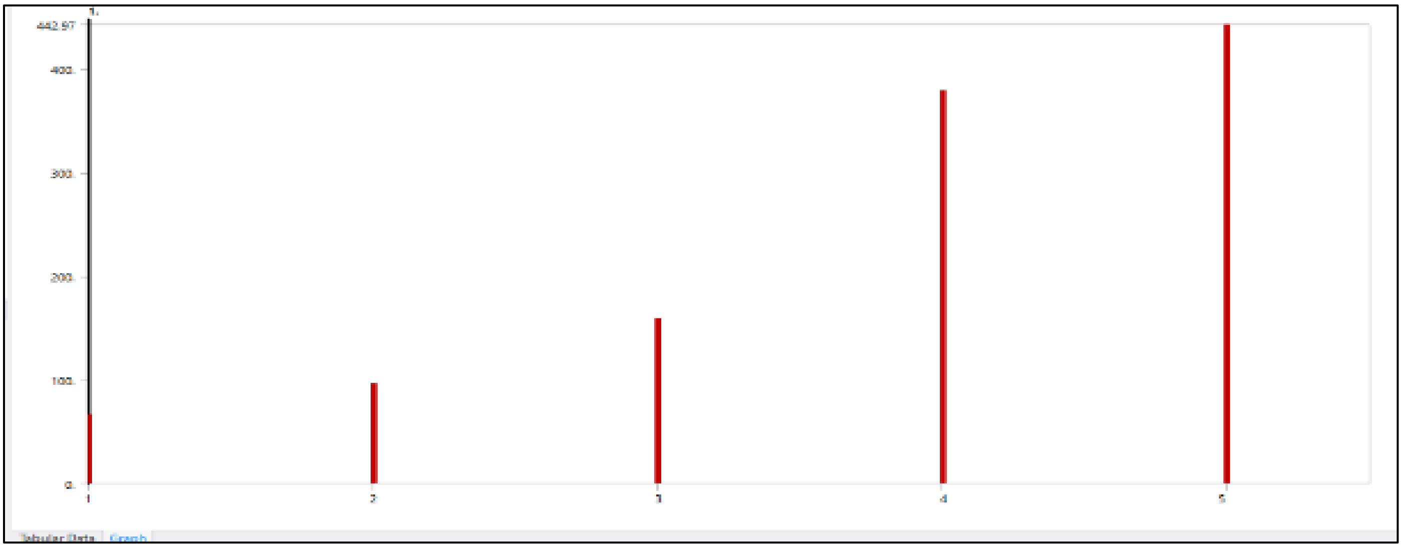


Fig 14: Total Deformation 1



Graph 1: Total Deformation 1

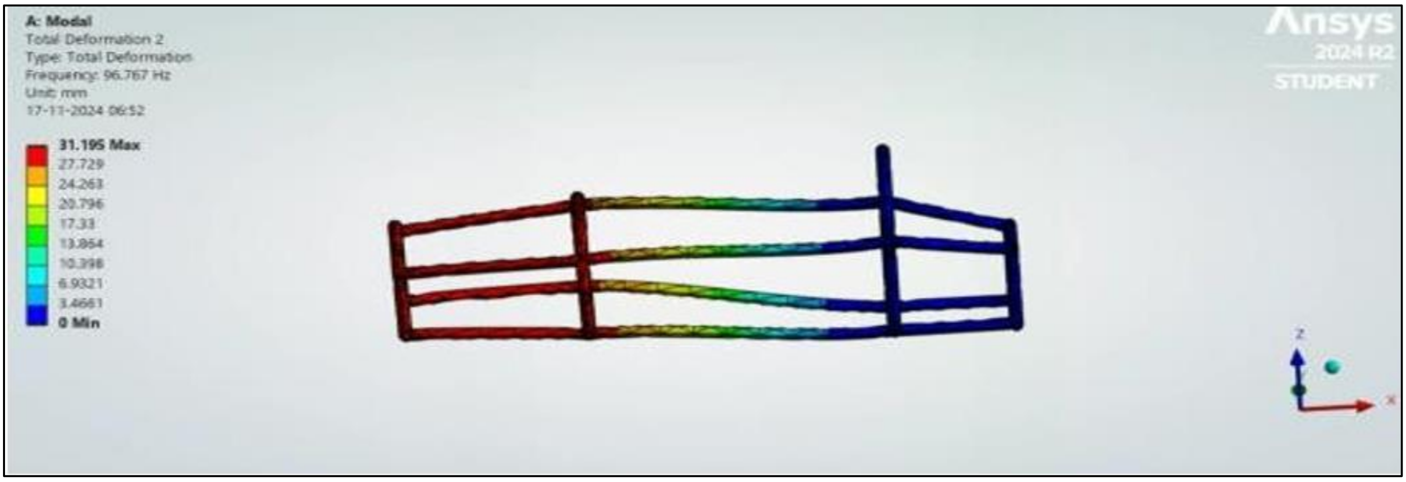
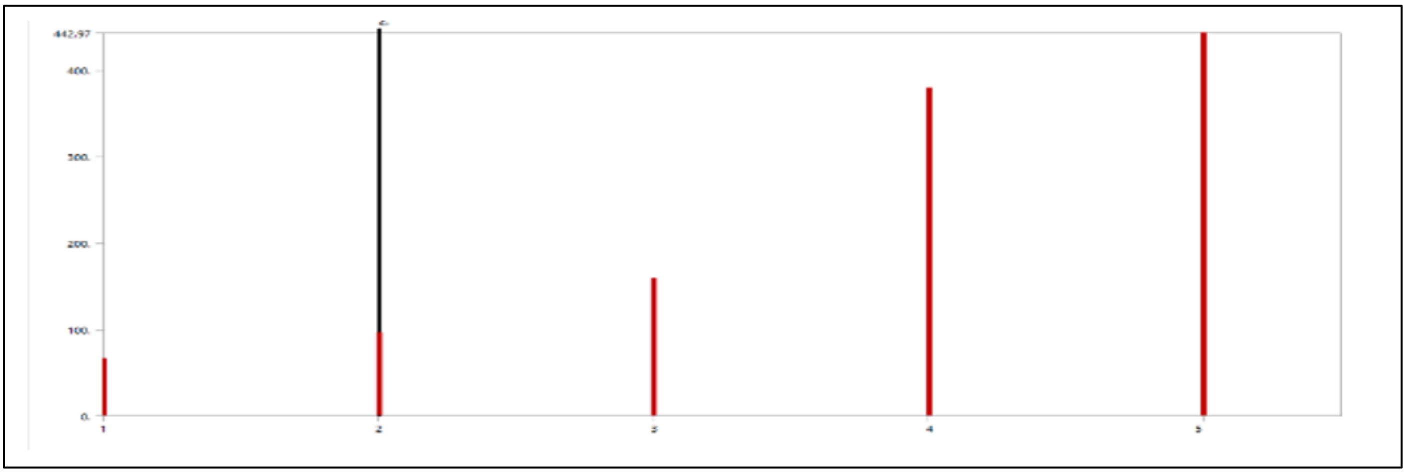
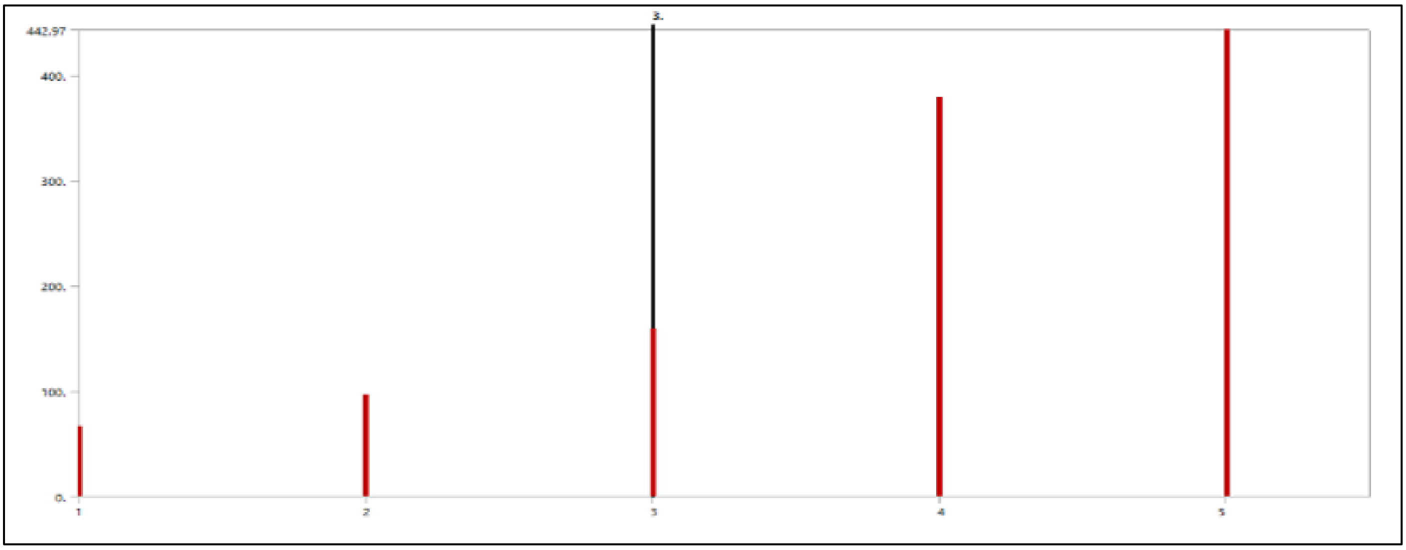


Fig 15: Total Deformation 2



Graph 2: Total Deformation 2

Fig 16: Total Deformation 3



Graph 3: Total Deformation 3

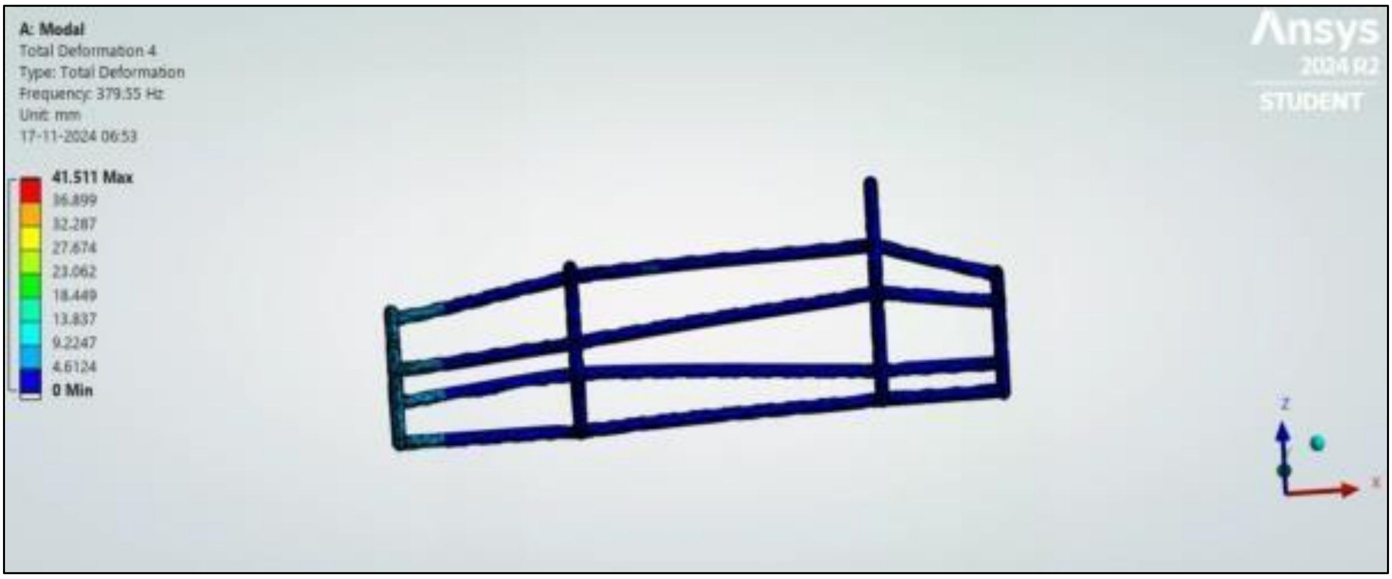
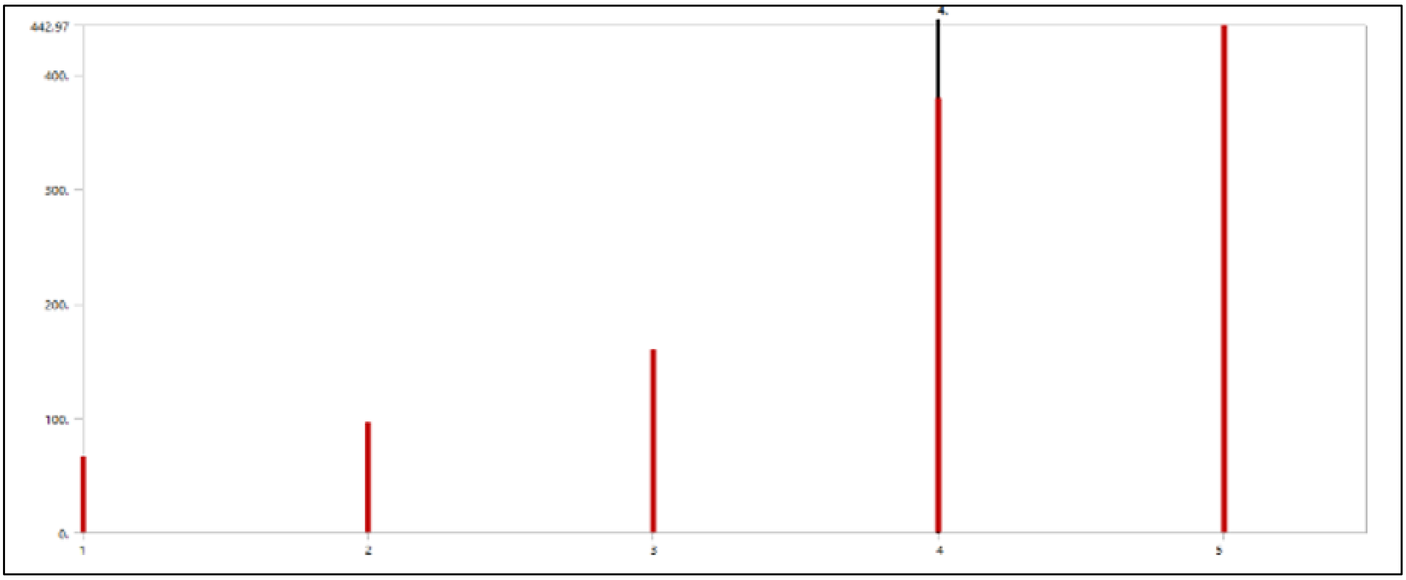


Fig 17: Total Deformation 4



Graph 4: Total Deformation 4

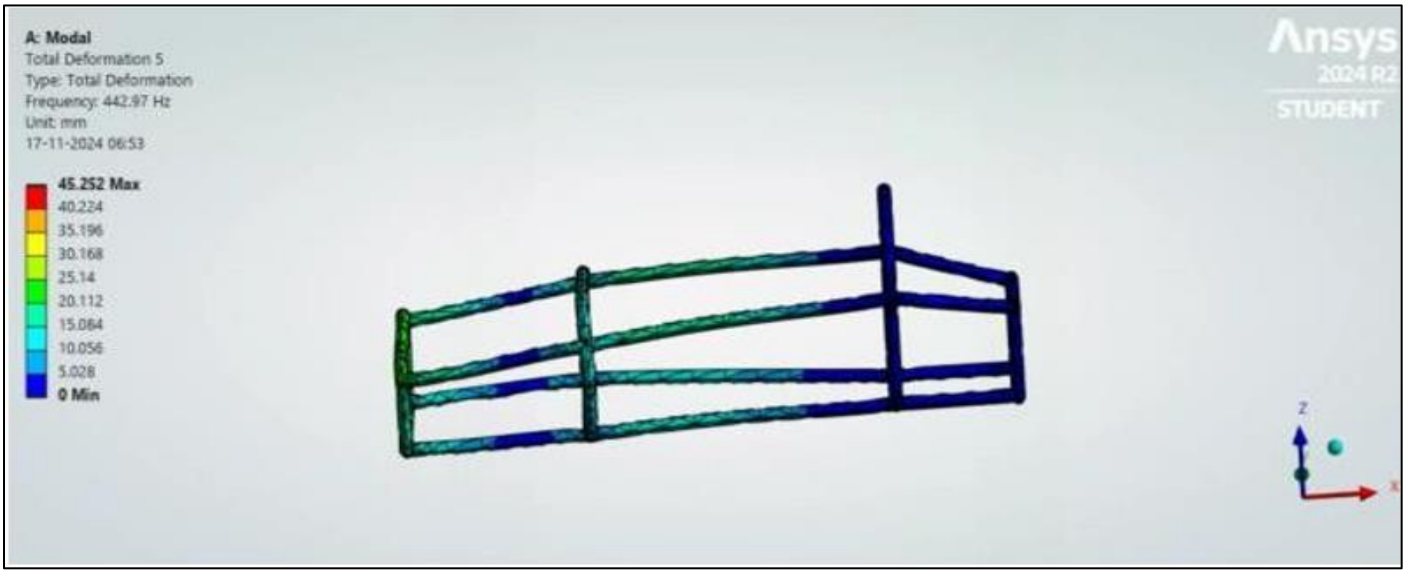
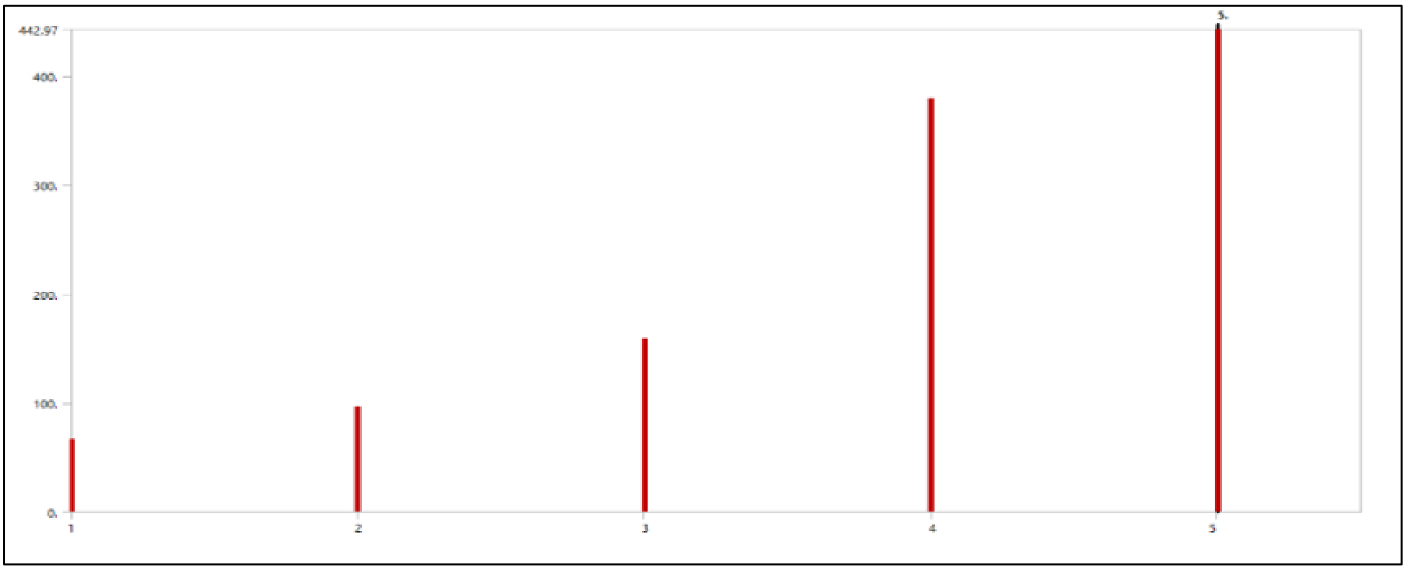


Fig 18: Total Deformation 5



Graph 5: Total Deformation 5

➢ *AISI 4130*

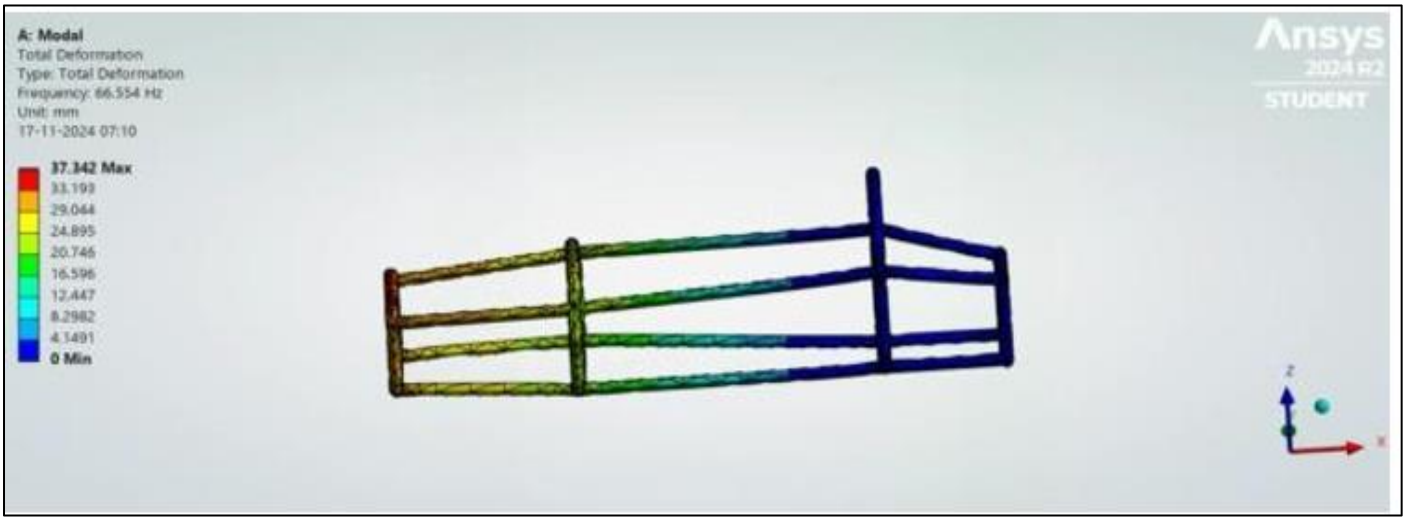
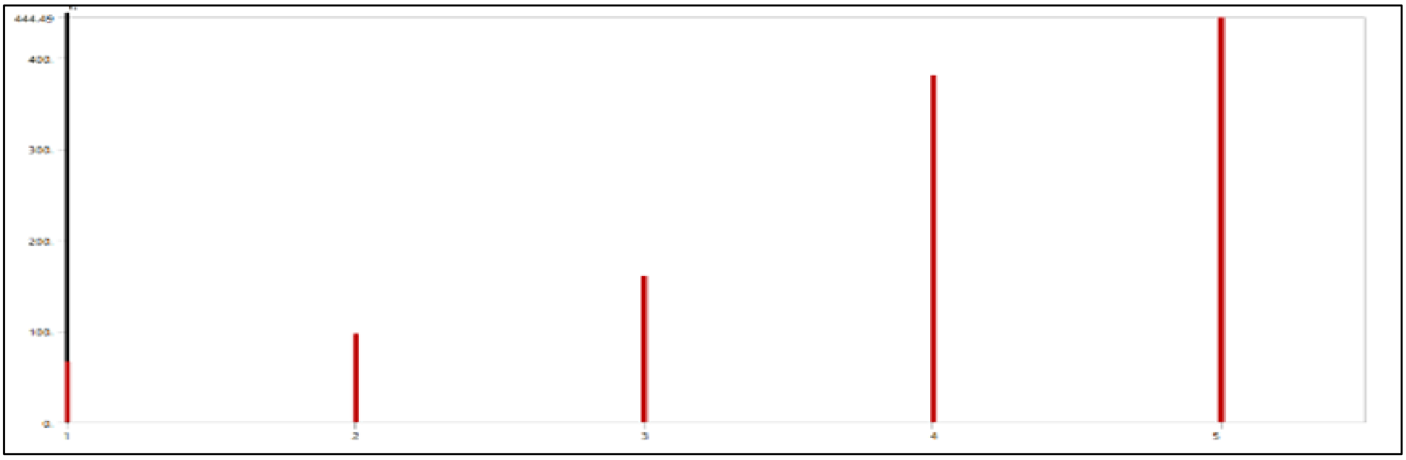


Fig 19: Total Deformation 1



Graph 6: Total Deformation

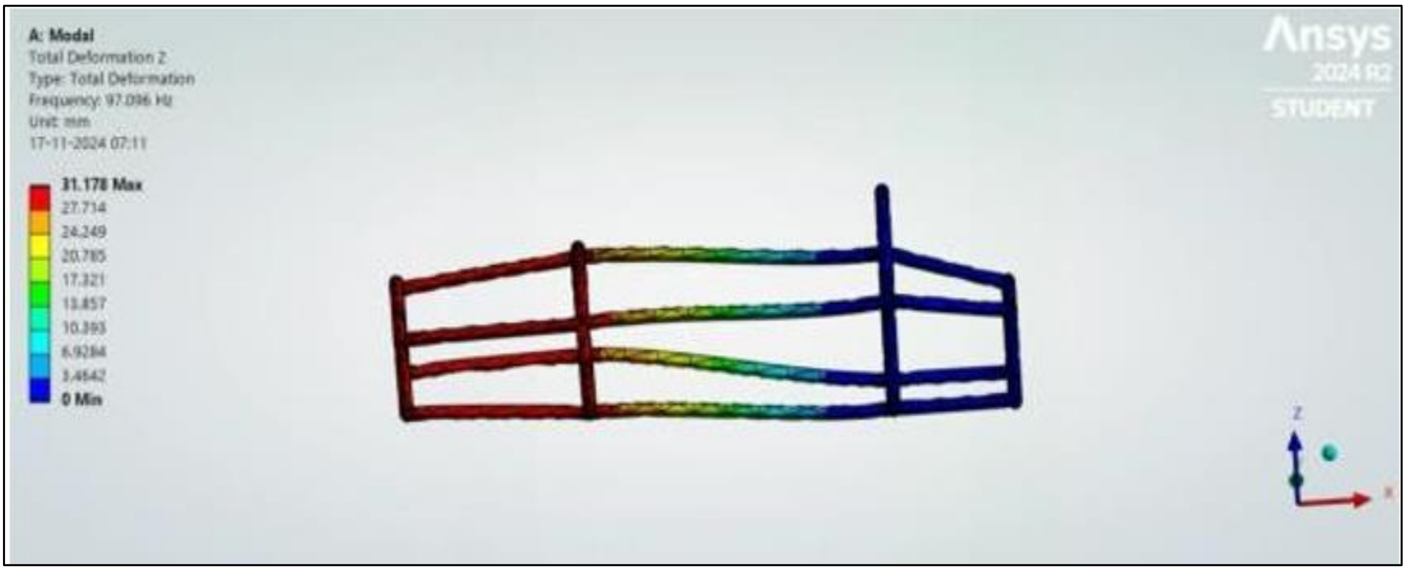
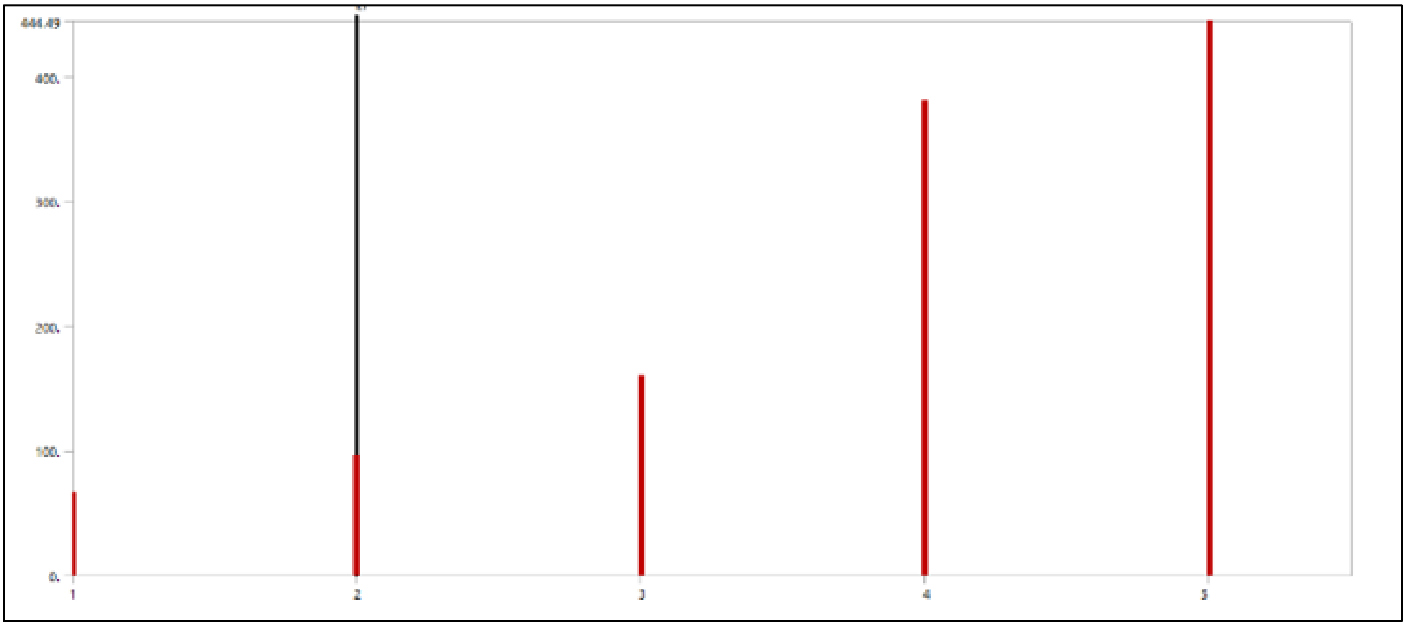


Fig 20: Total Deformation 2



Graph 7: Total Deformation 2

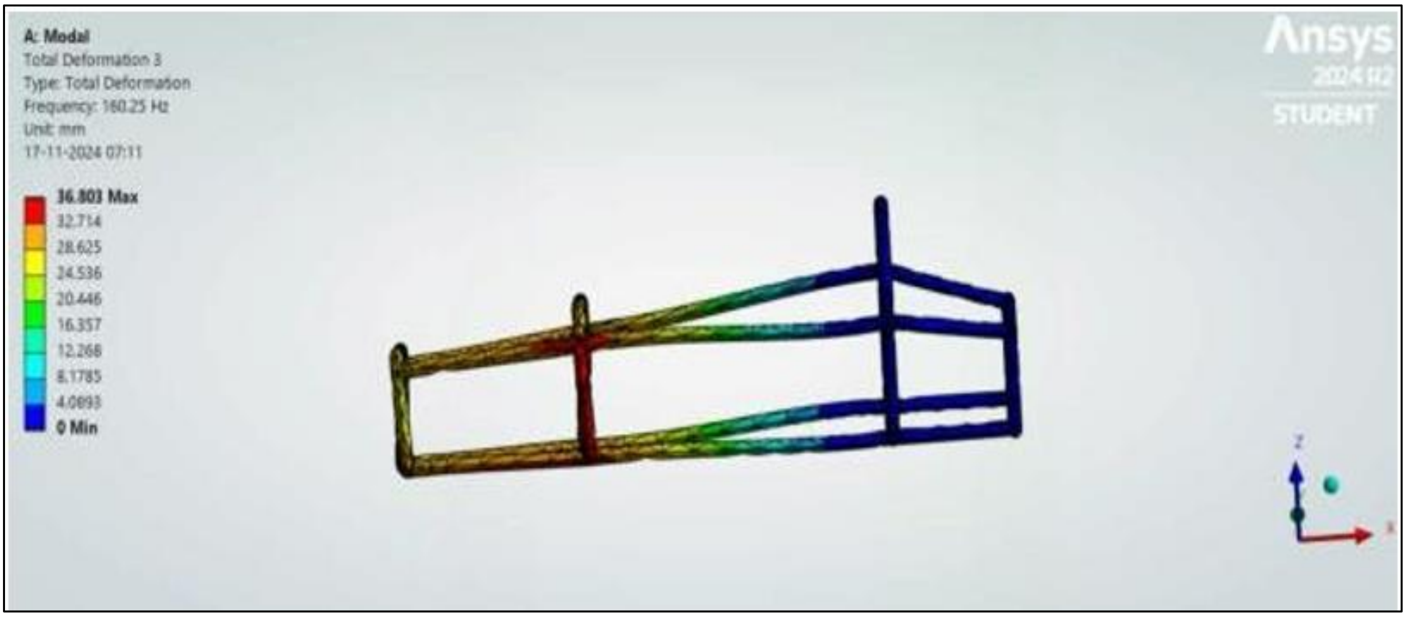
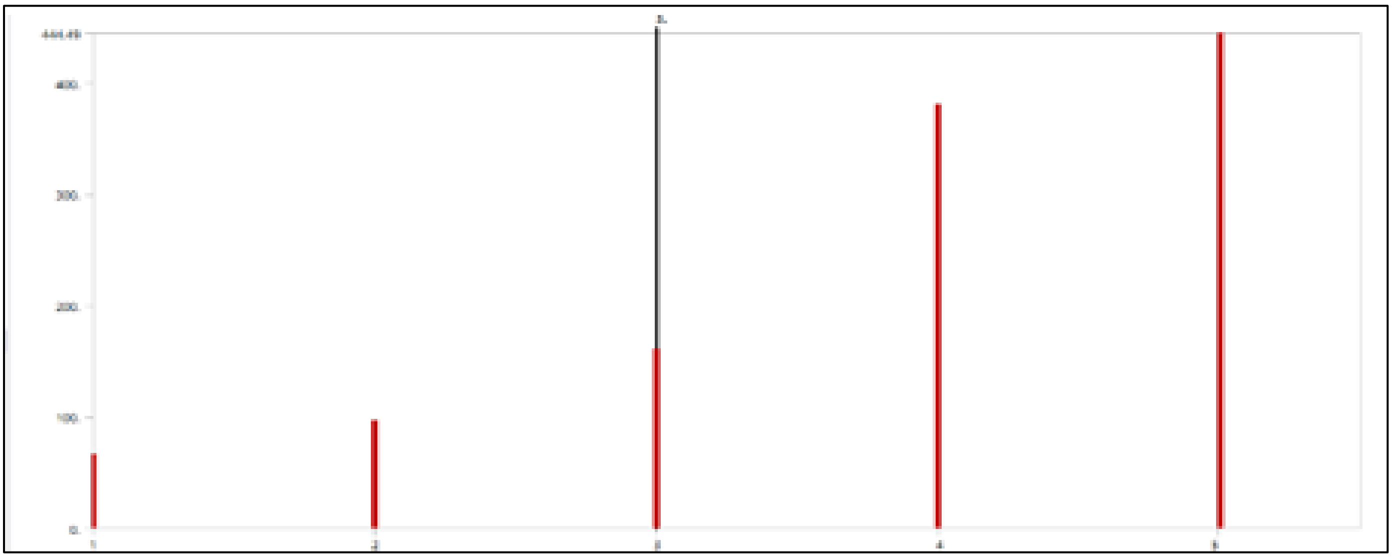


Fig 21: Total Deformation 3



Graph 8: Total Deformation 3

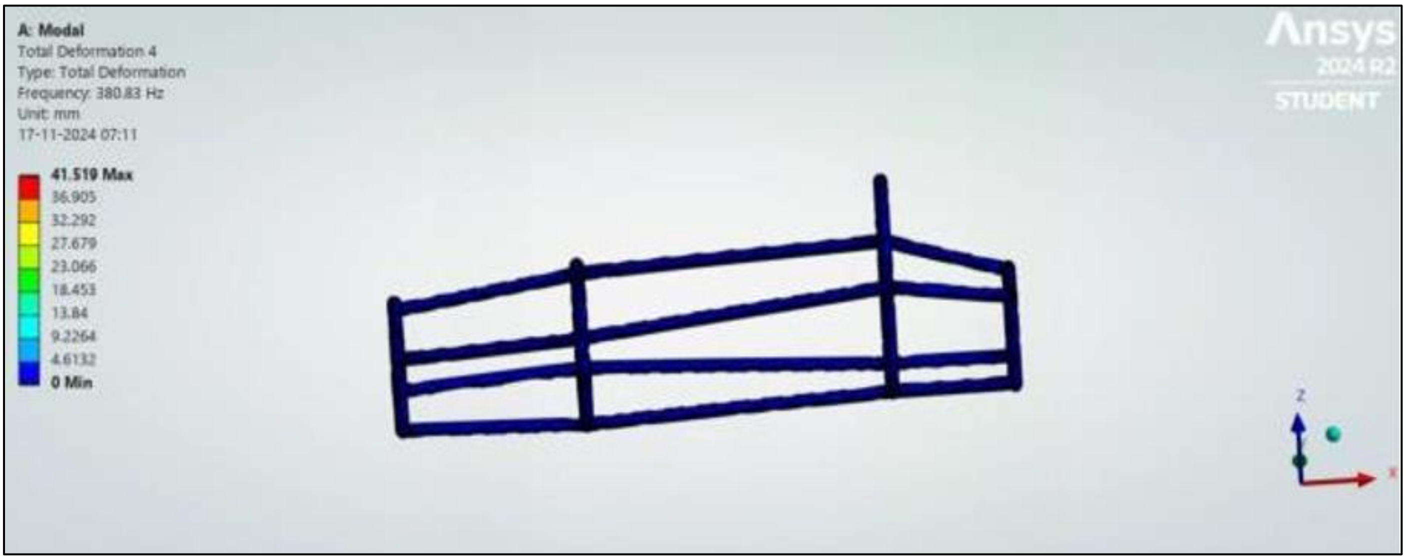
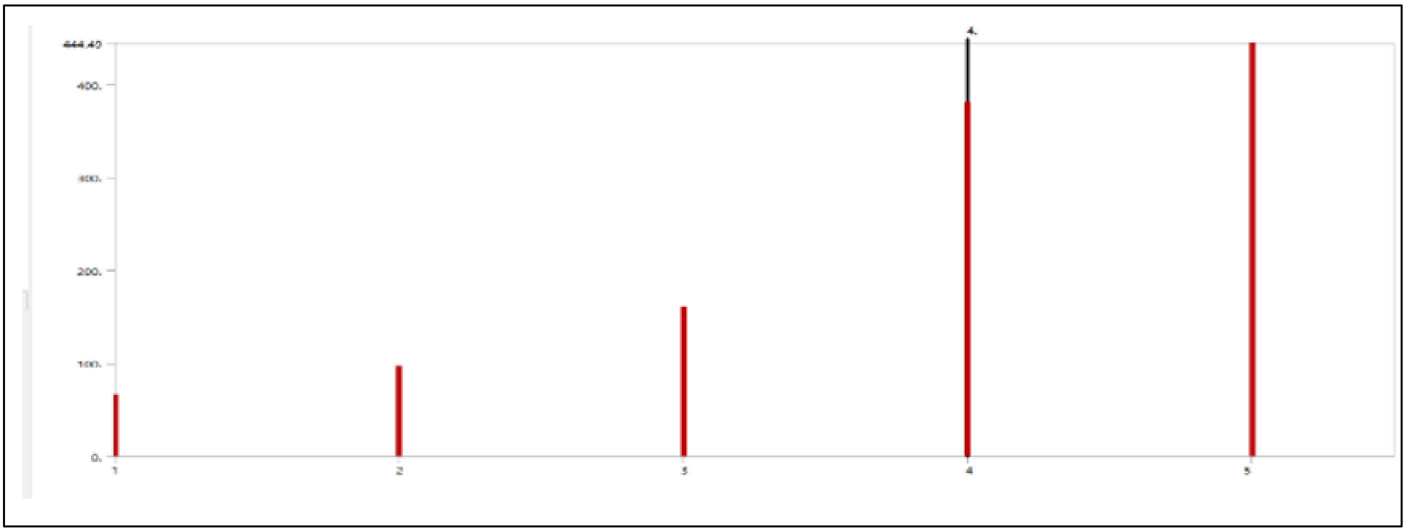


Fig 22: Total Deformation 4



Graph 9: Total Deformation 4

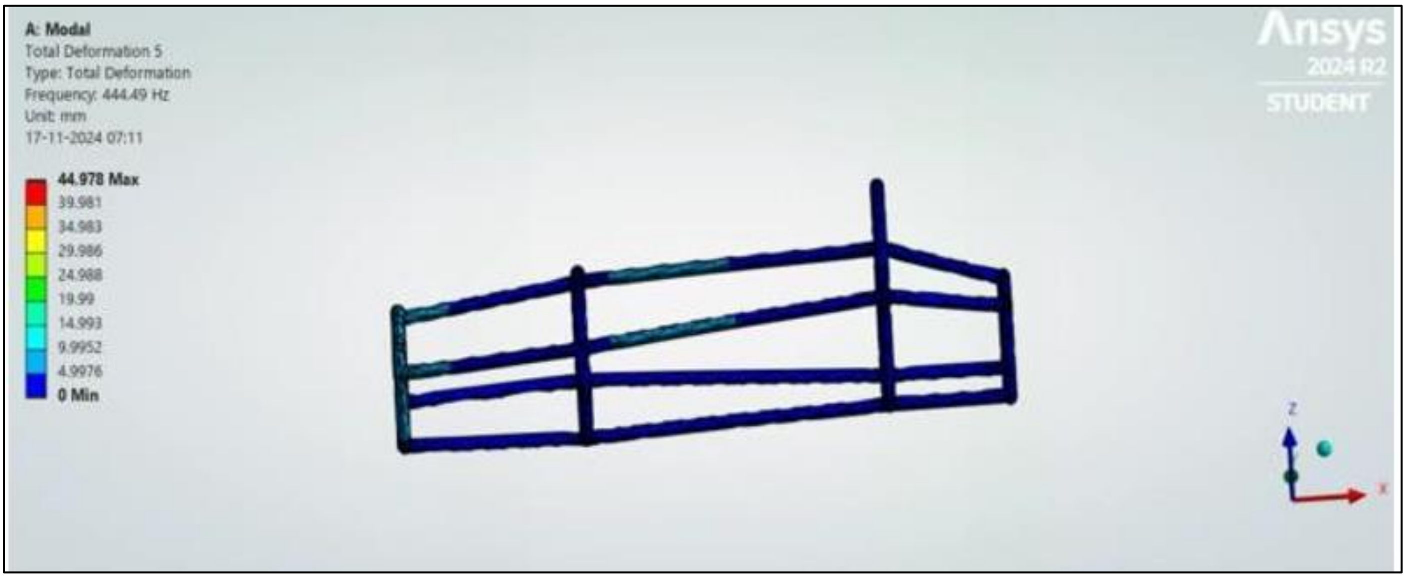
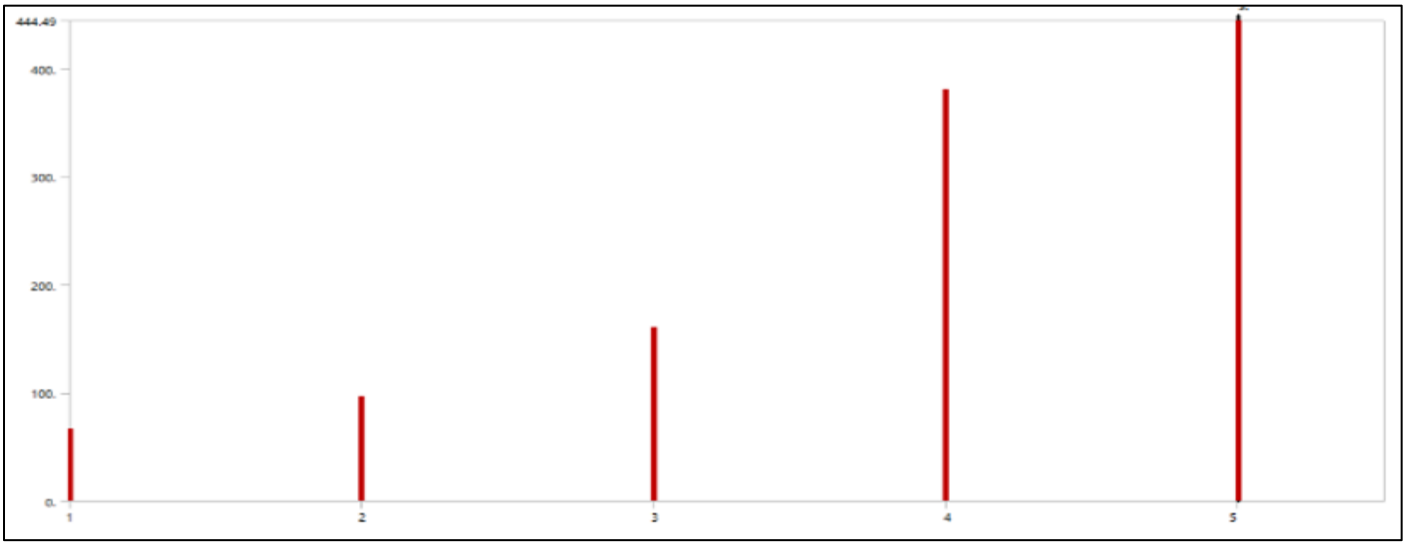


Fig 23: Total Deformation 5



Graph 10: Total Deformation 5

➢ *Results Summary of FSAE Chassis Design and Analysis*

- *Material Selection:*

✓ AISI 4130 Chromoly Steel demonstrated superior strength-to-weight ratio, lower deformation, and better fatigue resistance compared to structural steel.
✓ It ensured improved crashworthiness and energy absorption in frontal, side, and rear impact simulations.

- *Impact Analysis:*

✓ Frontal impact simulations showed lower Von-Mises stress and deformation for AISI 4130, ensuring driver safety during collisions.

- *Vibration Analysis:*

✓ AISI 4130 exhibited higher natural frequencies and better-damping characteristics, avoiding resonance under high-speed dynamic conditions.
✓ Modal analysis indicated enhanced stability and reduced risk of structural failure.

- *Weight Optimization:*

✓ Strategic use of AISI 4130, along with optimized chassis geometry, reduced overall weight while maintaining torsional rigidity.
✓ This balance improved vehicle handling and acceleration performance.

- *Safety and Performance:*

✓ Simulations validated minimal deflections and stress concentration at critical points.
✓ The final design met FSAE standards, ensuring competitive performance, safety, and manufacturability.

This study confirms the suitability of AISI 4130 chromoly steel for lightweight, high-performance FSAE chassis designs.

V. CONCLUSION

The optimized chassis design successfully achieves the critical objectives of increased torsional rigidity, weight reduction, and minimal deformation, ensuring the chassis performsat an optimal level. By utilizing chromoly steel AISI 4130, innovative structural designs, and comprehensive analysis techniques such as finite element analysis and dynamic testing,the chassis provides a robust backbone for the vehicle. This design not only enhances the

Overall performance and handling of the vehicle also ensure the safety of the driver by integrating essential protective features. The results demonstrate that the chassis experiences minimal deflections under race conditions, validating its effectiveness in real-world applications. Consequently, this research contributes valuable insights into chassis optimization, supporting the development of high-performance vehicles that excel in both safety and efficiency.

The design and analysis of the Formula SAE (FSAE) car chassis are pivotal steps in ensuringthe structural integrity, performance, and safety of the vehicle. Throughout this project, the design and analysis phases have been systematically carried out, leading to the developmentof an optimized and lightweight chassis. Below are the key findings and insights derived from the project:

A. *Structural Integrity and Material Selection:*

- The primary goal of the chassis design was to achieve an optimal strength-to-weight ratio, which is essential for competitive performance. AISI 4130 chromoly steel was selected as the chassis material due to its high strength and lightweight properties. The analysis of the AISI 4130 steel demonstrated excellent tensile and yield strength characteristics, which are crucial under dynamic loading conditions encountered in motorsport events.
- A comparison with structural steel highlighted the advantages of AISI 4130 in terms of weight savings while maintaining the required strength. Thisselection allowed for a chassis design that can withstand high-impact forces without compromising overall weight, making it suitable for the competitivenature of the FSAE event.

B. *Finite Element Analysis (FEA):*

- The Finite Element Analysis (FEA) was employed to evaluate the chassis under various loading conditions, such as vertical, lateral, and torsional forces. The analysis confirmed that the chassis design adheres to the required safety and performance standards, with minimal deformation and stress values within acceptable limits.
- Detailed simulations revealed critical points of stress and strain within the chassis, such as the attachment points for suspension and mounting points forvarious components. These findings allowed for targeted reinforcement, ensuring uniform strength distribution and enhancing overall performance.

C. *Weight Optimization:*

- One of the major design considerations was achieving a lightweight yet robust structure. By choosing AISI 4130 chromoly steel and performing targeted structural reinforcements, the final chassis design successfully achieved a favourable strength-to-weight ratio. This is vital for accelerating and handling during races.
- Weight reduction was achieved through strategic design choices, such as optimizing the number and placement of chassis members and minimizing the overall cross-sectional area while maintaining the necessary structural integrity.

D. *Manufacturability and Assembly:*

- The design was carefully considered to allow for ease of manufacturing and assembly. All parts were designed with manufacturability in mind, taking into account standard metalworking and welding techniques. This streamlined theconstruction process, making the chassis both efficient to build and maintainfor the competition season.

E. Simulation and Validation:

- Simulation results validated the design's performance under the expected loading conditions. This allowed for an accurate prediction of the chassis's behaviour, enabling quick iterations of design changes to optimize the final structure. The validation process also highlighted areas for potential improvement, leading to further refinements and enhanced structural performance.

F. Safety Considerations:

- Safety was a primary concern throughout the design process. The use of advanced materials, rigorous simulations, and targeted reinforcements were key to ensuring that the chassis could absorb impact forces without significant deformation. This contributes to the overall safety of the driver and improvesthe likelihood of survival in the event of an accident.

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