DESIGN AND ANALYSIS OF BICYCLE FRAME

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Abstract

Bicycles serve as an essential transportation solution for urban and rural populations, offering an economical and environmentally sustainable mobility option. As a zero-emission vehicle that promotes physical wellness, bicycles provide practical short-distance transit while also serving recreational purposes. The growing global demand for bicycles has driven manufacturers to optimize frame designs for enhanced load-bearing capacity, structural efficiency, and aesthetic appeal.

This project focuses on the structural evaluation of a bicycle frame through computational analysis. The frame design was developed using SolidWorks CAD software and subsequently analyzed in ANSYS finite element analysis (FEA) software

The computational analysis evaluated von Mises stress distributions, factor of safety, and total deformation characteristics. These results provide critical insights into the frame's structural performance, identifying potential failure zones and validating the design's safety margins. The study demonstrates the application of modern engineering analysis tools in bicycle frame optimization, contributing to the development of safer and more efficient bicycle designs.

INTRODUCTION

The bicycle, first developed in Europe during the early 19th century, has maintained its fundamental design architecture since the introduction of the chain-driven safety bicycle in 1885. While the core configuration of modern upright bicycles remains remarkably similar to these early models, continuous engineering refinements have led to numerous specialized variants tailored to diverse applications.

Contemporary bicycle manufacturers employ advanced engineering approaches to address evolving user requirements, focusing on key performance parameters including:

- *Aerodynamic efficiency optimization*
- *Enhanced rider ergonomics and comfort*
- *Structural weight reduction*
- *Improved lateral stiffness for efficient power transfer*
- *Enhanced safety characteristics*

The traditional trial-and-error approach to bicycle design has been largely superseded by computational engineering methods. This paradigm shift was necessitated by the limitations of empirical methods, which often produced inconsistent results and required substantial time and material resources. Modern Finite Element Analysis (FEA) techniques now provide engineers with precise solutions to complex boundary value problems in structural mechanics.

FEA represents a computational methodology that solves differential equations governing mechanical behavior while satisfying specified boundary conditions. This numerical approach enables accurate prediction of structural performance under various loading scenarios, revolutionizing the bicycle design process by:

- *Reducing development cycles*
- *Minimizing prototyping costs*
- *Providing quantitative performance metrics*
- *Enabling parametric design optimization*

This project applies these advanced computational techniques to analyze and optimize a modern bicycle frame design through FEA implementation in ANSYS mechanical simulation software.

Material Selection for Bicycle Frame Analysis

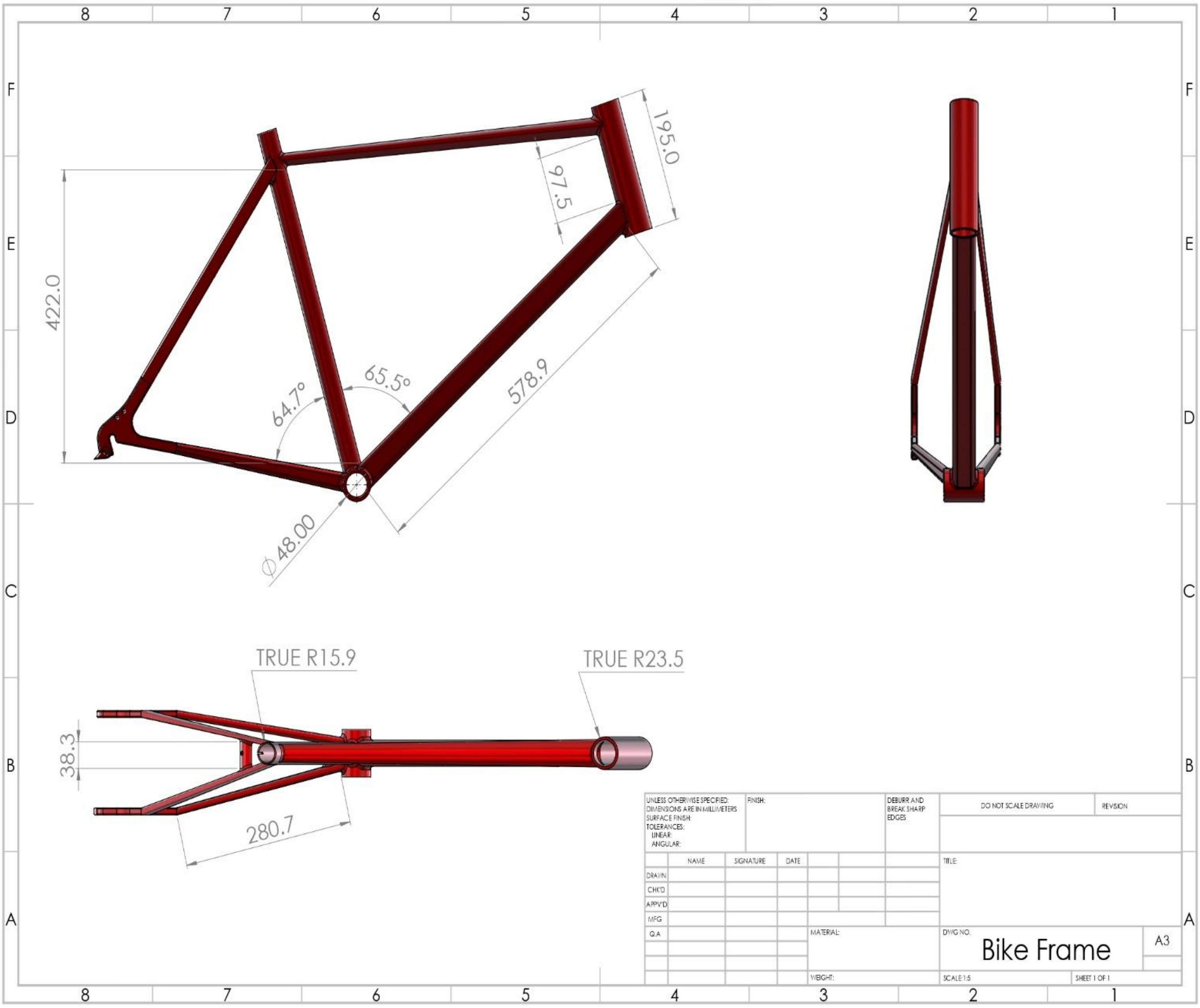
The structural integrity and performance of a bicycle frame are highly dependent on the choice of material. For this study, Aluminum Alloy 6061-T6 was selected as the primary material due to its excellent balance of mechanical properties, cost-effectiveness, and widespread use in bicycle manufacturing.

Material Properties of Aluminum Alloy 6061-T6:
The following key properties were considered for the finite element analysis (FEA) in ANSYS:

- *Young's Modulus (E): 68.9 GPa – Defines stiffness under elastic deformation.*
- *Poisson's Ratio (ν): 0.33 – Indicates material behavior under transverse strain.*
- *Density (ρ): 2.7 g/cm^3 – Contributes to lightweight design.*
- *Yield Strength (σ): 276 MPa – Determines the stress limit before plastic deformation.*
- *Ultimate Tensile Strength (UTS): 310 MPa – Maximum stress before failure.*

Why We Chose Aluminum 6061-T6:

- *Aluminum 6061-T6 is widely used in bicycle frames for the following reasons:*
- *High Strength-to-Weight Ratio – Provides sufficient rigidity while keeping the frame lightweight.*
- *Corrosion Resistance – Ensures durability in various environmental conditions.*
- *Cost-Effectiveness – More affordable than carbon fiber while offering better performance than steel in many cases.*
- *Manufacturability – Easily weldable and formable, making it ideal for mass production.*



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SHEET 1 OF 1

Bicycle Frame Modeling in ANSYS

The bicycle frame was modeled using SolidWorks 2022, incorporating key design parameters such as tube geometry, wall thickness, and joint reinforcements. Once the CAD model was finalized, it was exported in STEP format (Bike Frame.step) to ensure compatibility with ANSYS for structural simulation.

FEA analysis of bicycle frame using Ansys and meshing details:

- *Nodes: 105721*
- *Elements: 54086*
- *Mesh Size (single unit): 5 mm*
- *Type of Analysis: Static Structural*

1. Front Impact

To assess the structural integrity of the bicycle frame under collision-like conditions, a 1200N horizontal force was applied to the handlebars. This test scenario replicates a frontal impact, such as hitting a wall or another rigid obstacle, where the frame must withstand sudden loading without permanent deformation or failure.

Key Test Conditions:

- *Force Application: 1200N horizontal load at the handlebar center.*
- *Objective: Ensure no plastic deformation or cracks occur post-impact.*
- *Validation Criteria: Stress must remain below the material's yield strength (276 MPa for Aluminum 6061-T6)*

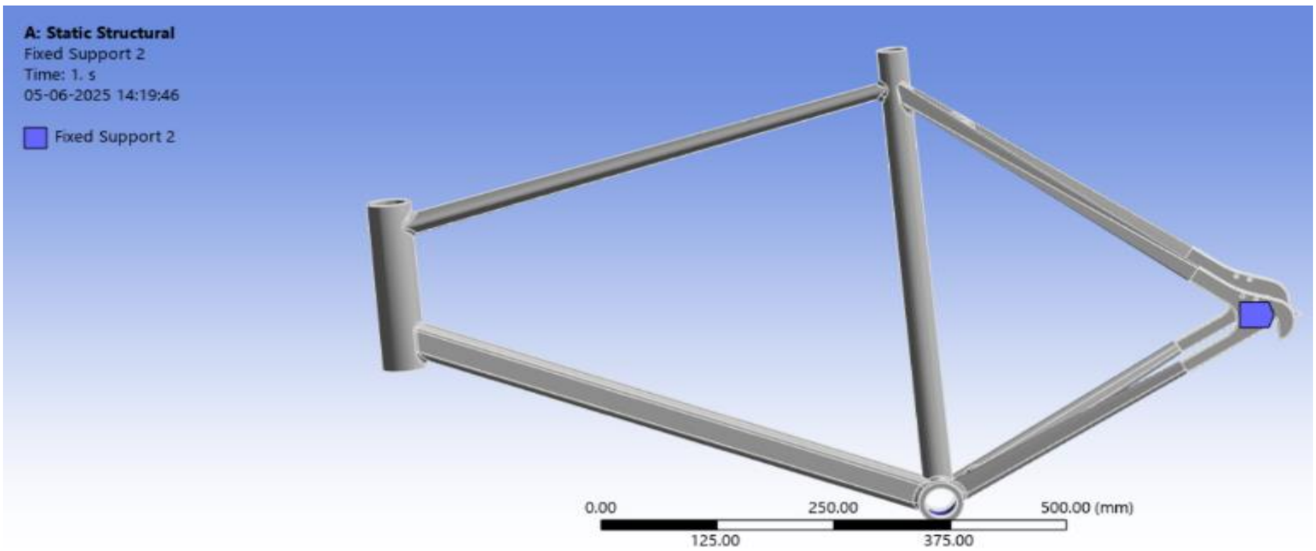

Fig 1: Fixed Support

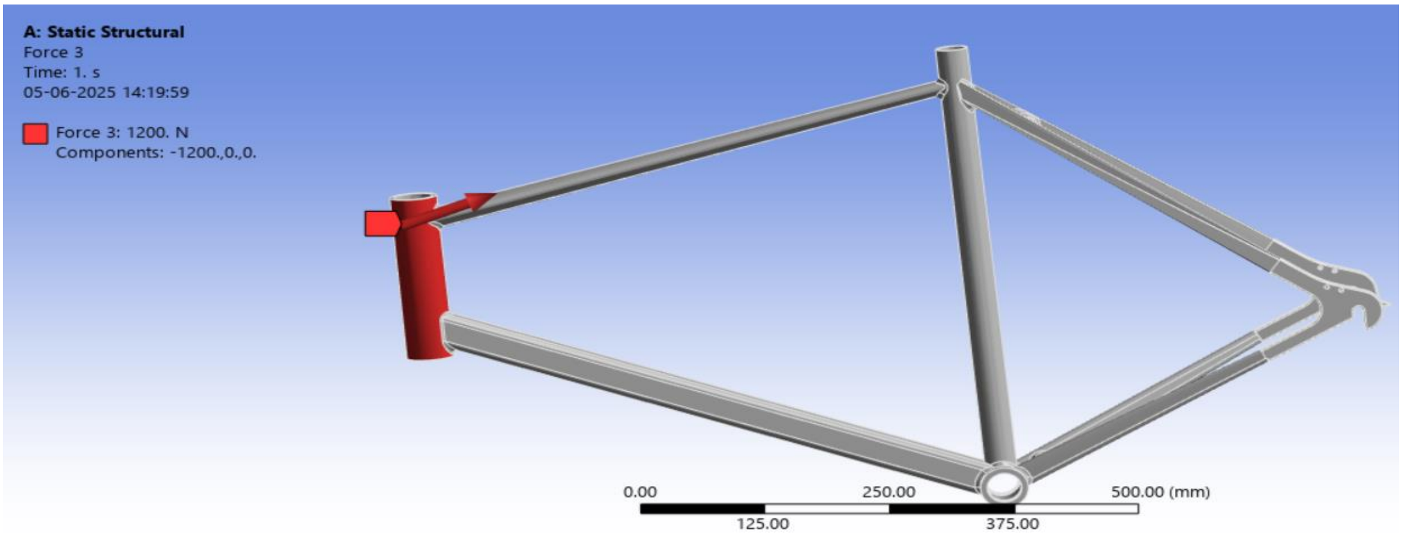

Fig 2: Direction of Force

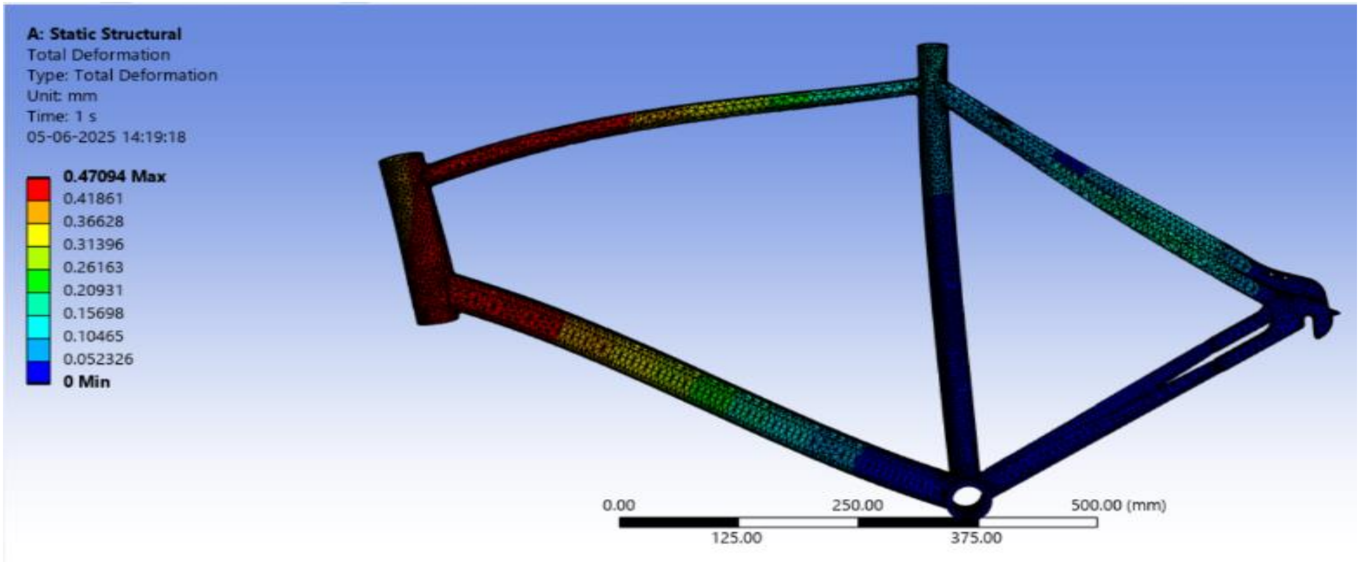

Fig 3: Deformation

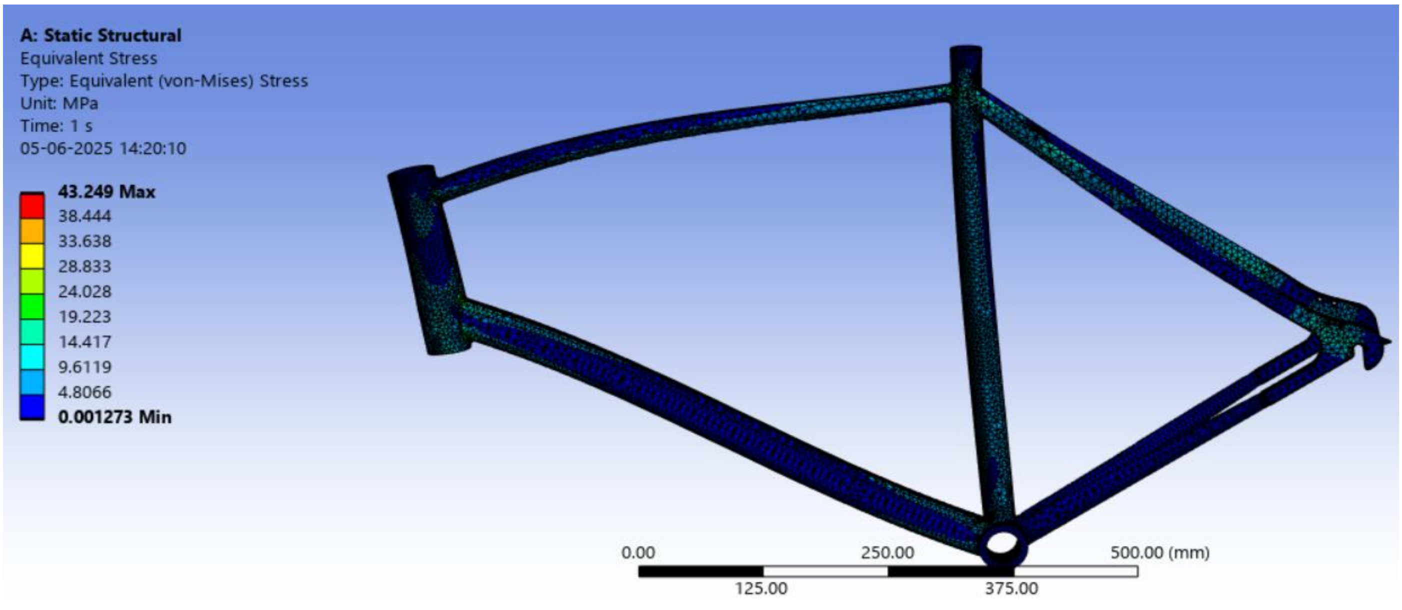

Fig 4: Equivalent Stress

2.Static Start up

A vertical force of 500N was applied to the pedal crank to simulate the initial pedaling force when starting from rest.

Key Test Conditions:

- *Force Application: 500N horizontal load at the Pedal Crank.*
- *Objective: Evaluate stress distribution and frame stiffness under initial pedaling force.*

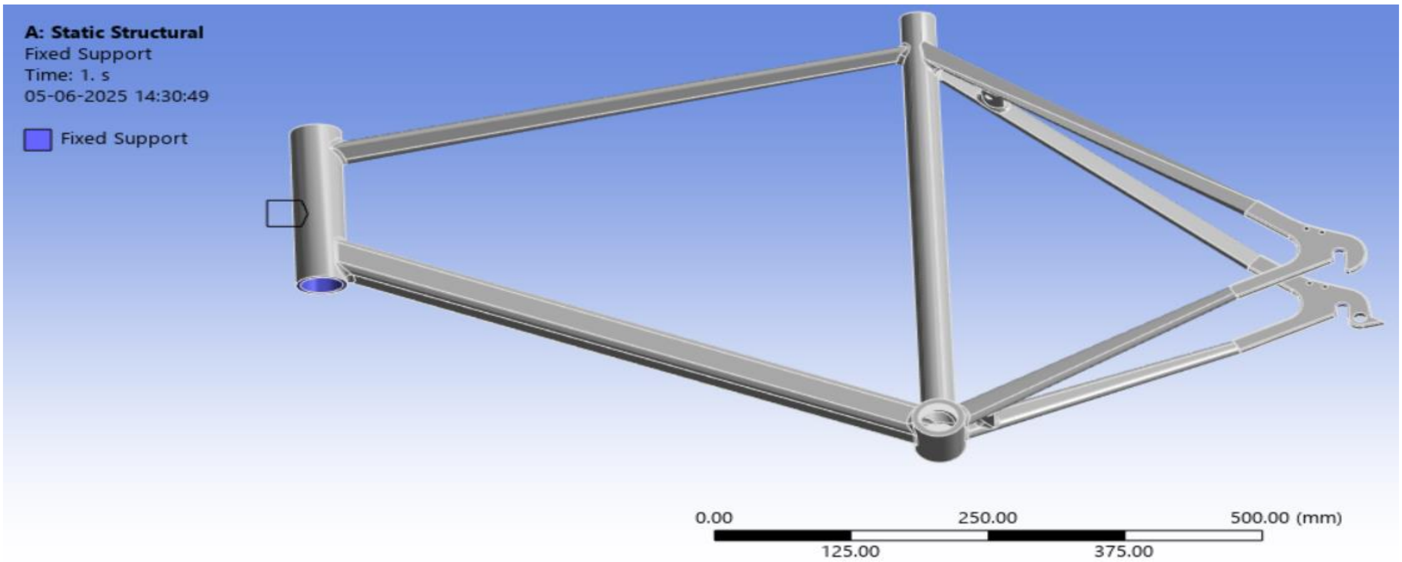

Fig 5: Fixed Support

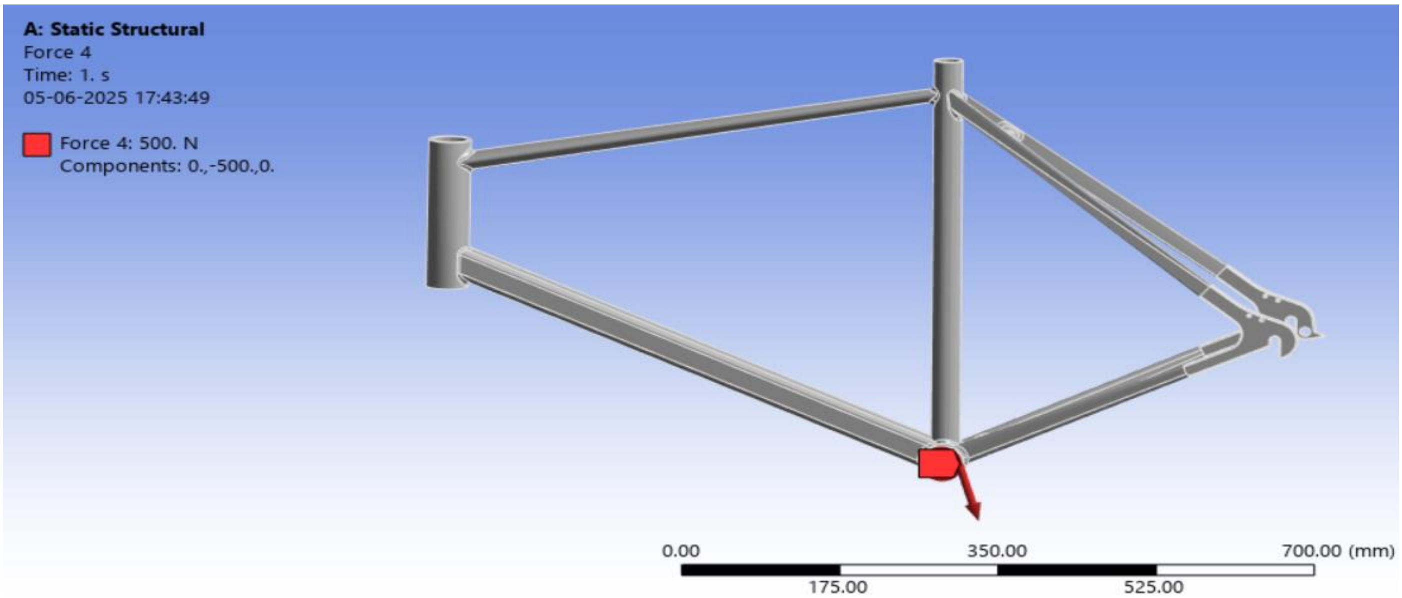

Fig 6: Direction of Force

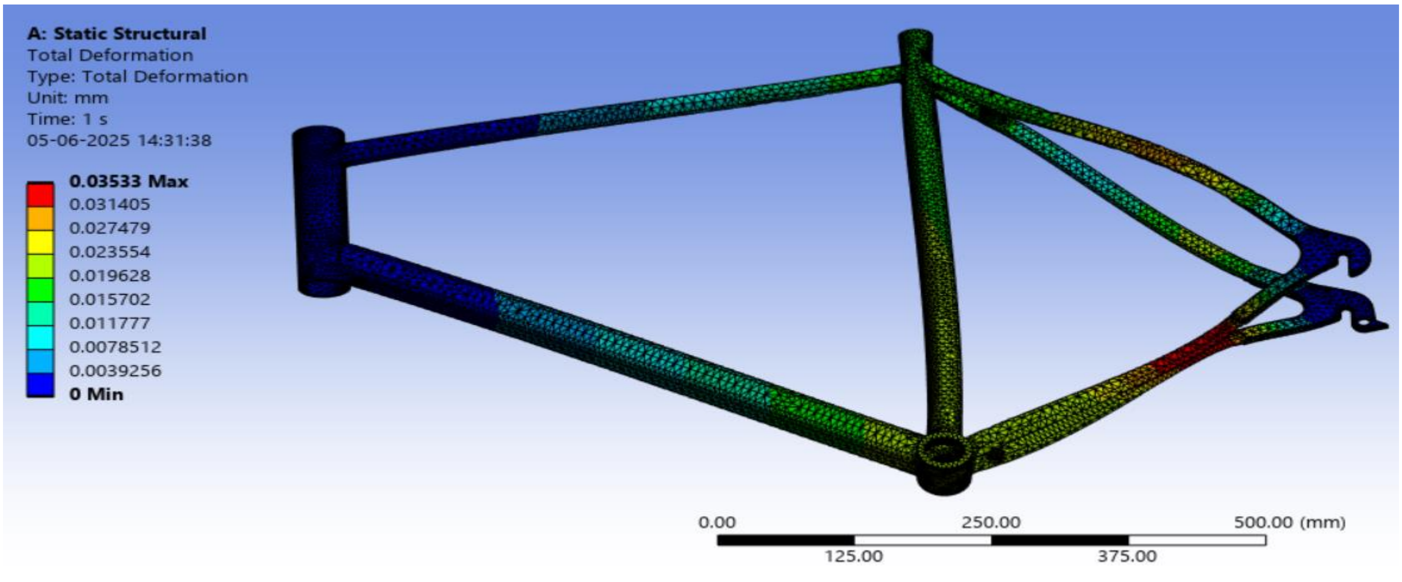

Fig 7: Deformation

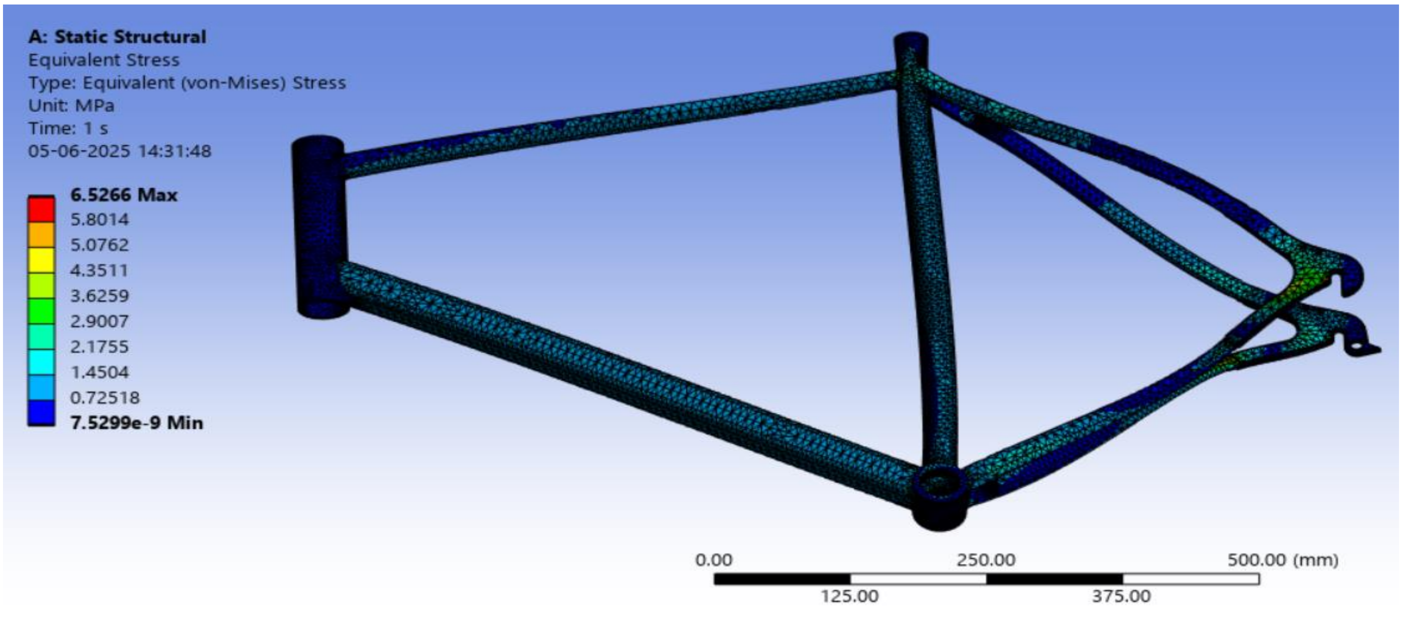

Fig 8: Equivalent Stress

3.<u>Steady state</u>

Rider with his 700 N weight seated on bicycle applied force of 200 N on pedal from his leg.

Boundary Conditions

- *Rear Wheel Hub: Fixed support (simulating ground contact)*
- *Front Fork: Constrained in vertical motion (allowing steering compliance)*

Objective

- *Evaluate stress distribution under typical riding conditions*
- *Ensure frame stiffness meets comfort and safety standards*

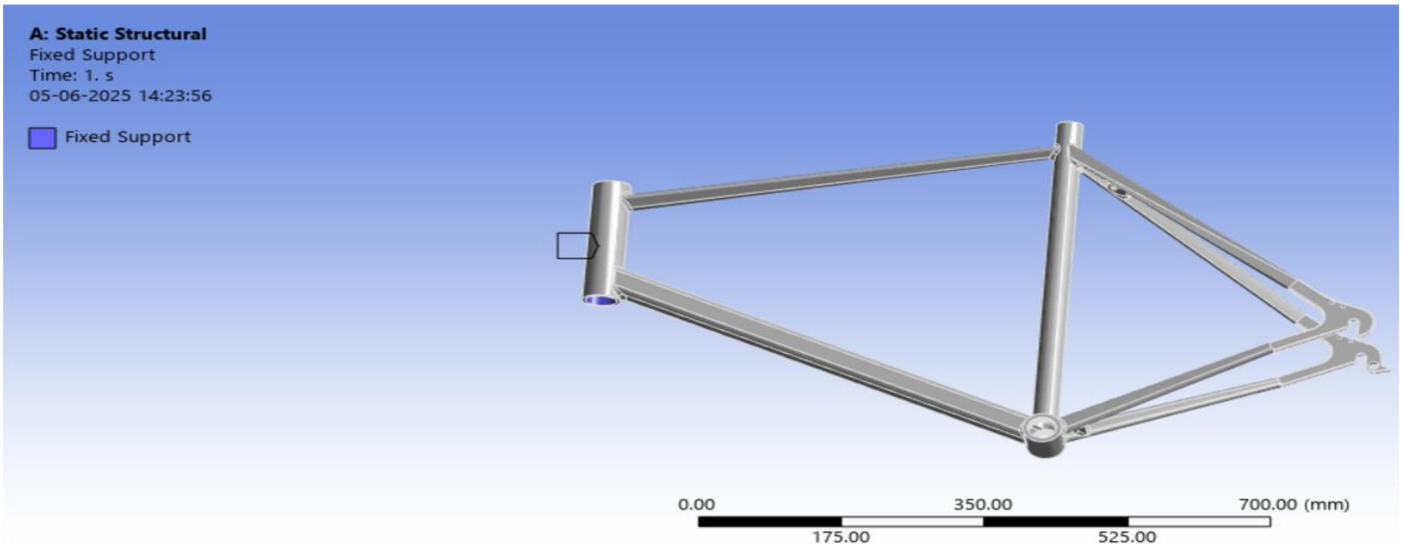

Fig 9: Fixed Support

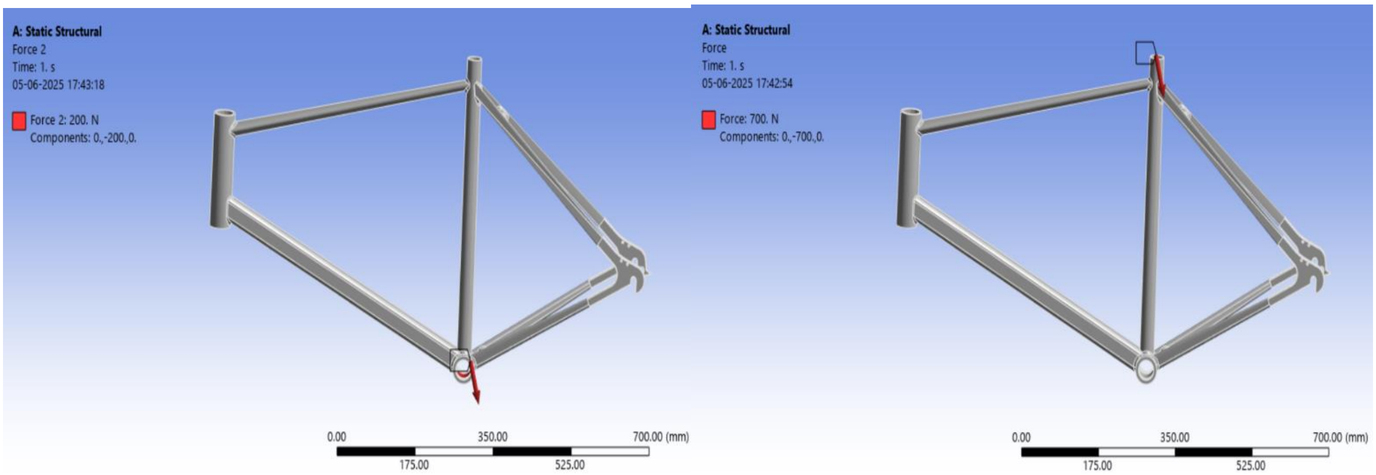

Fig 10: Direction of Force

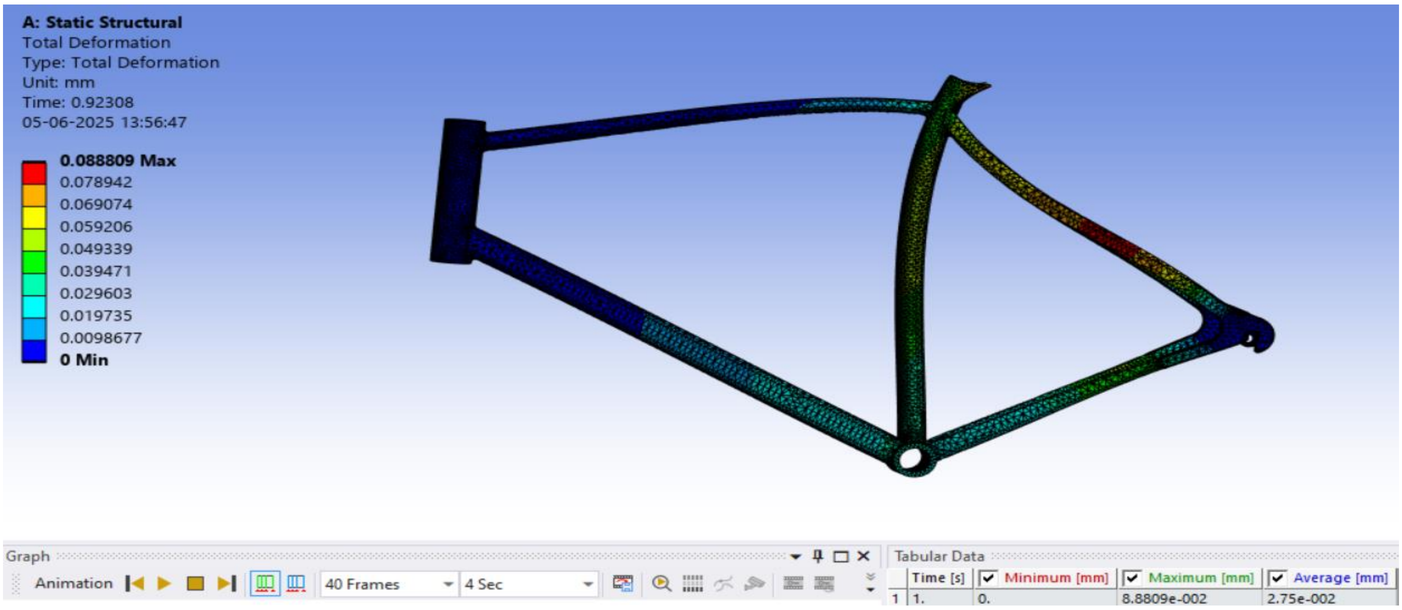

Fig 11: Deformation

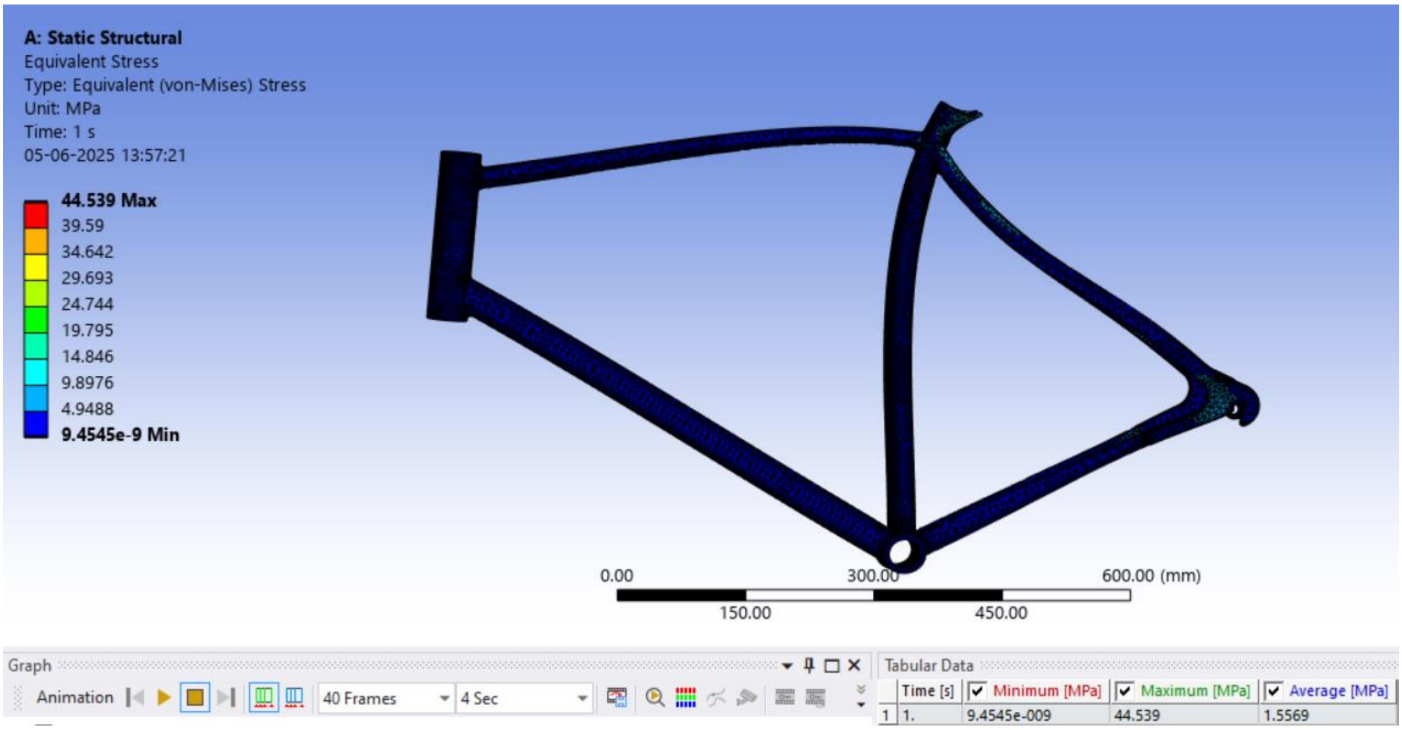

Fig 12: Equivalent Stress

Conditions	Max. Total deformation (in mm)	Max Stress (in Mpa)	Factor of Safety
Front impact	0.47	43.24	6.47
Static Start Up	0.035	6.52	15
Steady state	0.088	44.53	6.28

Table 1: Comparison table for different conditions

Conclusion

Finite element analysis confirms the bicycle frame's structural integrity under various loading conditions. The maximum von Mises stress of 44.53 MPa (steady-state pedaling) remains safely below Aluminum 6061-T6's yield strength (276 MPa), with a healthy factor of safety (FOS) of 6.28. Even under front impact (the most critical case), stress reaches only 43.24 MPa with FOS of 6.47, while static startup shows exceptional safety (FOS=15). Maximum deformations are negligible (≤0.47 mm), demonstrating optimal stiffness. These ANSYS-generated results validate the design's robustness and suggest potential for weight reduction while maintaining excellent safety margins (FOS>6 in all scenarios). The frame comfortably exceeds structural requirements for real-world cycling conditions.