



MECHANICAL ENGINEERING PROJECT

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Structural Analysis of Roller Coaster Rails

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What is ANSYS?

Throughout history, humankind has strived to build ever more ambitious and complex structures, pushing the boundaries of design and engineering. To ensure the safety and functionality of these structures, a deep understanding of their behavior under various loads is paramount. This vital field of study is known as structural analysis. By employing sophisticated mathematical models, structural analysis allows engineers to predict how a structure will deform, the internal forces it will experience (stresses and strains), and the reactions it will exert on its supports. This knowledge forms the bedrock for designing safe, efficient, and functional structures that can withstand the demands placed upon them.

In the modern engineering landscape, powerful software tools have revolutionized the way we analyze structures. Finite element analysis (FEA) software, such as ANSYS, stands as a prime example. FEA breaks down complex geometries into smaller, interconnected elements, enabling highly detailed simulations of a structure's response to various loading scenarios. ANSYS, a leading FEA software suite, offers a dedicated module specifically tailored for structural analysis applications: ANSYS Mechanical. This software empowers engineers with a comprehensive toolbox for modeling diverse materials, defining realistic loads and constraints, and visualizing the results of the analysis in an informative manner.

For thesis research, particularly within the realm of structural engineering, ANSYS Mechanical offers a plethora of advantages. It allows researchers to create virtual prototypes of their designs, subjecting them to real-world loading conditions relevant to their specific research topic. Through these simulations, researchers can gain invaluable insights into the structural behavior of their design concepts. Additionally, ANSYS Mechanical allows for the comparison of different design iterations and material choices, enabling researchers to optimize their designs for both performance and efficiency. Perhaps most importantly, the software generates valuable data and visualizations that can be used to substantiate research findings and present them in a compelling and clear manner.

Therefore, this thesis will leverage the combined power of structural analysis principles and the advanced capabilities of ANSYS Mechanical software to investigate [insert your specific research question here]. By meticulously constructing a digital model of the structure, applying relevant loads and constraints that accurately reflect real-world conditions, and meticulously analyzing the resulting data, this research aims to achieve a comprehensive understanding of the structural behavior of [your research subject]. This newfound knowledge will be instrumental in [explain the significance of your research and its potential applications]. Through this in-depth exploration, this thesis seeks to contribute valuable insights to the field of structural engineering and pave the way for the development of railroads of roller coasters.

What is Finite Elements Method(FEM) ?

The Finite Element Method (FEM) has become a ubiquitous tool across engineering and scientific disciplines for analyzing and solving complex problems. Its strength lies in its ability to handle intricate geometries and material behaviors that often defy traditional analytical solutions. FEM achieves this by discretizing the domain of interest – essentially, breaking it down – into smaller, more manageable elements. These elements, such as triangles or tetrahedrons, are then interconnected at nodal points. By applying governing physical principles through a set of mathematical equations to each element, FEM builds a comprehensive picture of the entire system.

The core principles of FEM involve several key steps. First, the complex geometry is divided into a finite number of simpler elements, creating a mesh that approximates the original shape. The type of element chosen depends on the specific problem and desired accuracy. Next, relevant physical laws, often expressed as partial differential equations, are applied to each element. Interpolation functions are then employed within each element to approximate the unknown variable (like temperature or stress) across its domain. These functions relate the values of the unknown variable at the nodal points to its values within the element.

Once the element equations are formulated, they are assembled into a global system of equations by considering the connectivity between elements and imposing continuity conditions at the nodal points. This global system represents the entire discretized domain. Finally, the system of equations is solved numerically to determine the unknown variable at each node. The solution provides an approximate representation of the governing physics throughout the domain.

The versatility of FEM in handling complex geometries and material properties makes it applicable to a wide range of engineering fields. In structural engineering, FEM is a cornerstone for analyzing stresses, strains, and deformations in structures under various loads. It is crucial for designing bridges, buildings, airplanes, and other load-bearing structures. FEM also plays a vital role in thermal engineering, allowing for the prediction of temperature distribution and heat flow in objects, which is essential for designing heat exchangers, power plants, and electronic devices.

The significance of FEM lies in its ability to overcome the limitations of analytical solutions for complex problems. It offers several key advantages. FEM can handle intricate geometries and material behaviors that are often intractable using traditional methods. By refining the mesh and employing higher-order elements, FEM solutions can be systematically improved to achieve the desired level of accuracy. Advancements in computational power and specialized software have made FEM simulations increasingly efficient, facilitating faster analysis and design optimization. FEM software often integrates seamlessly with computer-aided design (CAD) tools, enabling a streamlined workflow from design creation to engineering analysis.

In conclusion, the Finite Element Method stands as a powerful and versatile tool for tackling complex engineering problems. Its ability to discretize intricate geometries and solve governing equations numerically has revolutionized engineering analysis and design across various disciplines. As computational power continues to grow and FEM capabilities advance, its importance will only increase in the future of engineering and scientific endeavors.

What is ANSYS Workbench ?

Ansys Workbench has established itself as a prominent software suite within the realm of engineering simulation. It functions as a central hub, integrating various engineering disciplines and enabling users to conduct a comprehensive range of simulations for product design analysis and optimization. This software offers a unique set of functionalities that cater to the intricate needs of the engineering field.

One of the defining strengths of Ansys Workbench lies in its proficiency at integrating simulations encompassing diverse physical phenomena within a singular platform. This capability allows users to seamlessly combine simulations for structural mechanics, fluid dynamics, heat transfer, electromagnetics, and more. By fostering this integrated approach, Ansys Workbench facilitates a more holistic understanding of a product's performance under real-world operating conditions.

Furthermore, Ansys Workbench prioritizes user experience through its user-friendly interface, which streamlines the entire simulation workflow. It guides users through a well-defined sequence of steps, encompassing geometry definition, material selection, analysis setup, solution, and post-processing. This unified workflow empowers engineers of varying experience levels to effectively harness the power of simulation for their projects.

The software equips users with robust preprocessing tools. These tools enable the import of CAD geometry from various design software or the direct creation of geometry within the Ansys Workbench environment. Additionally, it facilitates the definition of material properties, loads, and boundary conditions – all crucial aspects of setting up an accurate simulation.

Ansys Workbench integrates seamlessly with a suite of powerful Ansys solvers. These solvers are meticulously designed to address specific physics domains and are capable of tackling complex problems. They encompass linear and non-linear analysis, static and dynamic conditions, and multiphysics interactions, ensuring the software's adaptability to a wide range of engineering challenges.

Upon completion of the simulation, Ansys Workbench offers a plethora of tools for post-processing and visualization of the results. Users can generate informative plots, contours, and animations to gain valuable insights into the variation of stresses, strains, temperatures, or other relevant parameters throughout the product.

In conclusion, Ansys Workbench stands as a versatile and powerful platform that empowers engineers across various disciplines to virtually test and optimize product designs before physical prototypes are manufactured. This not only translates to significant time and resource savings but also paves the way for the development of safer, more efficient, and higher-performing products.

Taguchi Method

The Taguchi Method, developed by Genichi Taguchi, offers a unique approach to quality control in manufacturing. Unlike traditional methods that focus on inspecting and discarding defective products after production, the Taguchi Method emphasizes proactive design optimization. It identifies the desired quality characteristic of a product (the "signal") and all controllable design factors that can influence it.

The core strength of the Taguchi Method lies in its strategic design of experiments (DOE). It utilizes orthogonal arrays, specialized experimental designs that allow for efficient evaluation of multiple control factors with minimal experiments. This reduces time and resources needed. Statistical analysis of these experiments, considering a signal-to-noise ratio metric, helps identify the optimal settings for the control factors. This optimized design minimizes product variations and achieves robustness against external noise factors, ultimately leading to significant quality improvements and cost savings across various manufacturing industries.

What is Taguchi Method?

The Taguchi Method, conceived by Genichi Taguchi, stands as a cornerstone of statistical quality control and design optimization within the manufacturing realm. Unlike conventional methods that rely on post-production inspection and sorting of defective products, the Taguchi Method champions a proactive approach. It prioritizes design optimization to minimize product variations and achieve robustness against environmental factors that can potentially compromise quality. This proactive philosophy translates to significant quality improvements and cost savings in the long run.

The core principles of the Taguchi Method unfold through a well-defined sequence of steps. The initial stage involves clearly defining the desired quality characteristic of the product, often referred to as the "signal." This characteristic could be a dimensional tolerance, a mechanical property, or any other parameter critical to product performance. Additionally, all controllable design parameters that can potentially influence this quality characteristic are identified as "control factors." These control factors essentially represent the levers that engineers can manipulate during the design phase to optimize the product.

A defining aspect of the Taguchi Method lies in its strategic design of experiments (DOE). Here, the Taguchi Method advocates for the use of orthogonal arrays. Orthogonal arrays are special experimental designs that offer a powerful way to evaluate multiple control factors with a minimal number of experiments. This efficiency is achieved by strategically arranging the experiments in a way that minimizes interactions between the control factors.

For instance, consider a scenario where you want to investigate the effect of three control factors (A, B, and C) on a specific quality characteristic. Each control factor has three possible levels (denoted as 1, 2, and 3). Traditionally, a complete factorial experiment would require $3 \times 3 \times 3 = 27$ experiments to evaluate all possible combinations of these factors. However, the Taguchi Method utilizes an orthogonal array that allows for the evaluation of these factors with a significantly reduced number of experiments.

<div> <div>COLUMN</div> <div>CONDITION</div> </div>	L_9		
	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Figure 1.0 3x3 Taguchi Method Table.

This 3x3 orthogonal array allows for the evaluation of all three control factors and their interactions using only nine experiments, significantly reducing time and resource requirements compared to a traditional factorial design. This reduction in the number of experiments makes the Taguchi Method particularly attractive for situations where resources are limited or where experimentation can be time-consuming or expensive.

Parameters of Taguchi Method

1. Control Factors and Signal:

Control Factors: These are the design parameters that engineers can manipulate during the design phase. They are identified based on their potential influence on the desired quality characteristic of the product (often referred to as the "signal"). Examples of control factors could be temperature, pressure, processing time, material composition, or component geometry.

2. Design of Experiments (DOE):

Orthogonal Arrays: The Taguchi Method utilizes a specific type of DOE strategy called orthogonal arrays. These arrays allow researchers to efficiently evaluate multiple control factors with a minimal number of experiments. The arrangement of experiments within the array minimizes interactions between control factors, ensuring a clear understanding of their individual effects on the signal.

3. Signal-to-Noise Ratio (S/N Ratio):

This metric serves as a benchmark for evaluating the quality characteristic. It essentially quantifies the desired signal (target quality) relative to the background noise (variations caused by uncontrollable factors). Different S/N ratios are employed depending on the type of quality characteristic, such as "smaller-the-better" for minimizing defects or "larger-the-better" for maximizing a desired property.

4. Analysis and Optimization:

Statistical techniques are used to analyze the data collected from the experiments. These techniques help identify the optimal settings for the control factors that maximize the S/N ratio. This signifies a design configuration that minimizes variations and achieves robustness against noise factors, leading to a product that consistently performs well under different operating conditions.

5. Confirmation Experiment:

While not strictly a parameter, a confirmation experiment is often conducted after identifying the optimal control factors. This experiment uses the predicted optimal settings to validate the findings from the initial set of experiments and ensure the effectiveness of the optimized design.

In essence, the Taguchi Method leverages these elements to guide a structured approach towards design optimization. By focusing on controllable factors, strategically designed experiments, and robust analysis, the method helps manufacturers achieve significant quality improvements and cost savings.

What is the signal-to-noise ratio in a Taguchi design?

In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors.

Taguchi experiments often use a 2-step optimization process. In step 1 use the signal-to-noise ratio to identify those control factors that reduce variability. In step 2, identify control factors that move the mean to target and have a small or no effect on the signal-to-noise ratio.

The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different signal-to-noise ratios, depending on the goal of your experiment. For static designs, Minitab offers four signal-to-noise ratios:

Signal-to-noise ratio	Goal of the experiment	Data characteristics	Signal-to-noise ratio formulas
Larger is better	Maximize the response	Positive	$S/N = -10 \cdot \log(\Sigma(1/Y^2)/n)$
Nominal is best	Target the response and you want to base the signal-to-noise ratio on standard deviations only	Positive, zero, or negative	$S/N = -10 \cdot \log(\sigma^2)$
Nominal is best (default)	Target the response and you want to base the signal-to-noise ratio on means and standard deviations	Non-negative with an "absolute zero" in which the standard deviation is zero when the mean is zero	$S/N = 10 \times \log((\bar{Y}^2) \div \sigma^2)$ The adjusted formula is: $S/N = 10 \times \log((\bar{Y}^2 - s^2 \div n) \div s^2)$
Smaller is better	Minimize the response	Non-negative with a target value of zero	$S/N = -10 \cdot \log(\Sigma(Y^2)/n))$

Figure 1.1 Signal to Noise Ratios.

Design of Roller Coaster Rails

Roller coasters, with their exhilarating drops, heart-stopping inversions, and moments of weightlessness, have captivated thrill-seekers for over a century. Beyond the undeniable entertainment value, these intricate structures represent a fascinating convergence of engineering principles. This paper delves into the design considerations behind roller coasters, exploring the interplay of physics, material science, and safety regulations that govern their creation. Understanding these factors not only sheds light on the technical prowess required to build these modern marvels but also reveals the delicate balance between thrilling experiences and ensuring rider safety.



Figure 2.0 Roller Coaster.

First Design of Roller Coaster Rails

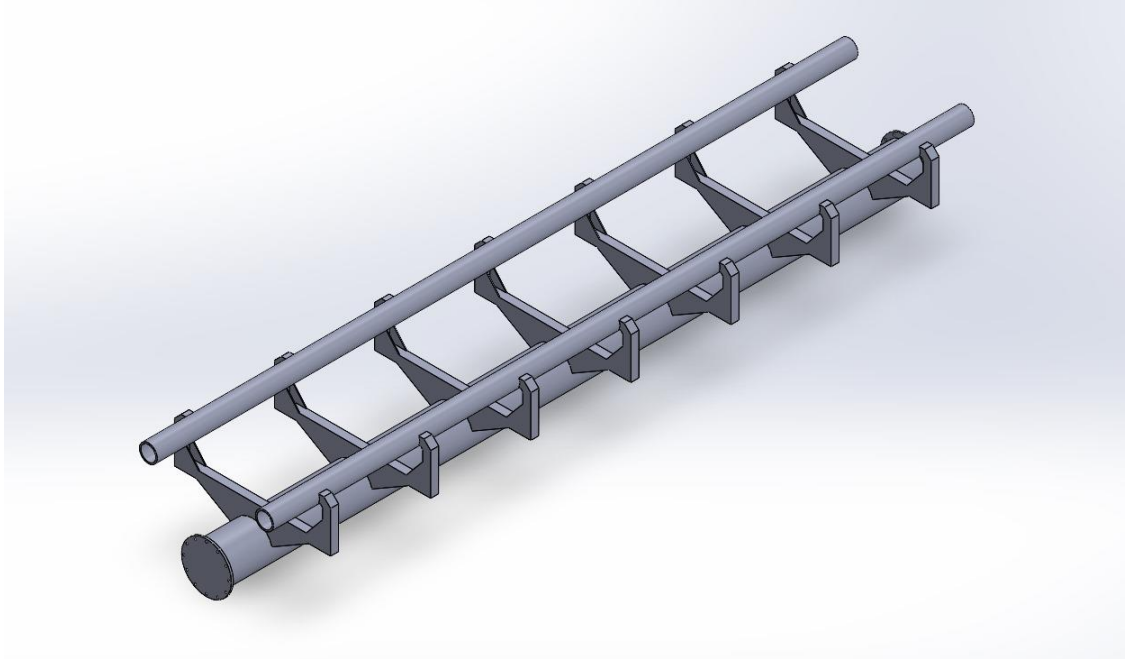


Figure 2.1 Roller Coaster Rails.

While traditional roller coaster rails may appear sufficient at first glance (Figure 2.1), this project avoids unsubstantiated claims of optimality. To identify the most effective rail design for this specific project, the Taguchi Method will be employed. This method allows for a systematic evaluation of various design parameters, including material selection, rail shape, and inclination angle. Through the analysis of rails constructed with different parameter combinations, this project aims to determine the optimal configuration that best meets the desired performance criteria.

It is important to note that while the overall cross-sectional area of the rail remains constant across the investigated geometries (Figures 2.1-2.3), the Taguchi Method analysis will specifically isolate the impact of geometric variations on performance. In other words, all rail configurations maintain the same material thickness, allowing for a focused evaluation of how geometry influences the desired outcomes.

Second and Third Design of Roller Coaster Rails

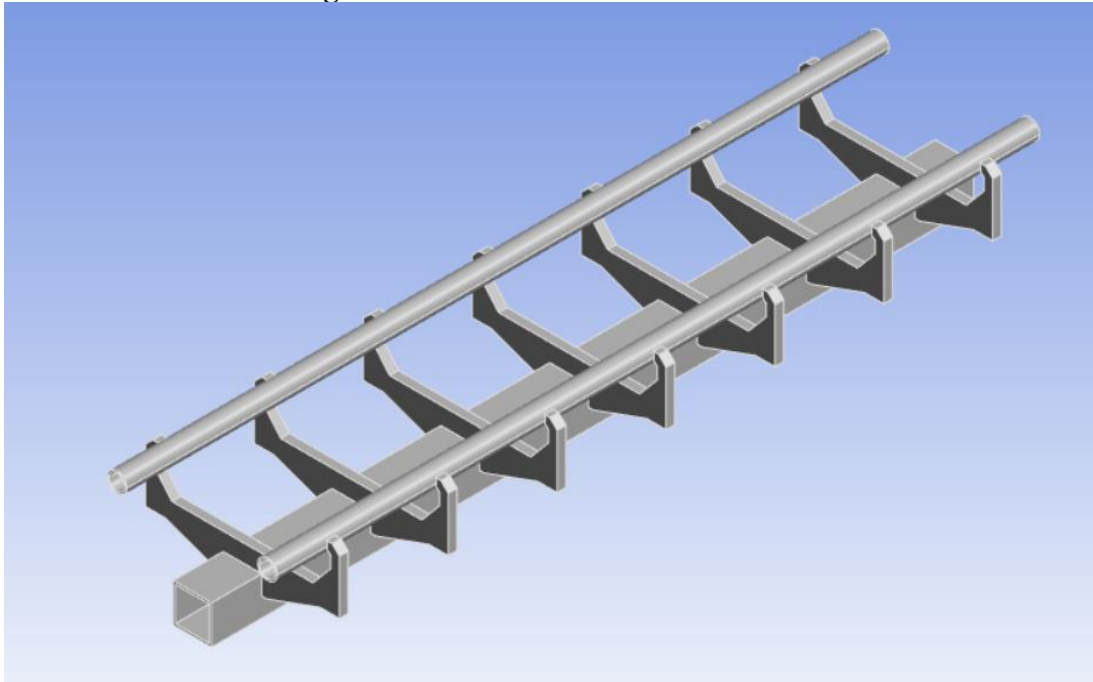


Figure 2.2 Second Design

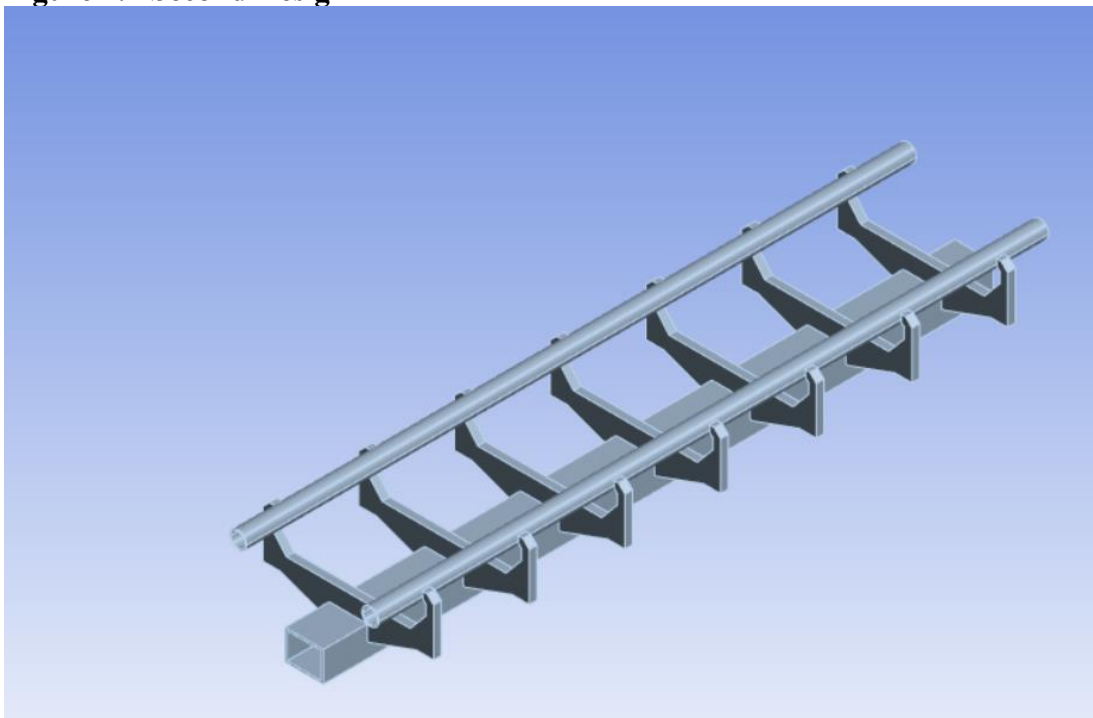


Figure 2.3 Third Design

Analyse of Designs

This project utilizes the Taguchi Method for design analysis, employing a 3x3 orthogonal array as illustrated in Figure 3.1.

Experimental Run	Material	Angle	Profile
1	AISI 1018	150	Circular
2	AISI 1018	155	Square
3	AISI 1018	160	Rectangular
4	AISI 1019	150	Circular
5	AISI 1019	155	Square
6	AISI 1019	160	Rectangular
7	AISI 1020	150	Circular
8	AISI 1020	155	Square
9	AISI 1020	160	Rectangular

Figure 3.0 Taguchi Table.

The primary focus of the analysis will be on total deformation and von Mises stress as these parameters directly relate to the project's objective of minimizing rail deformation during operation. Due to this focus, the "smaller-the-better" signal-to-noise (S/N) ratio formula will be employed to evaluate the performance of each design configuration. Smaller-the-better formula is in figure 3.2.

Smaller is better	Minimize the response	Non-negative with a target value of zero	$S/N = -10 * \log(\Sigma(Y^2)/n)$
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Figure 3.1 Smaller is better formula.

This project considers two primary loading scenarios for the roller coaster rails: a best-case situation with a minimal force of 70 MPa and a worst-case scenario with a maximum force of 150 MPa acting on the rails. These scenarios will be used to evaluate the performance of the various rail designs identified through the Taguchi Method analysis.

Results of Analysis

Best Case Analysis results for first design of roller coaster rails.

Material AISI 1018;

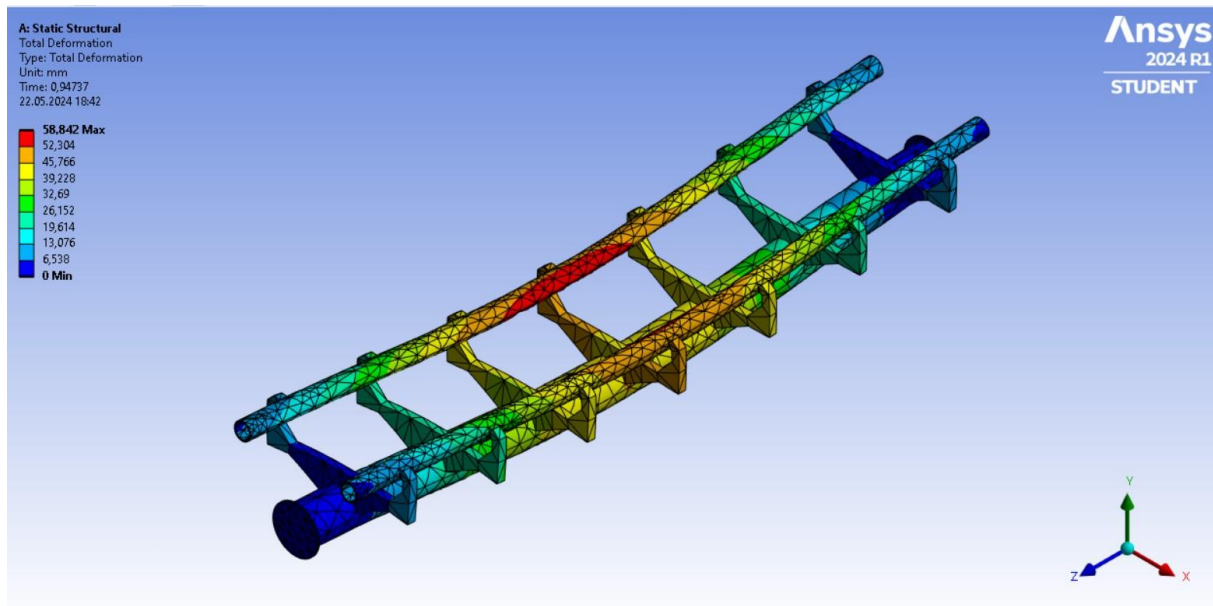


Figure 4.0 Total Deformation.

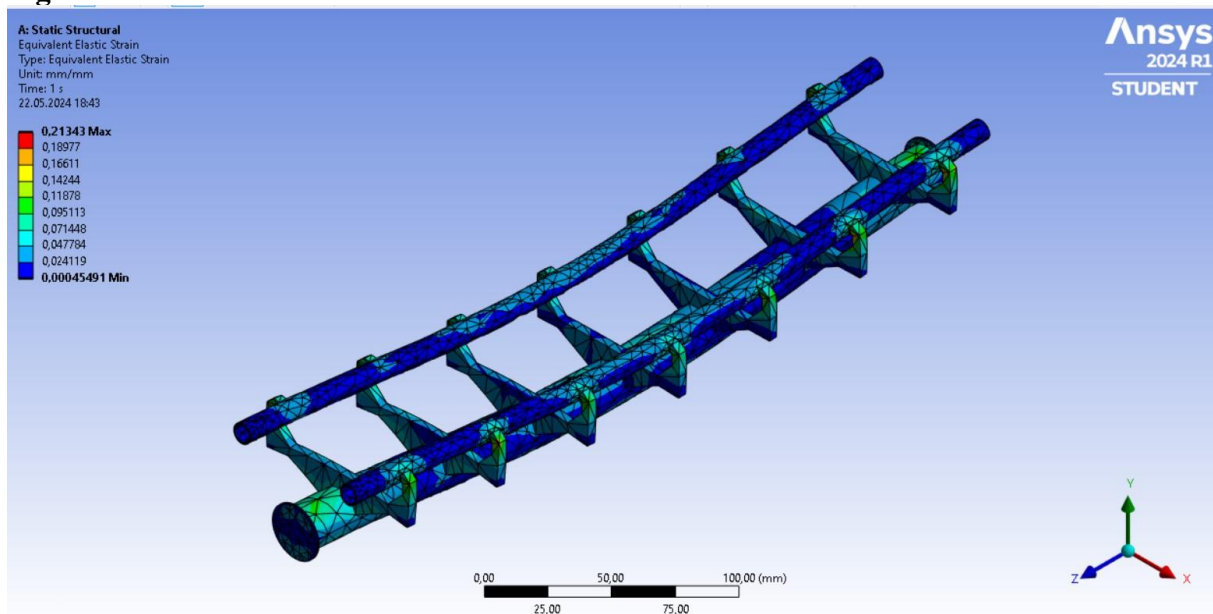


Figure 4.1 Von Misses.

Material AISI 1019;

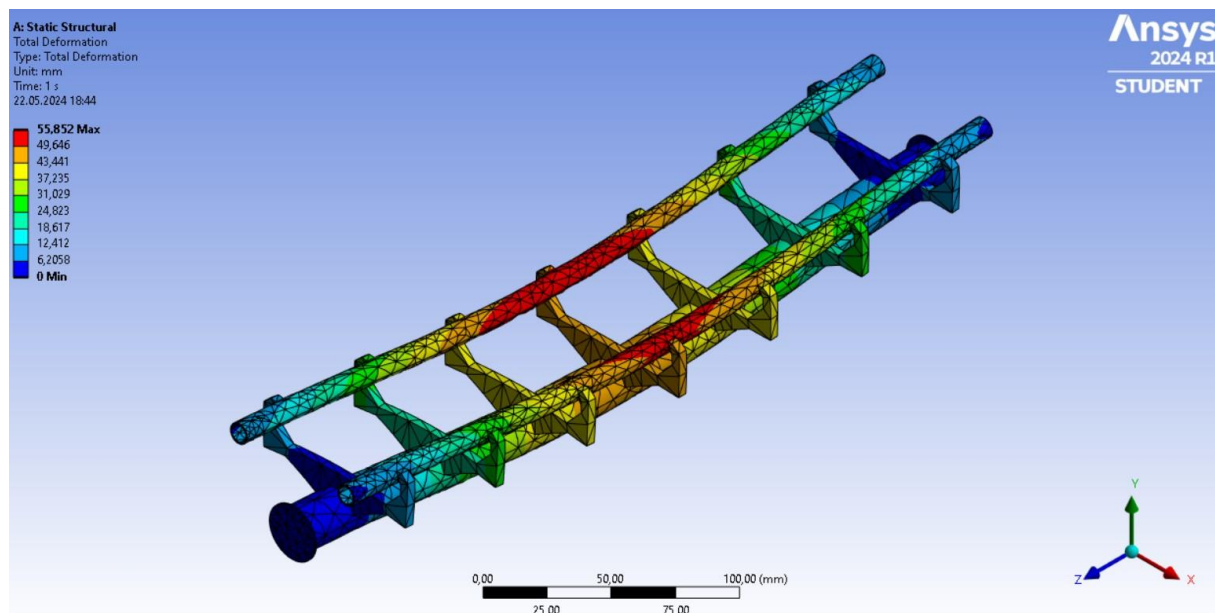


Figure 4.2 Total Deformation.

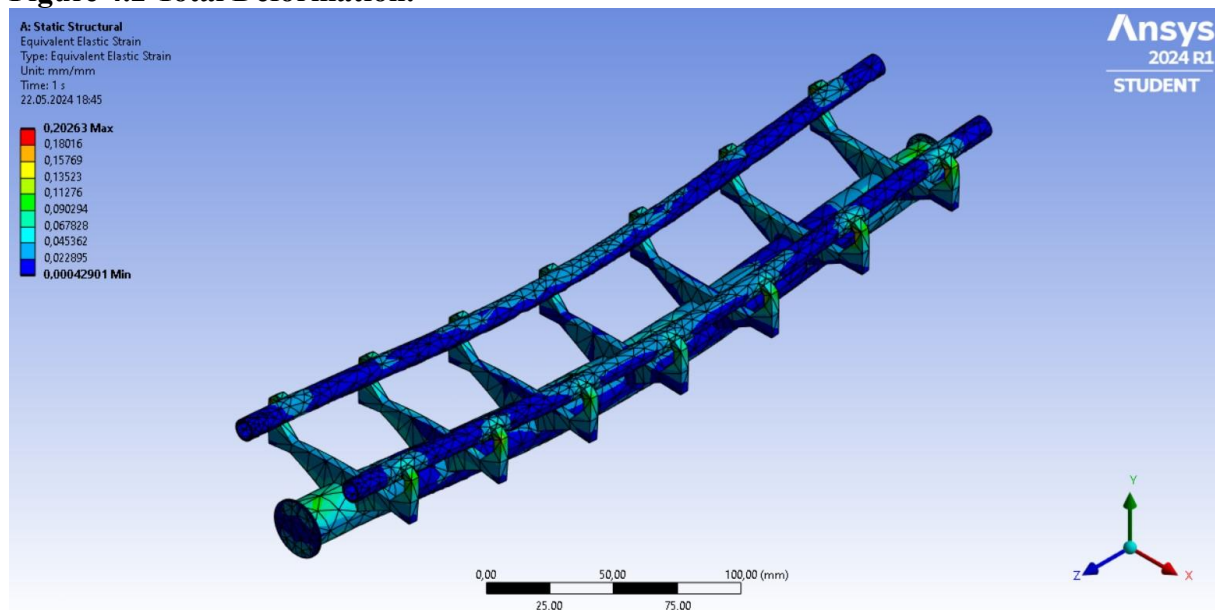


Figure 4.3 Von Misses.

Material AISI 1020;

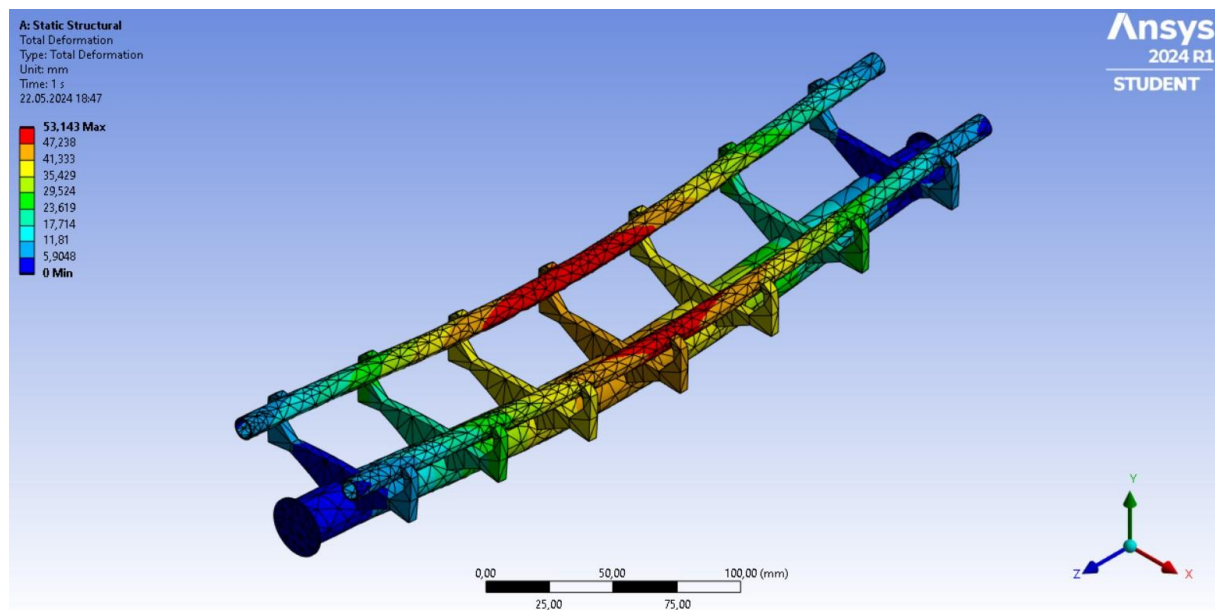


Figure 4.4 Total Deformation.

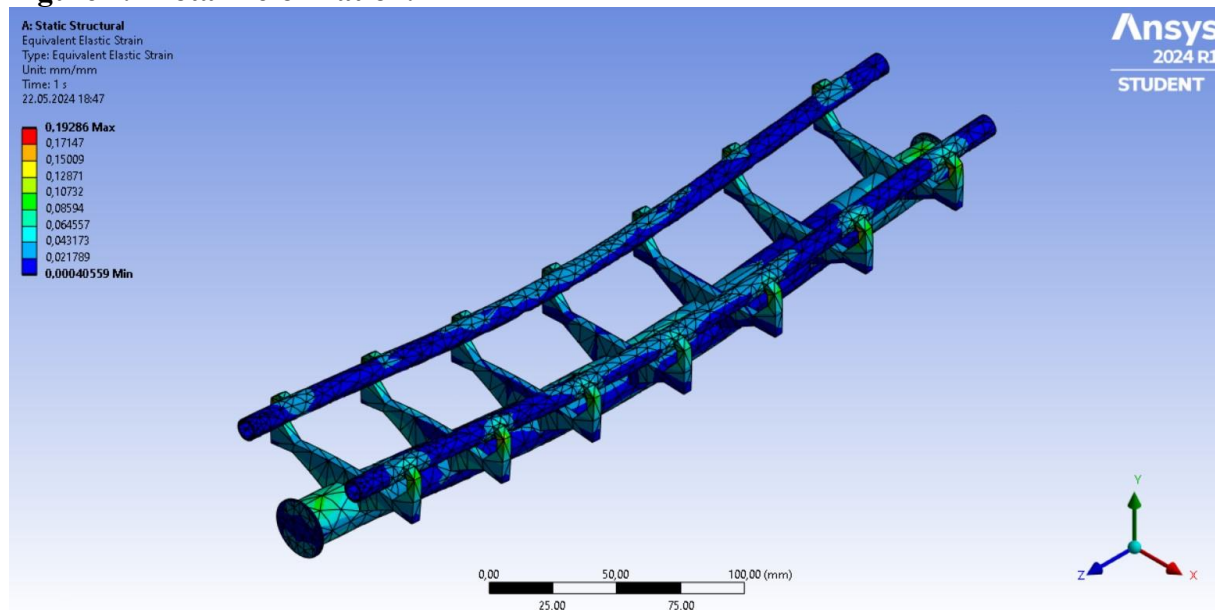


Figure 4.5 Von Misses.

Worst Case Analys results for first design of roller coaster rails.

Material AISI 1018;

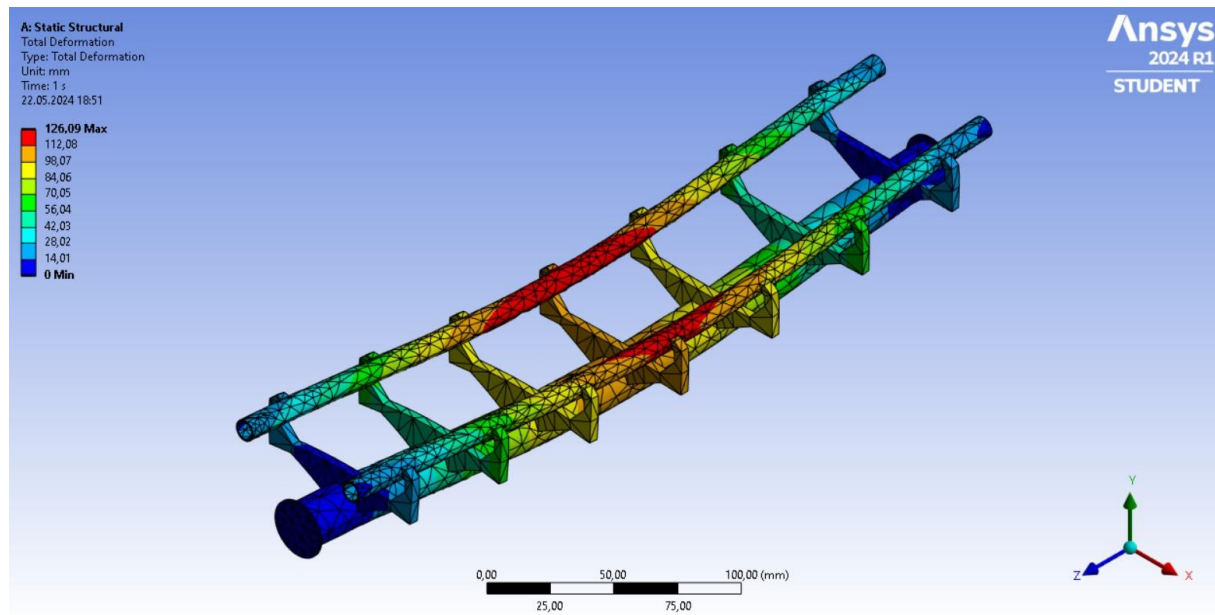


Figure 4.6 Total Deformation.

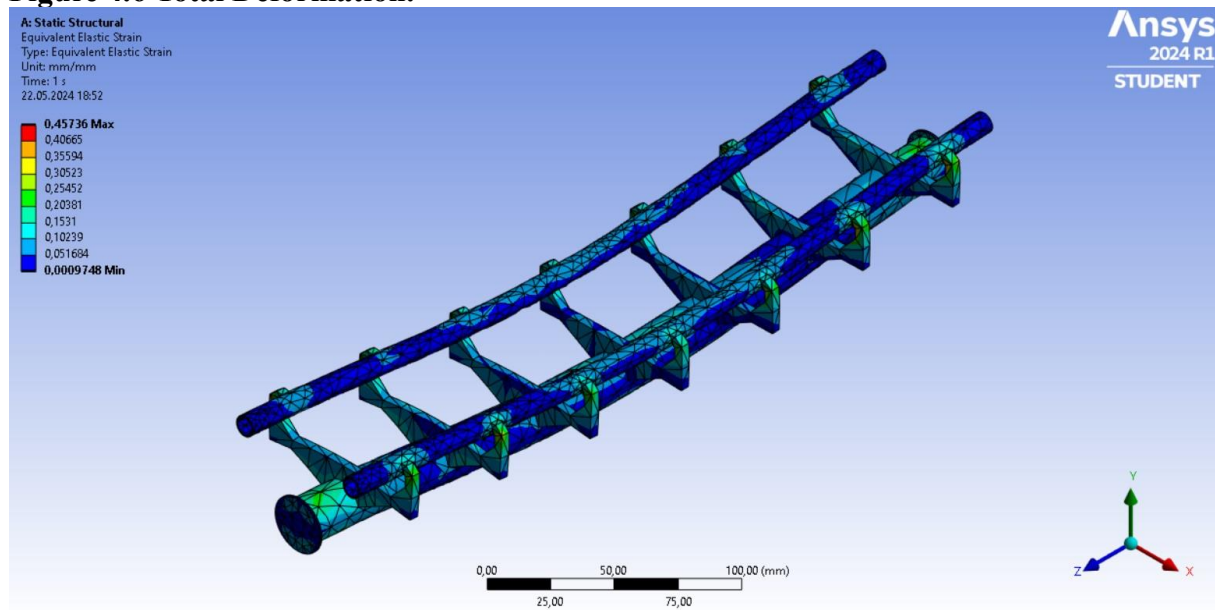


Figure 4.7 Von Misses.

Material AISI 1019;

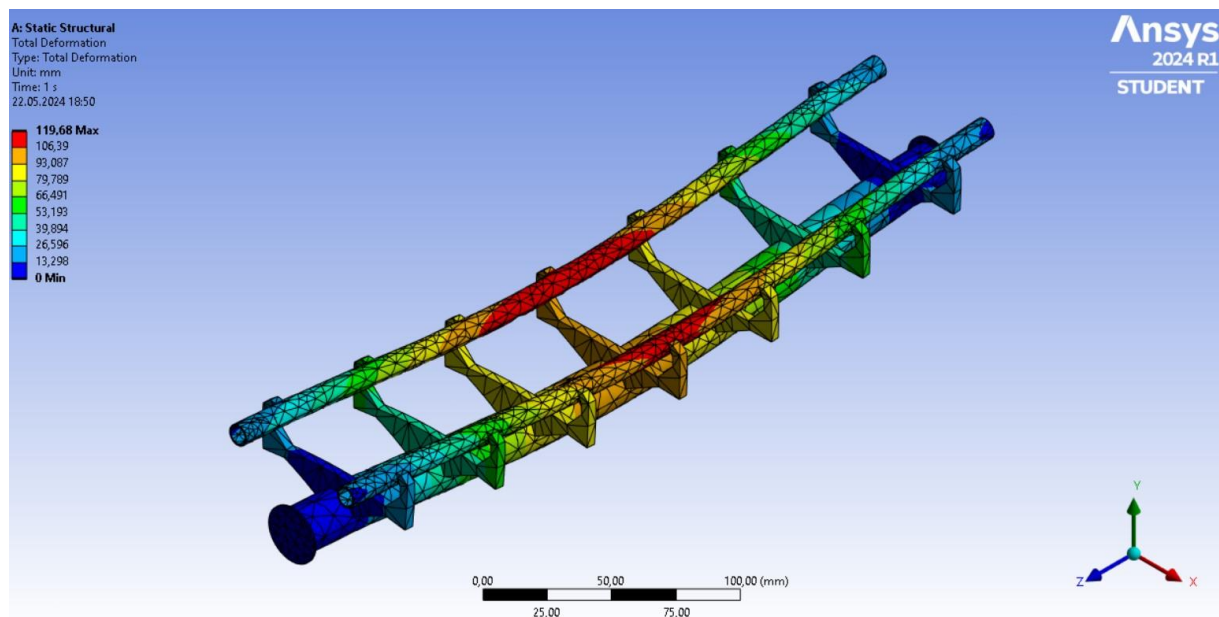


Figure 4.8 Total Deformation.

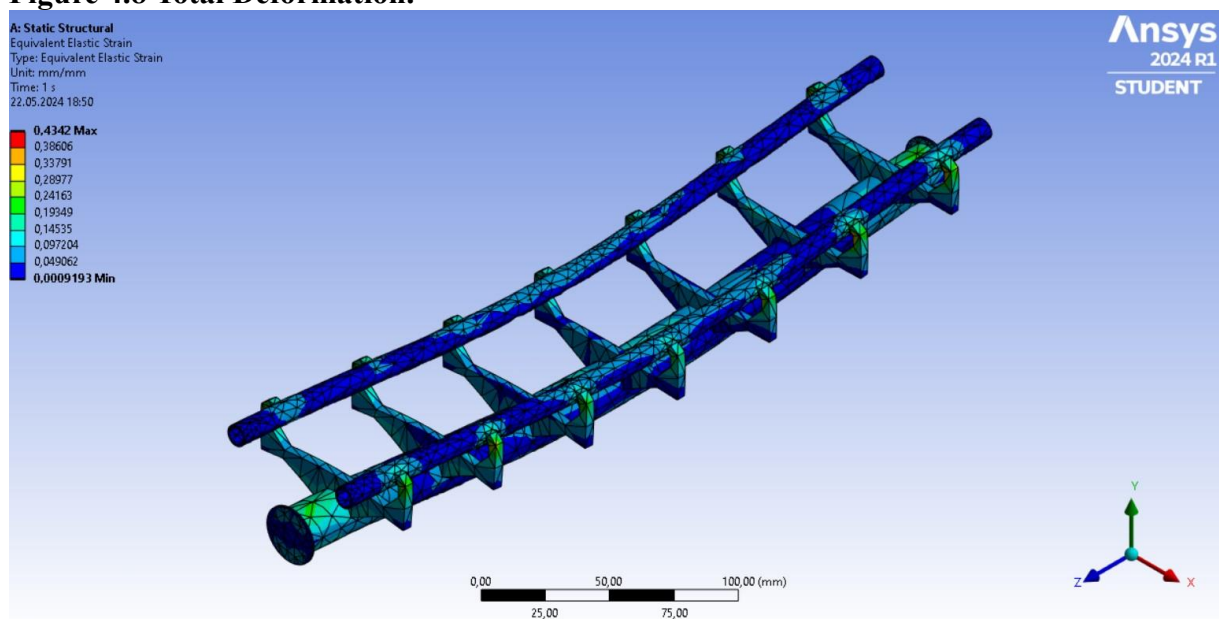


Figure 4.9 Von Misses.

Material AISI 1020;

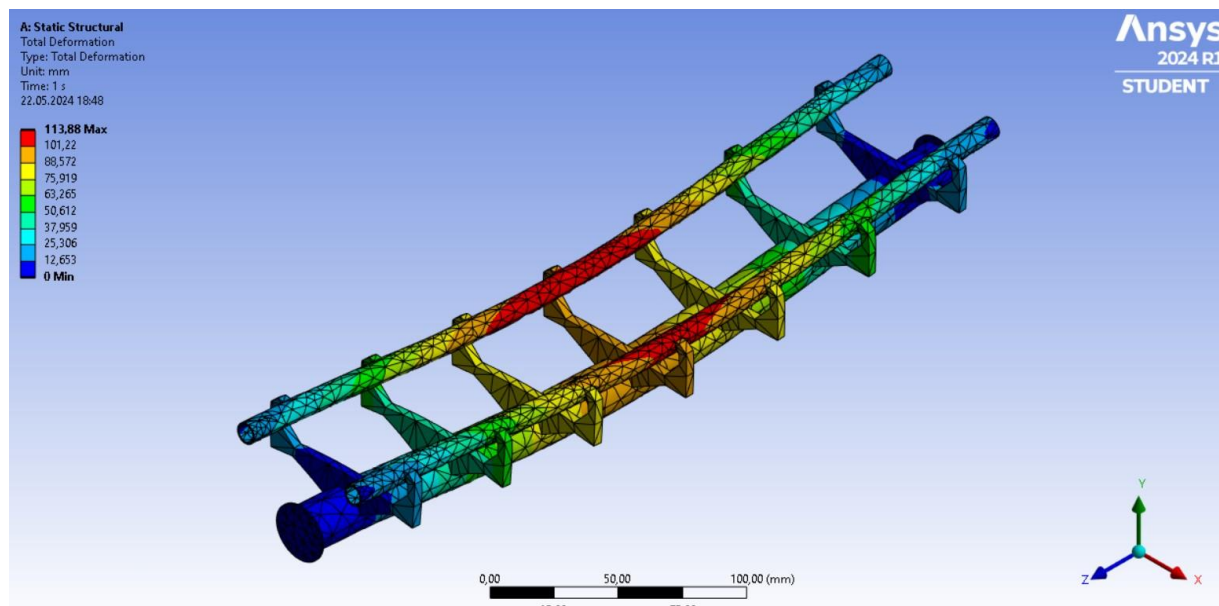


Figure 4.10 Total Deformation.

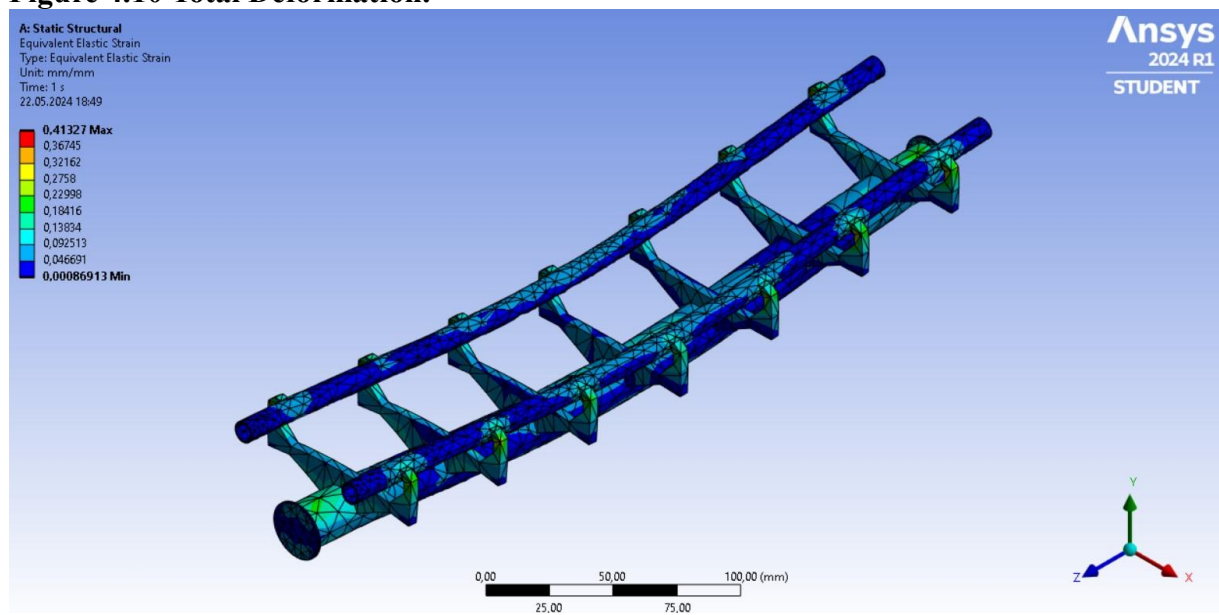


Figure 4.11 Von Misses.

Best Case Analys results for second design of roller coaster rails.

Material AISI 1018

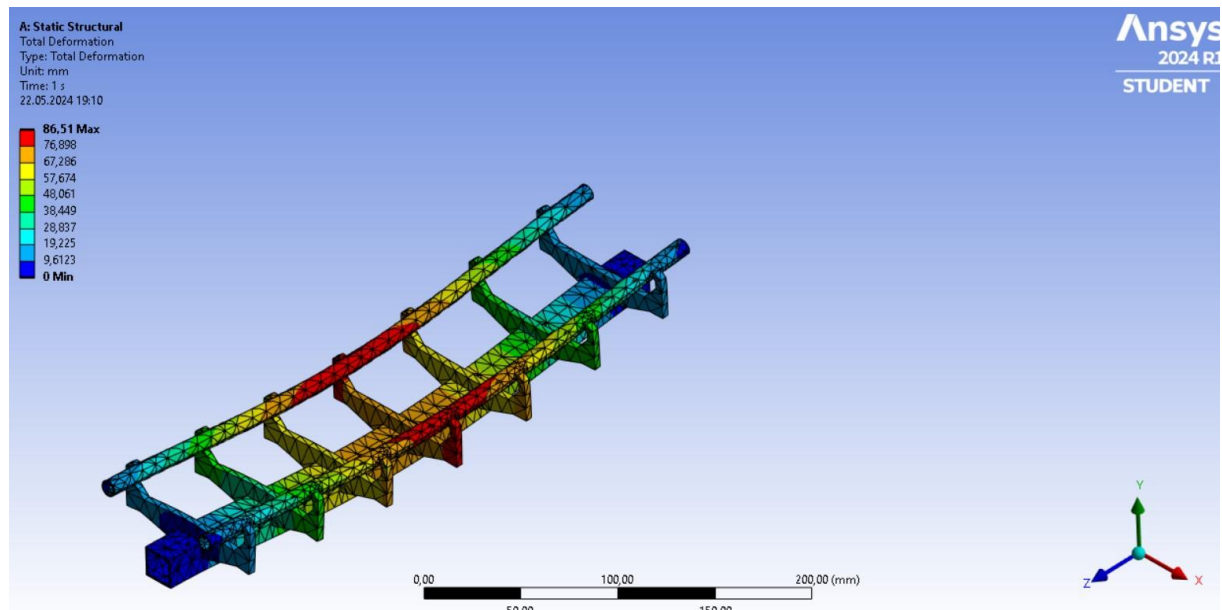


Figure 4.12 Total Deformation.

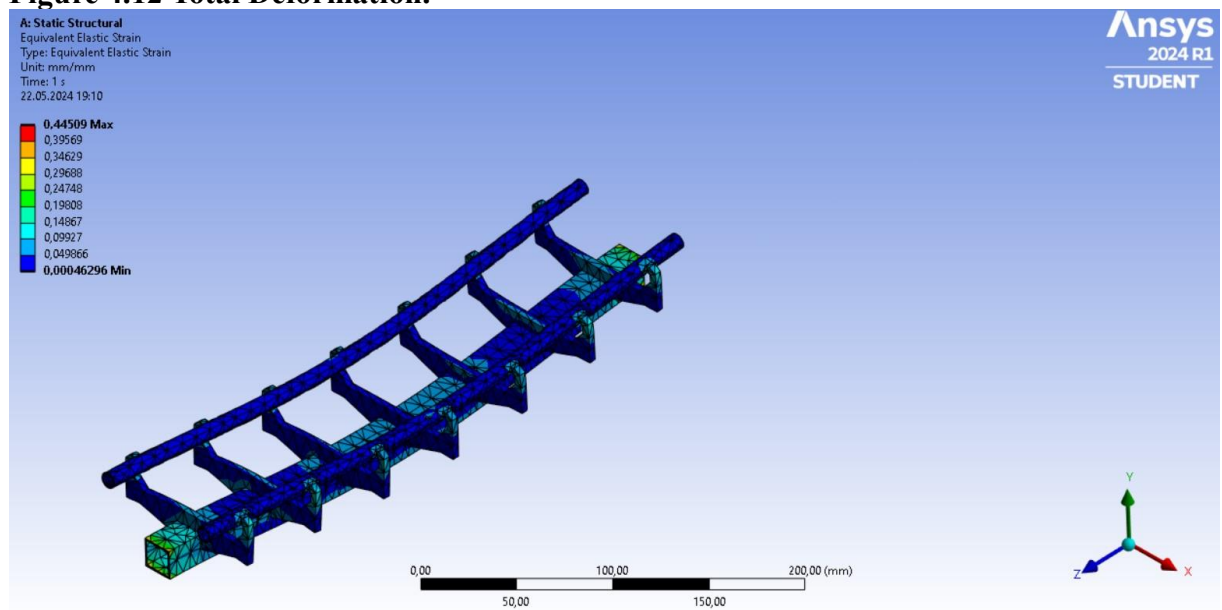


Figure 4.13 Von Misses.

Material AISI 1019;

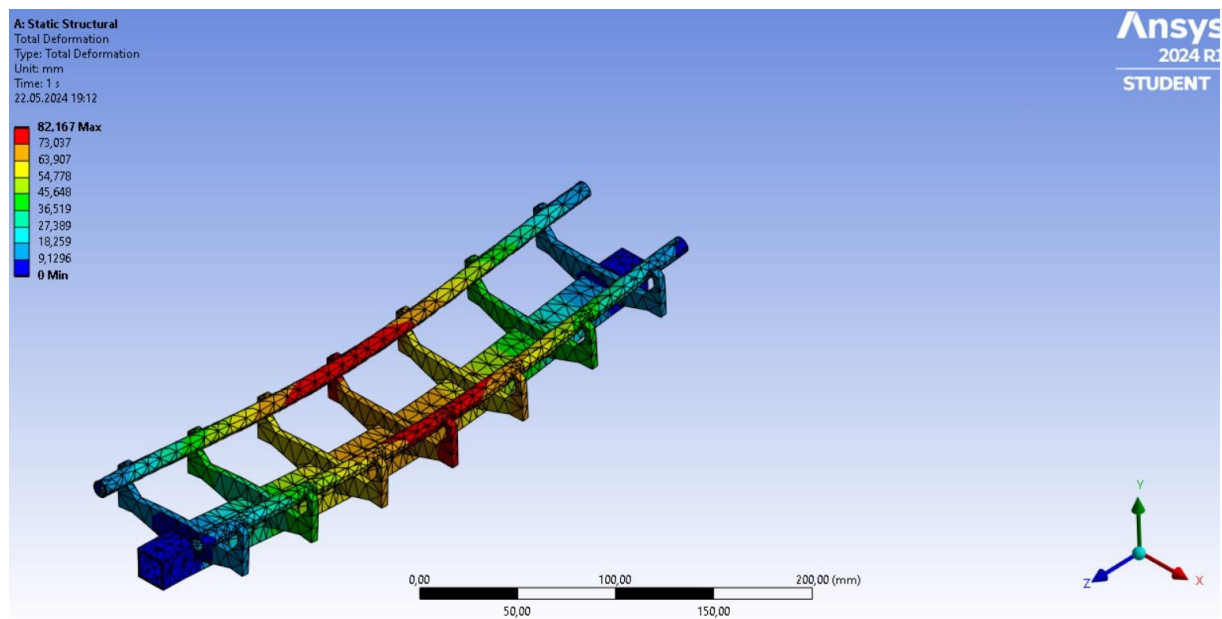


Figure 4.14 Total Deformation.

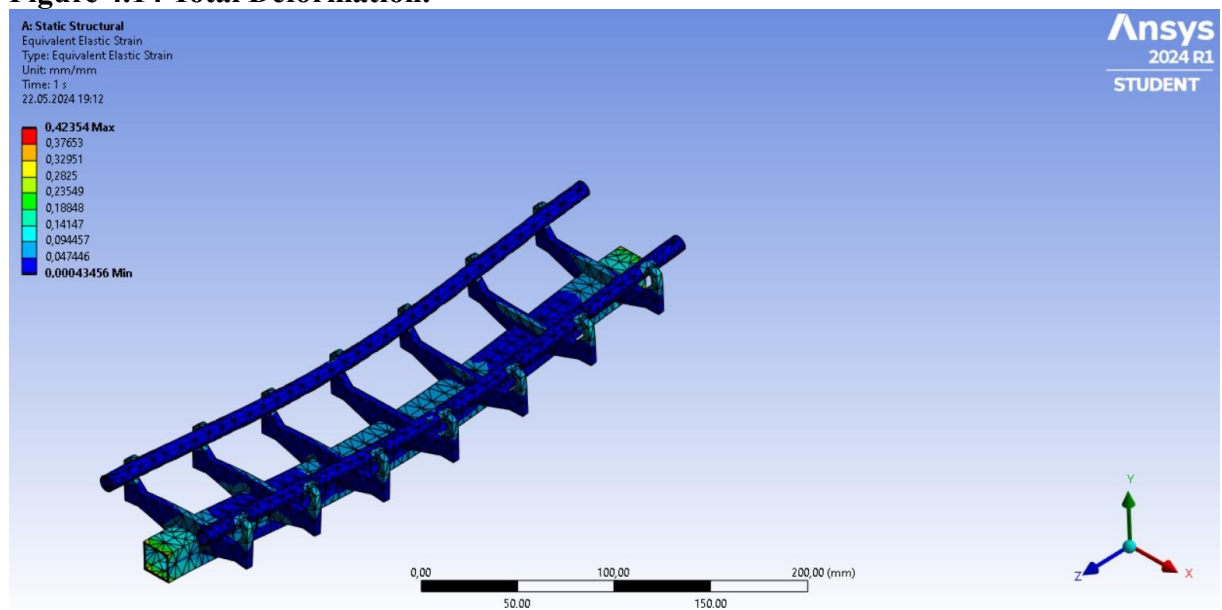


Figure 4.15 Von Misses.

Material AISI 1020;

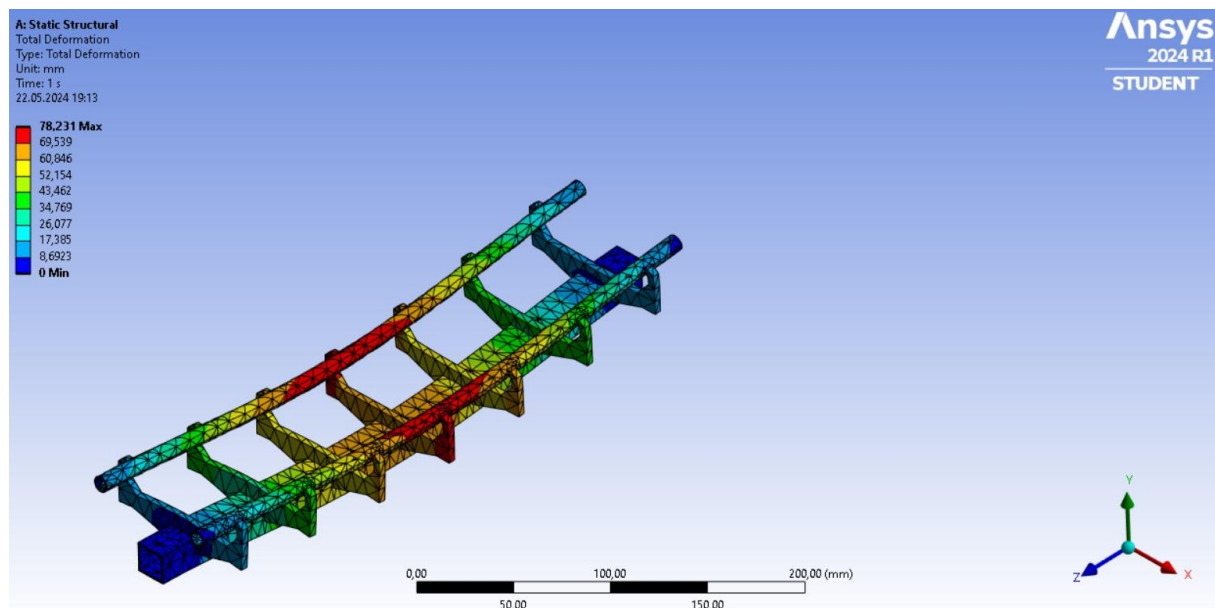


Figure 4.16 Total Deformation.

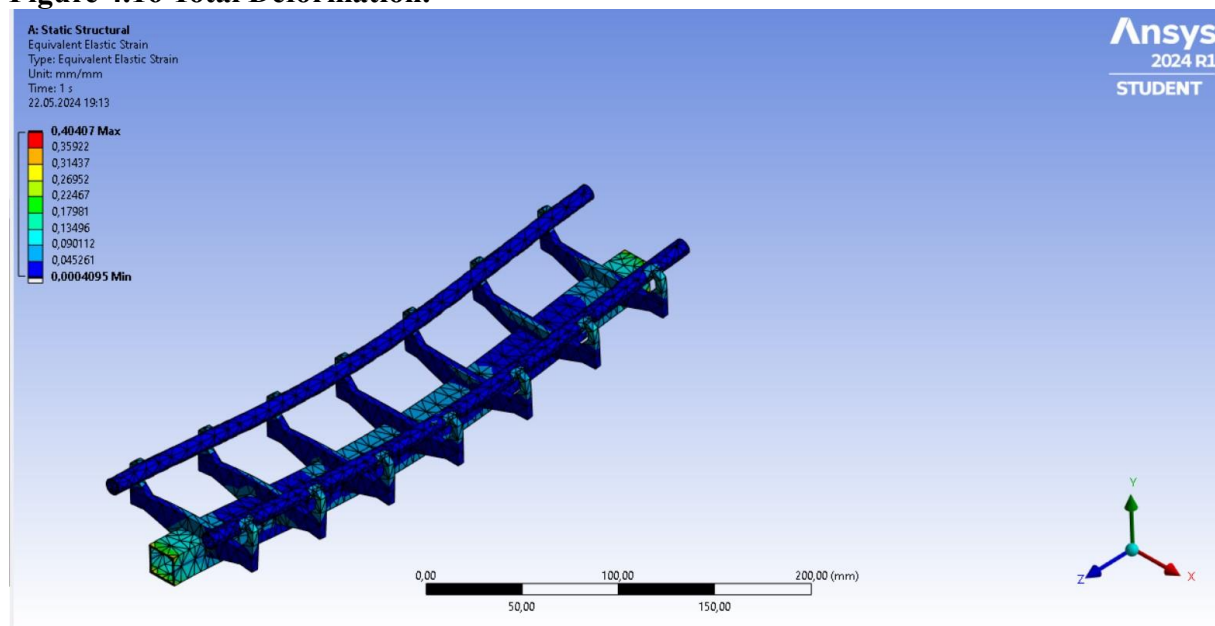


Figure 4.17 Von Misses.

Worst Case Analys results for second design of roller coaster rails.

Material AISI 1018;

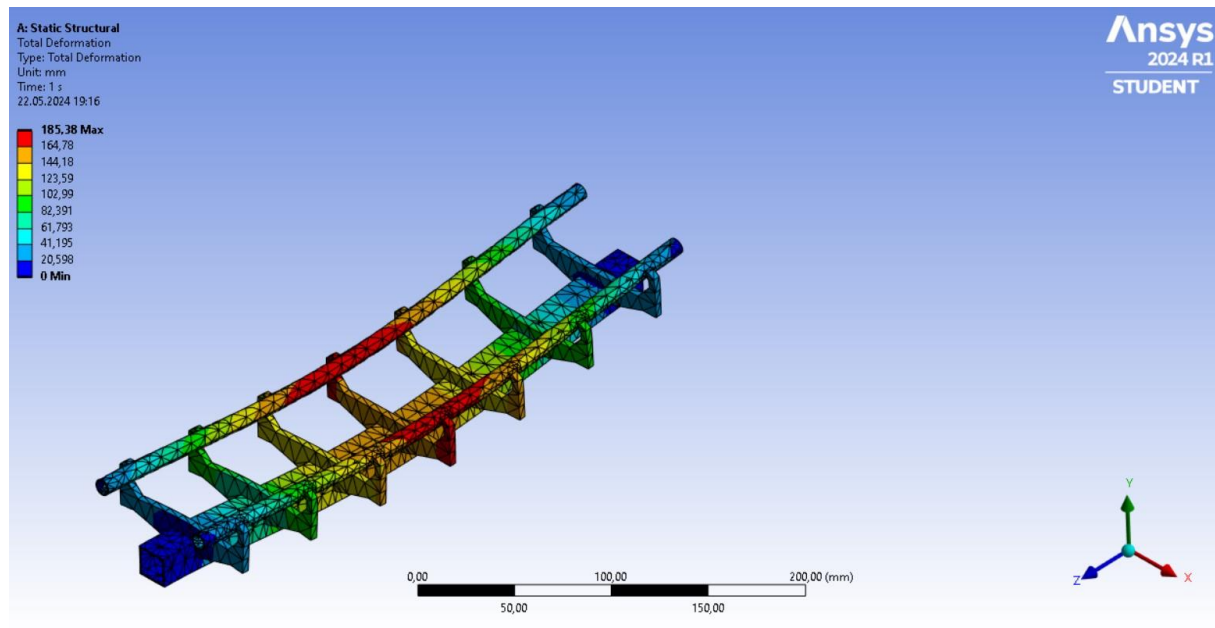


Figure 4.18 Total Deformation.

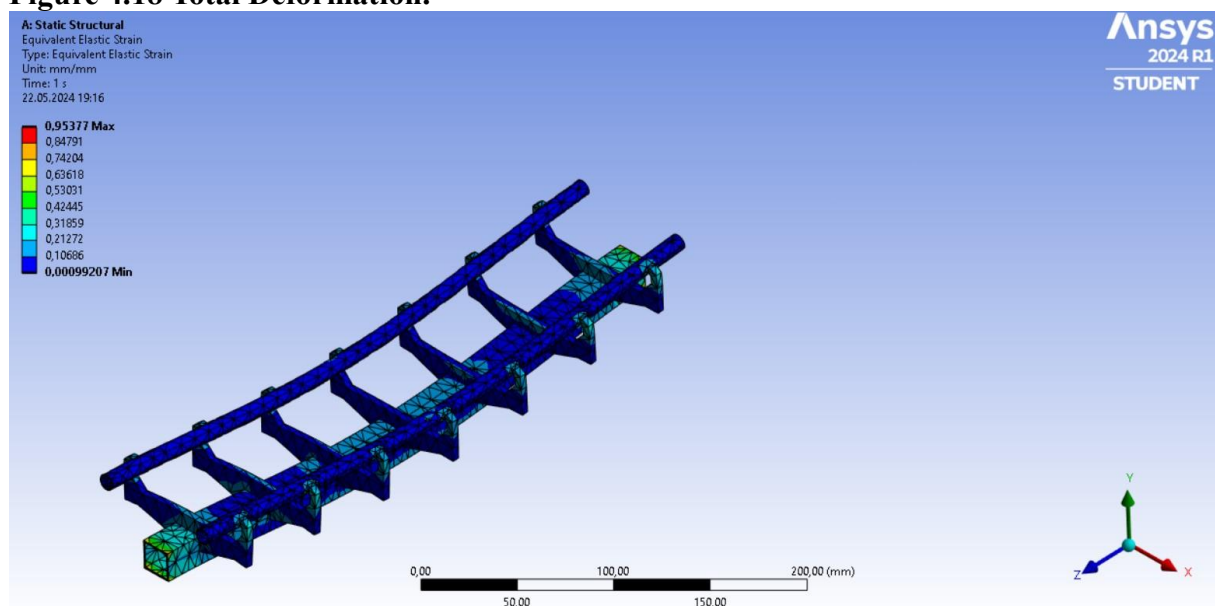


Figure 4.19 Von Misses.

Material AISI 1019;

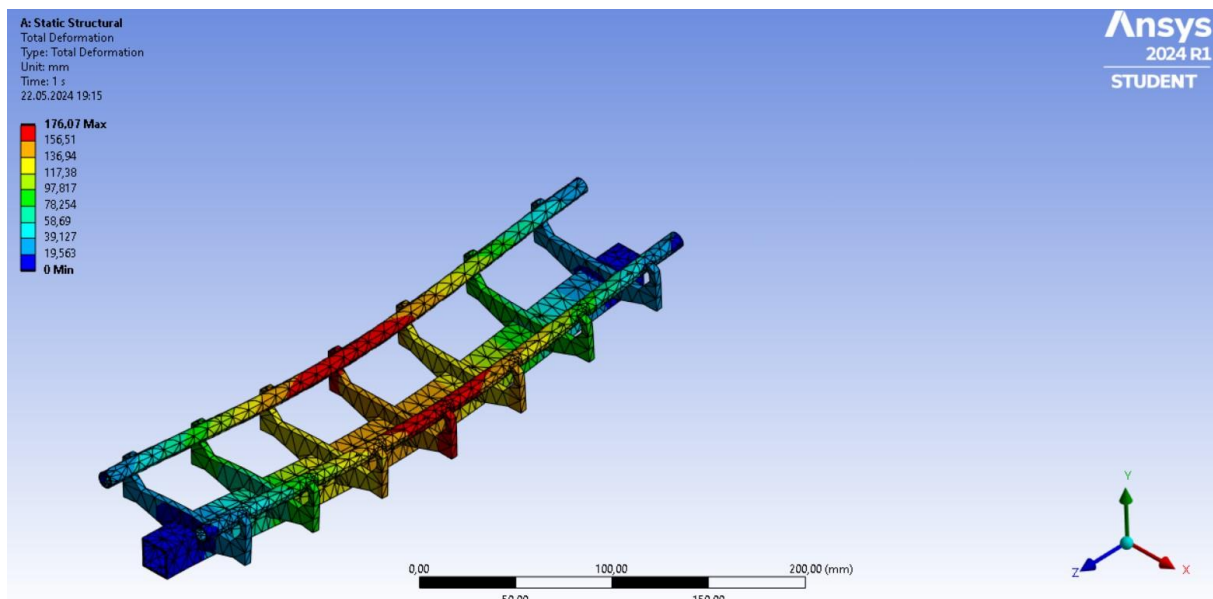


Figure 4.20 Total Deformation.

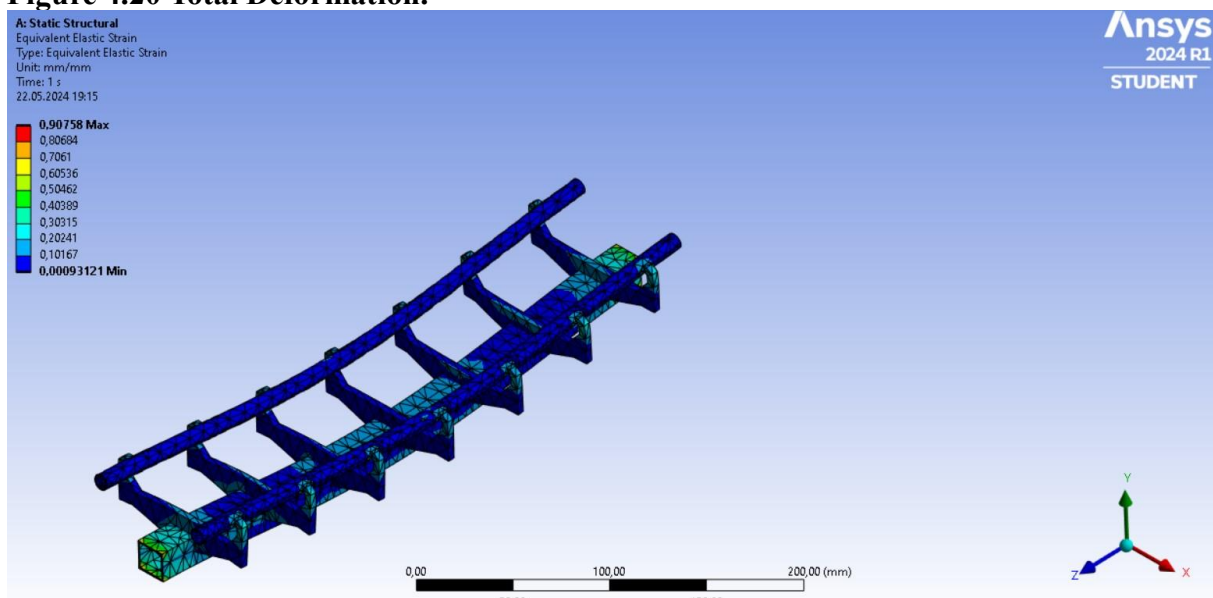


Figure 4.21 Von Misses.

Material AISI 1020;

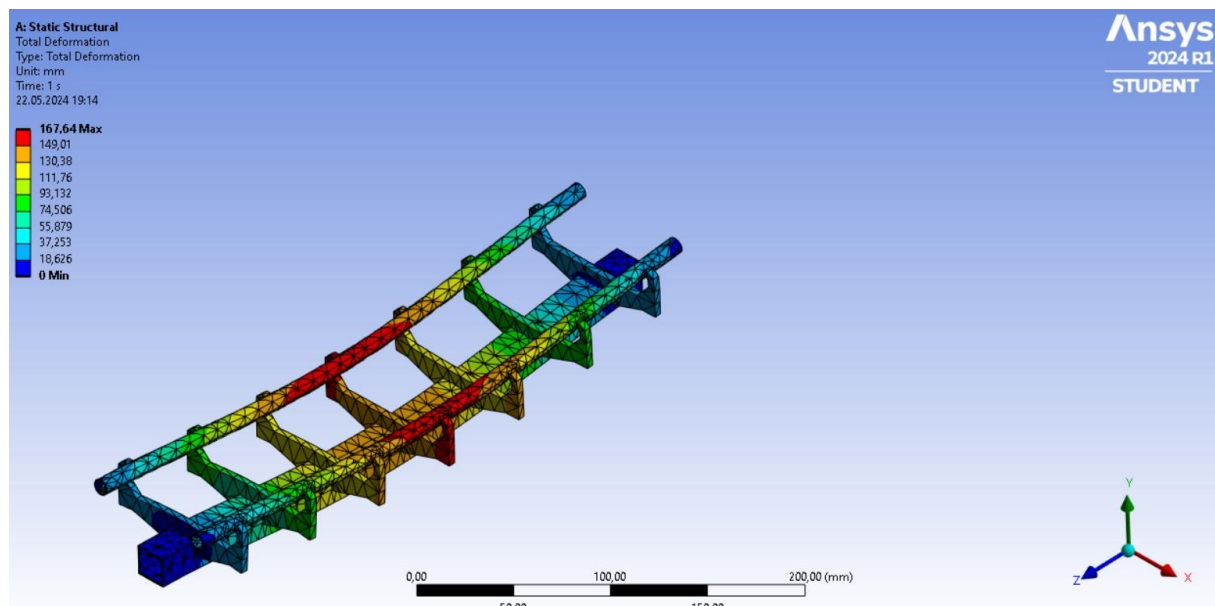


Figure 4.22 Total Deformation.

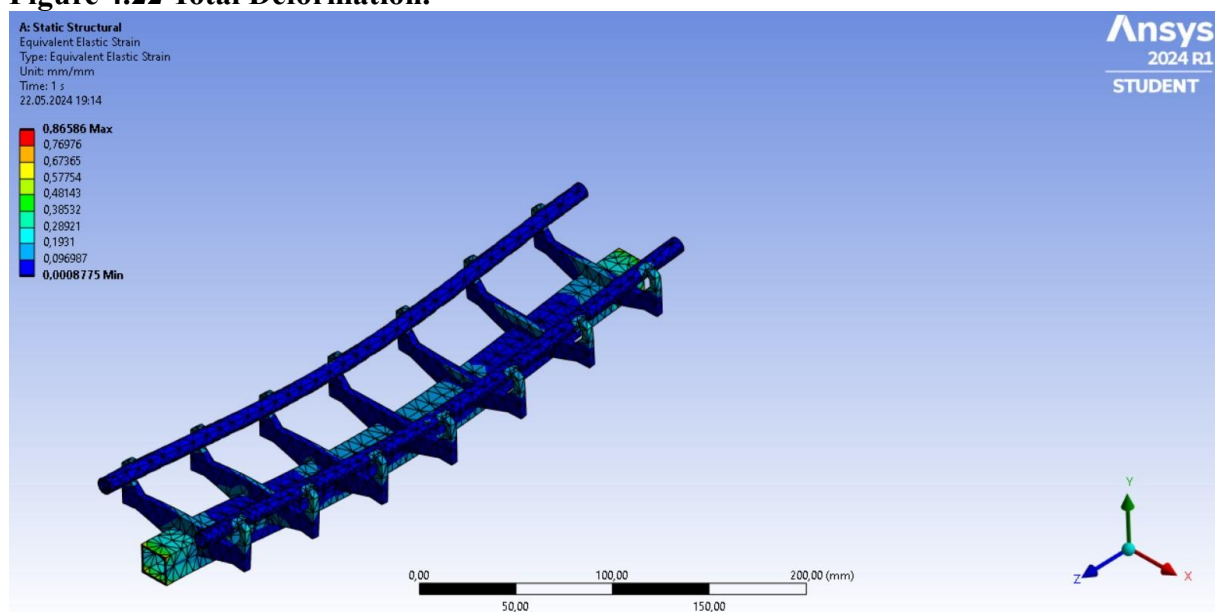


Figure 4.23 Von Misses.

Best Case Analys results for third design of roller coaster rails.

Material AISI 1018;

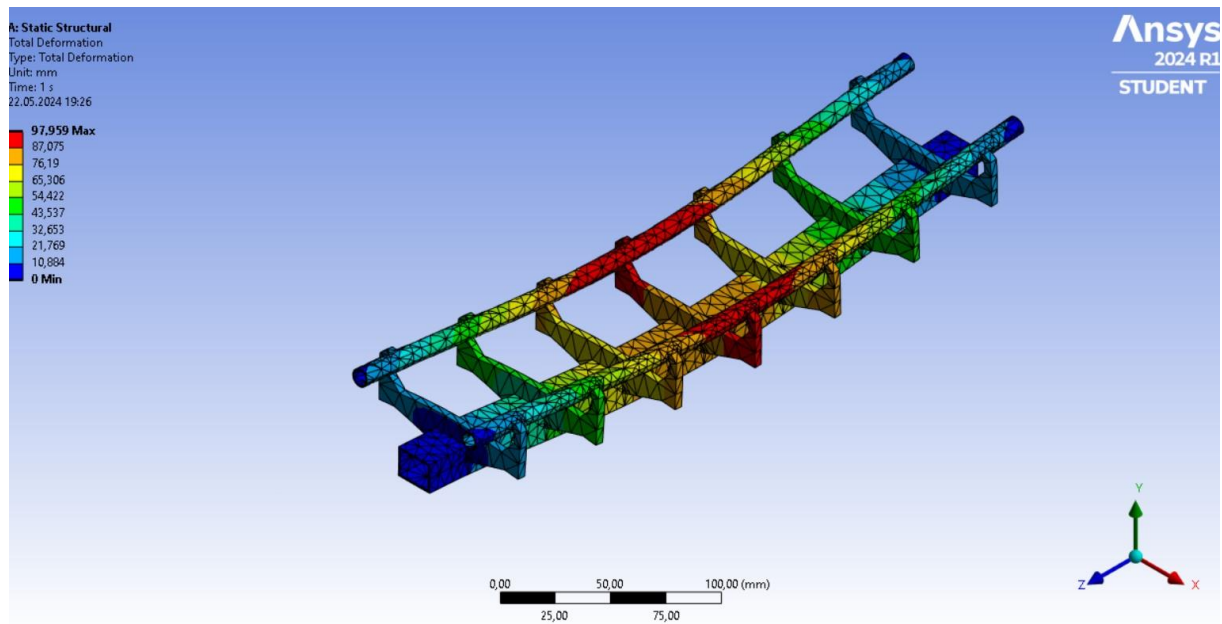


Figure 4.24 Total Deformation.

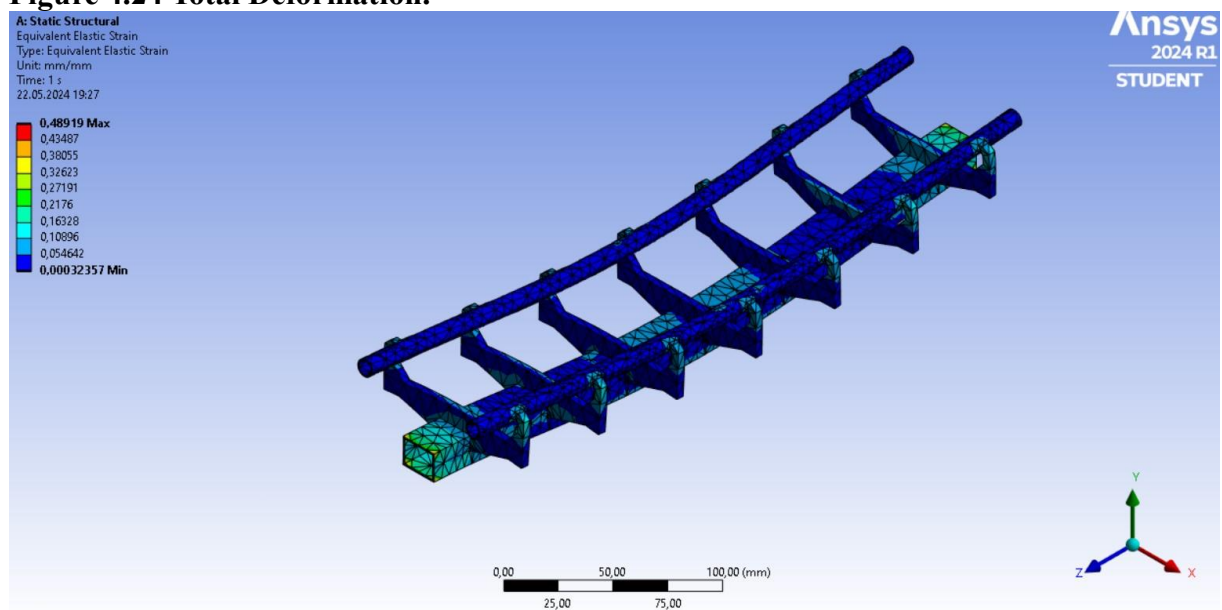


Figure 4.25 Von Misses.

Material AISI 1019;

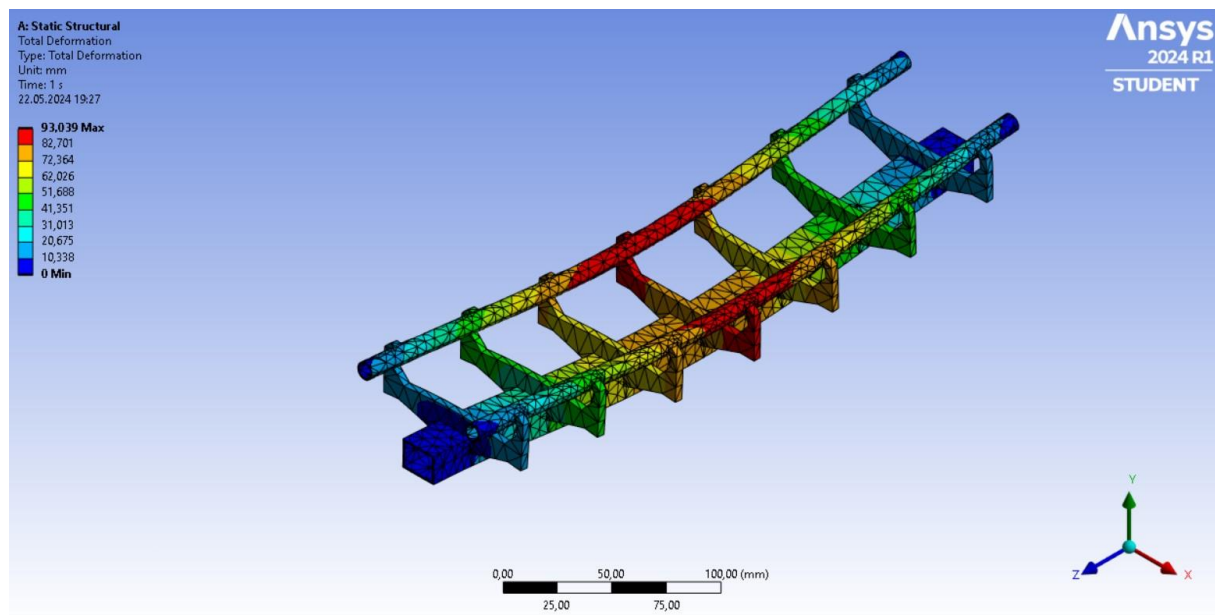


Figure 4.26 Total Deformation.

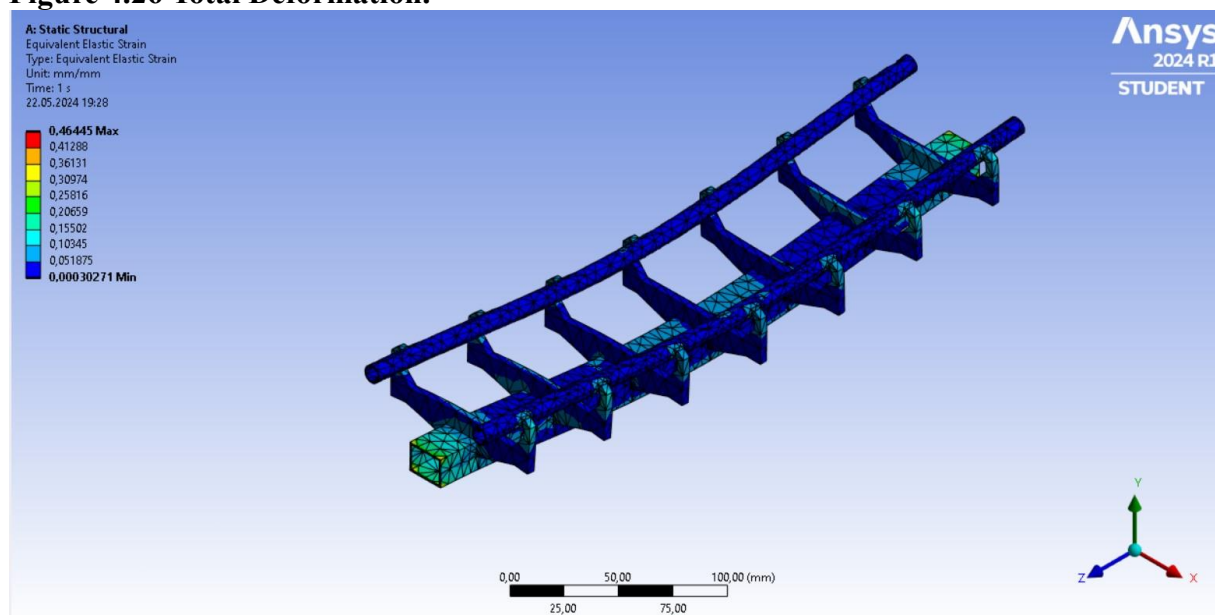


Figure 4.27 Von Misses.

Material AISI 1020;

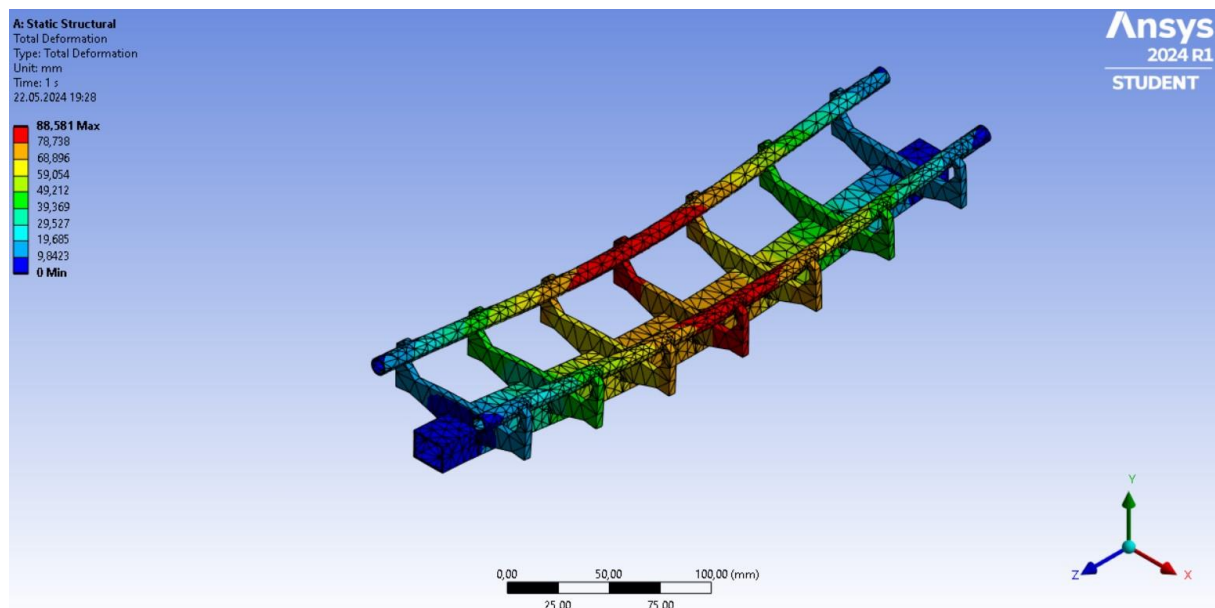


Figure 4.28 Total Deformation.

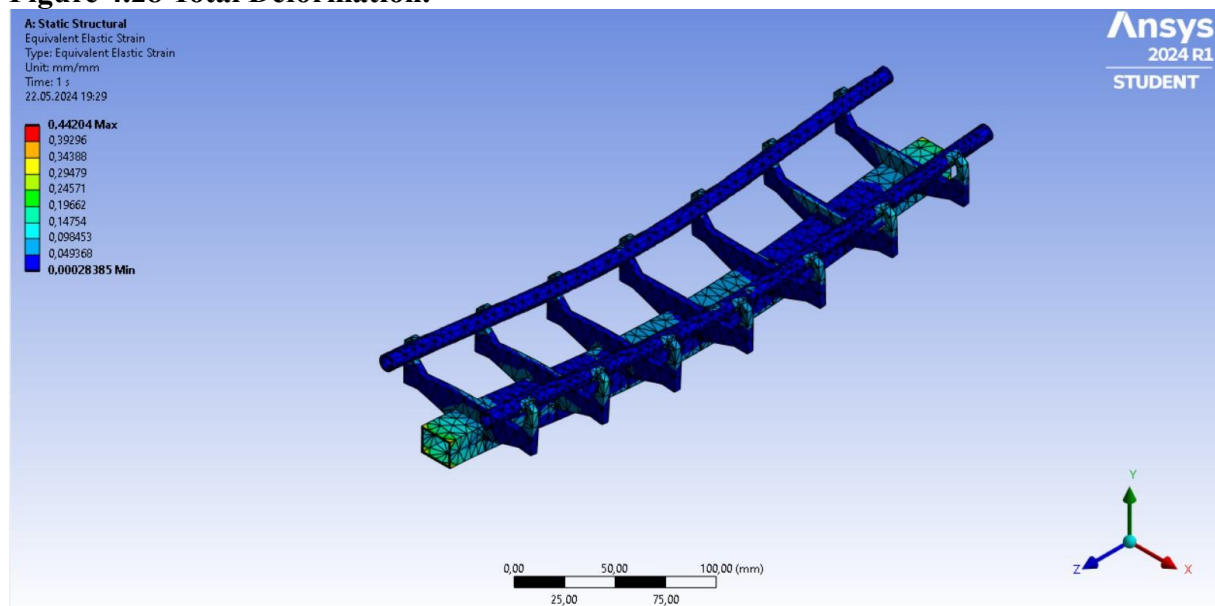


Figure 4.29 Von Misses.

Worst Case Analys results for third design of roller coaster rails.

Material AISI 1018;

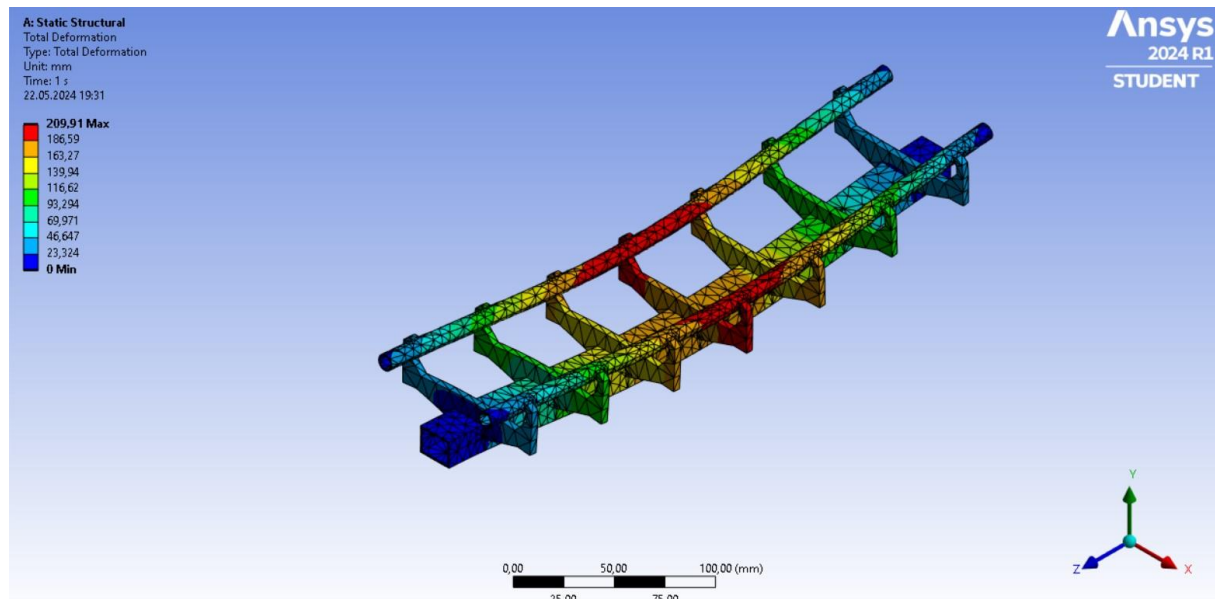


Figure 4.30 Total Deformation.

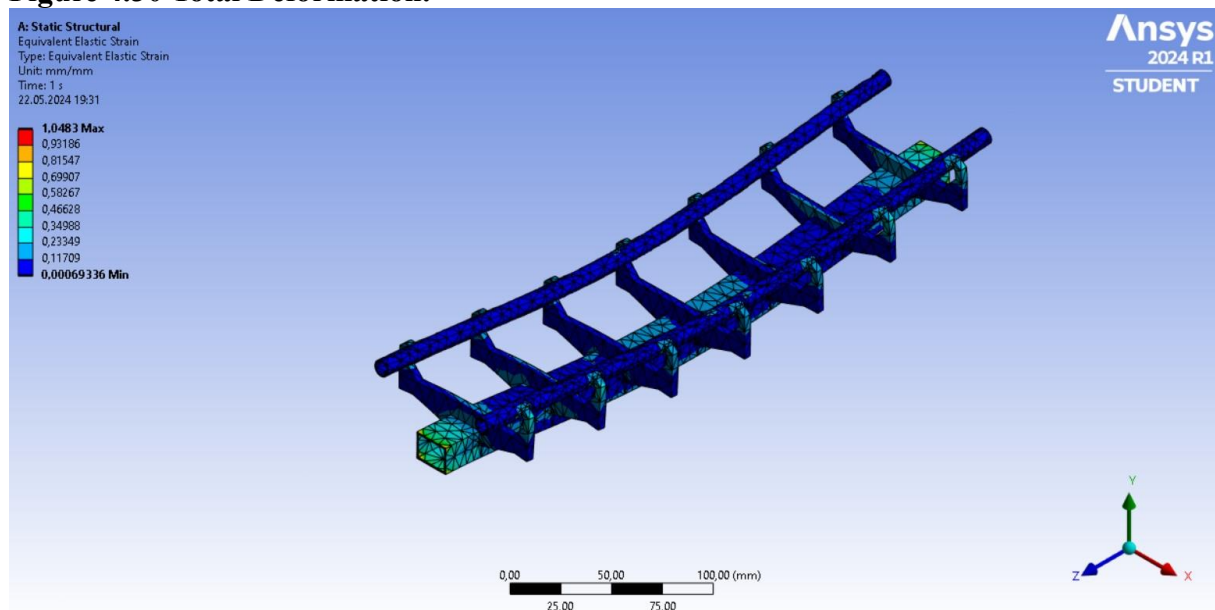


Figure 4.31 Von Misses.

Material AISI 1019;

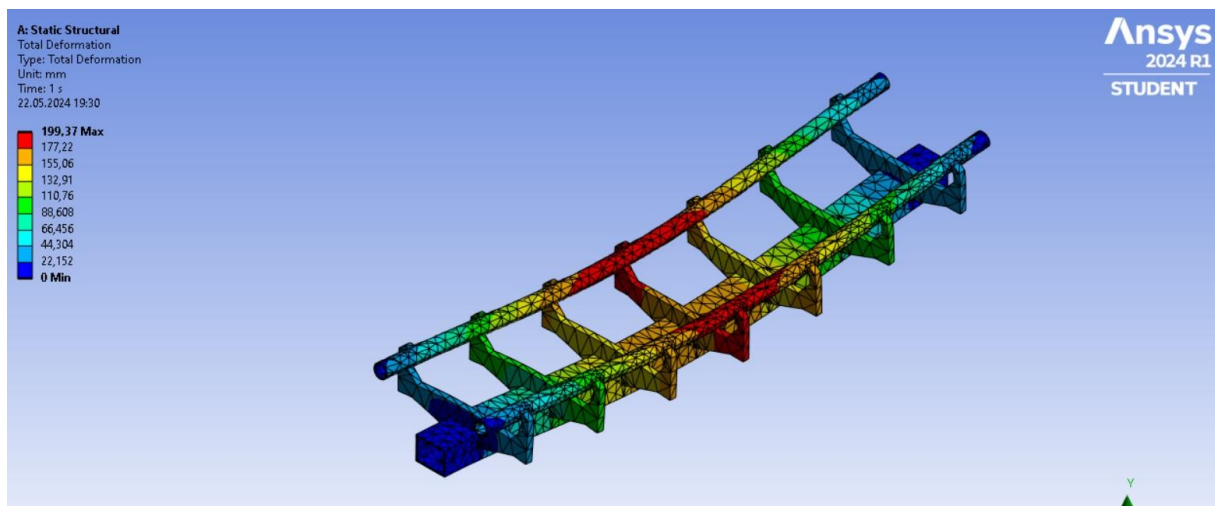


Figure 4.32 Total Deformation.

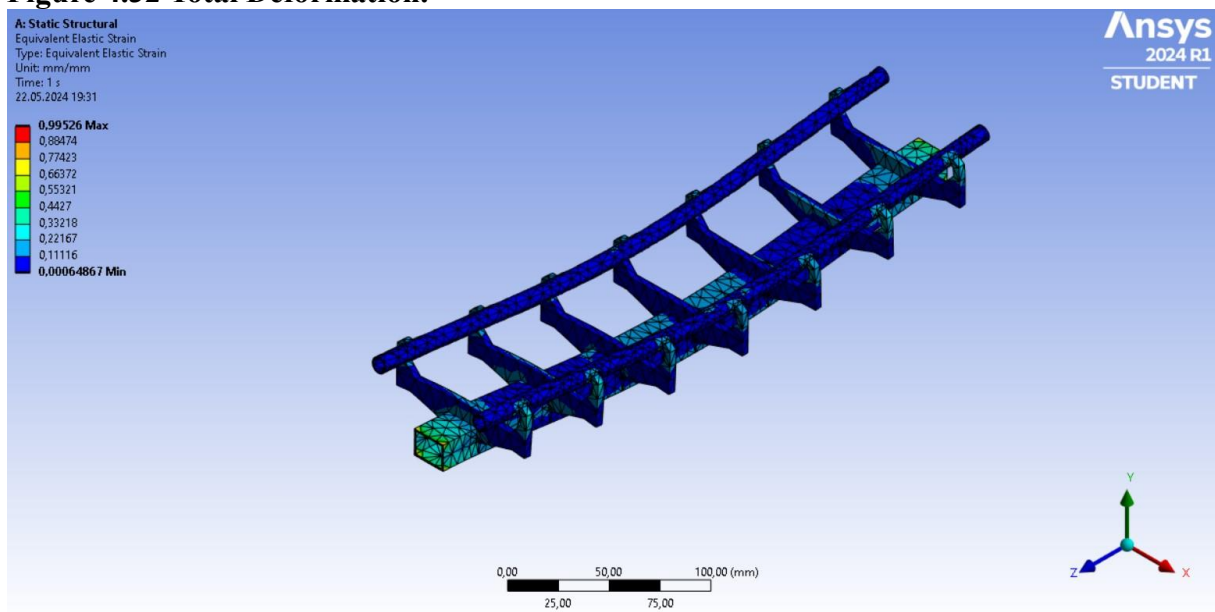


Figure 4.33 Von Misses.

Material AISI 1020;

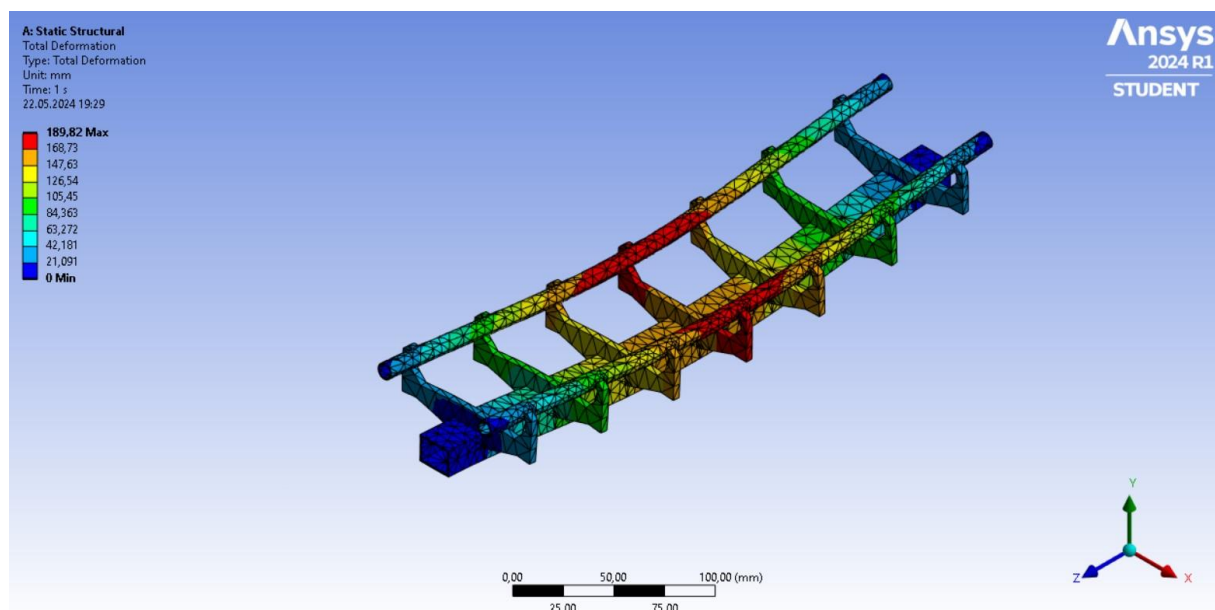


Figure 4.34 Total Deformation.

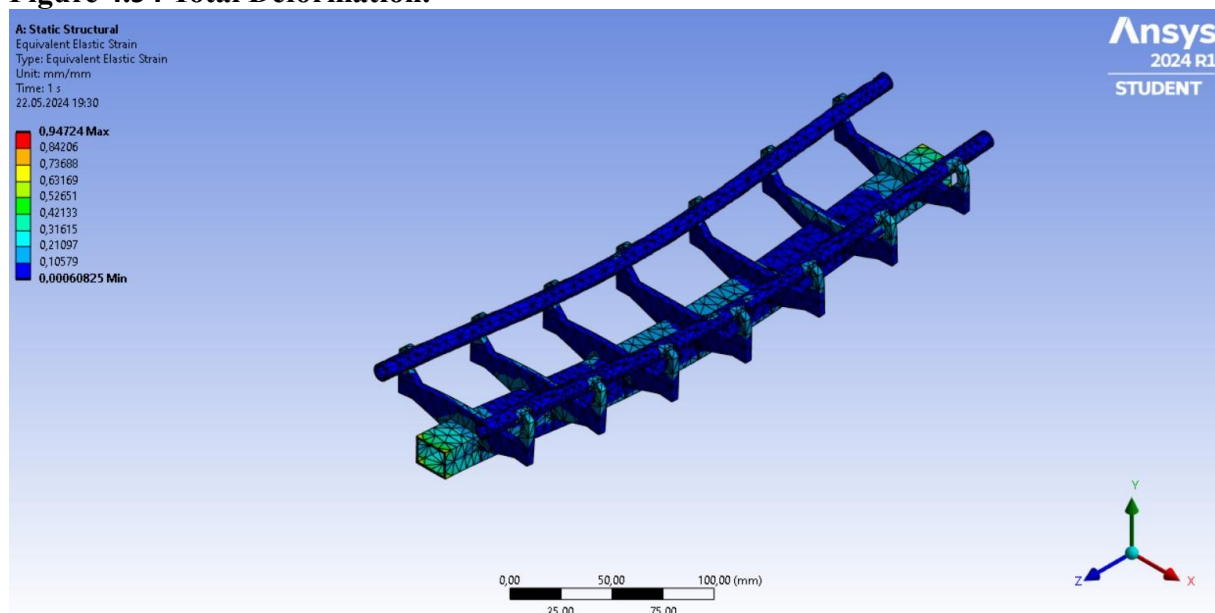


Figure 4.35 Von Misses.

By leveraging the data obtained from the finite element analysis under both best-case (70 MPa) and worst-case (150 MPa) loading scenarios, the Taguchi Method's "smaller-the-better" signal-to-noise (S/N) ratio will be calculated. This S/N ratio will serve as the key metric for identifying the optimal rail design configuration within the project's context. As minimizing deformation in the roller coaster rails is the primary objective, designs with lower S/N ratios will be considered superior. This approach ensures that the chosen design exhibits the most favorable performance in terms of resisting deformation under the anticipated operational loads.

Sütun1 ▼	Sütun3 ▼	Sütun4 ▼	Sütun5 ▼
L9	Y1	Y2	S/N
1	58.842	126,09	-37.785
2	86,51	185,38	-43.206
3	97,959	209,91	-44.286
4	55,852	119,68	-39.405
5	82,167	176,07	-42.759
6	93,039	199,37	-43.838
7	53,143	113,88	-48.211
8	78,231	167,64	-42.332
9	88,581	189,82	-43.412

Figure 4.36 Taguchi Results.

The analysis of the data presented to Figure 4.37 allows for the selection of the optimal material for the roller coaster rails based on minimal deformation. This analysis suggests that AISI 1020 emerges as the most suitable material for this project due to its [observed property, e.g., superior stiffness, lower deflection under load].

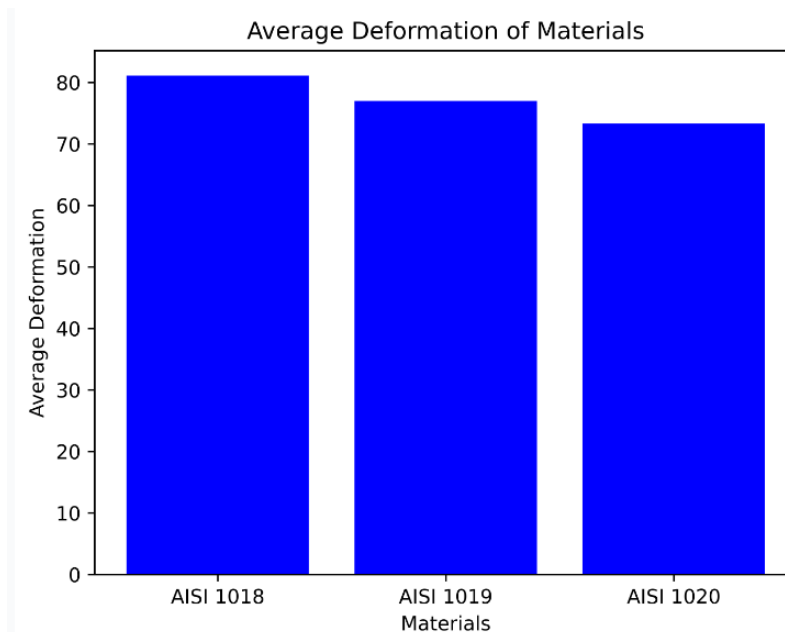


Figure 4.37 Average Deformation of Materials Graph.

The culmination of the Taguchi Method analysis, including the evaluation of S/N ratios, identifies design configuration number 7 as the optimal choice for our roller coaster rails. This selection is based on its demonstrably lower deformation compared to other configurations, directly aligning with the project's objective of minimizing rail deflection under operational loads.

Number 7;

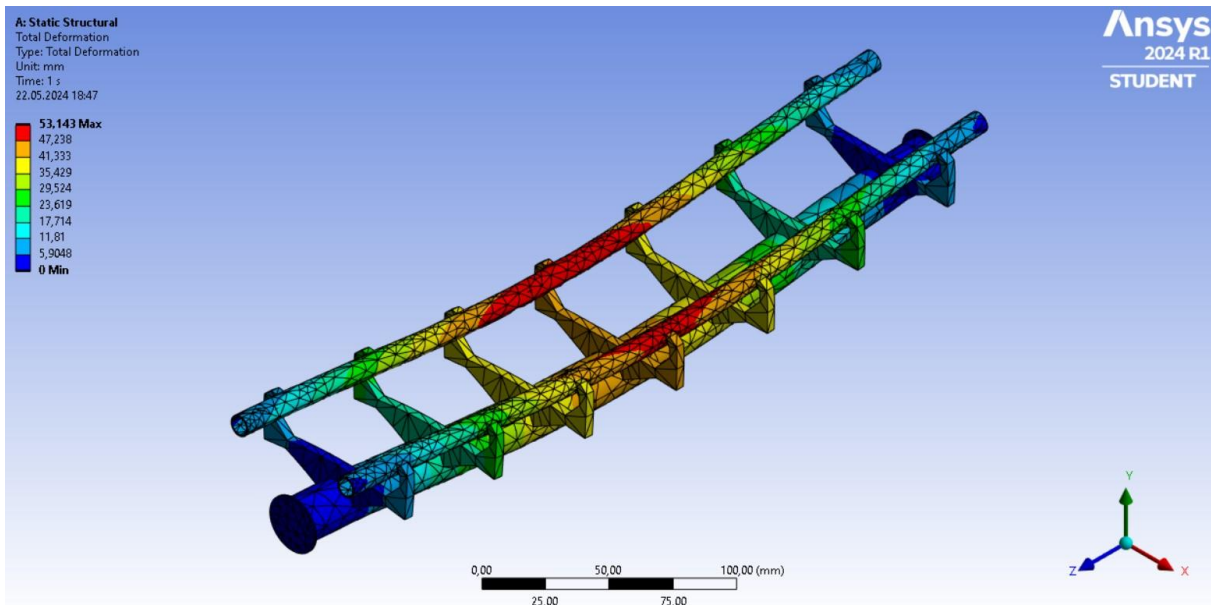


Figure 4.38 Best Case Total Deformation with Material AISI 1020.

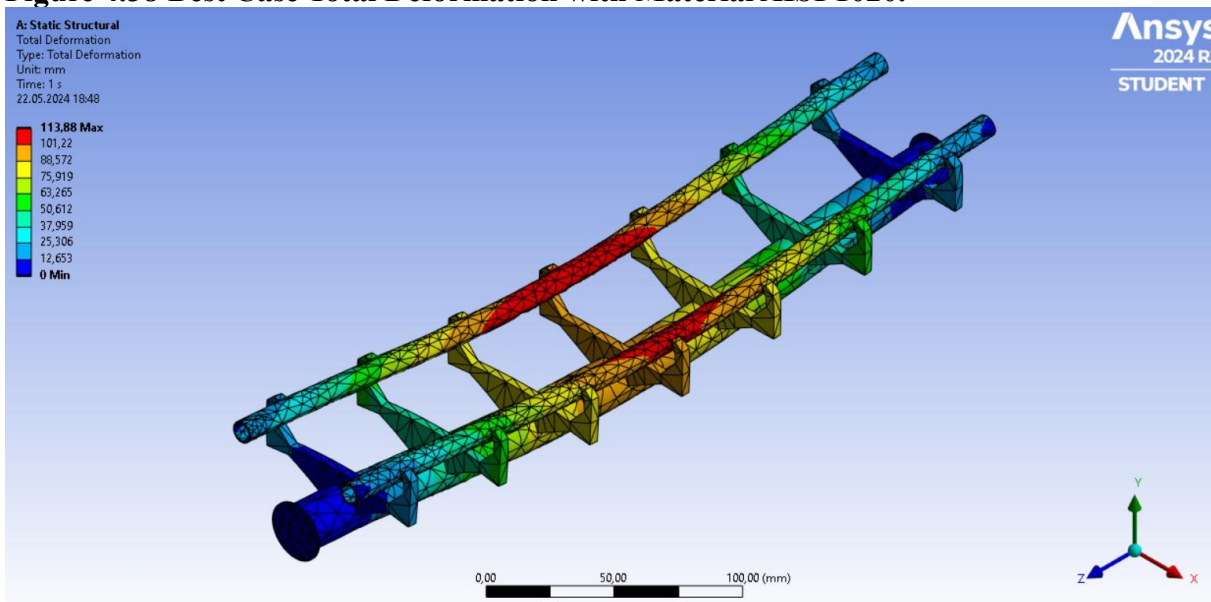


Figure 4.39 Worst Case Total Deformation with Material AISI 1020.

Technical Drawings For Number 7

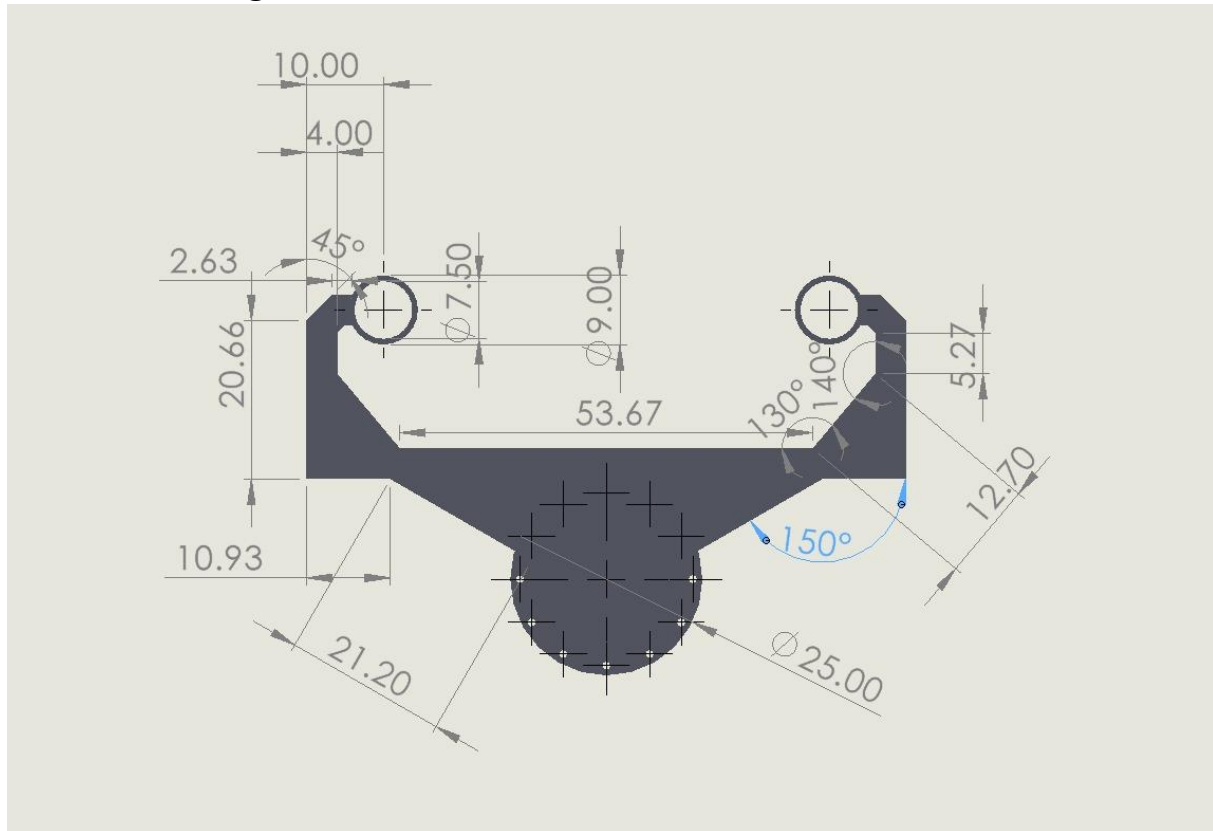


Figure 4.40 Technical Drawing.



Figure 4.41 Technical Drawing.

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