DESIGN OF MACHINE ELEMENTS
(MTS -322)

DE-43 Mechatronics

Syndicate – A

Project Report

Theoretical and Simulation-Based Analysis of the NERC Robot

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Table of Contents

1. Abstract:

This report provides a theoretical and simulation-based analysis of the National Engineering Robotics Contest (NERC) robot, specifically designed with a focus on the theme of tree planting, however this module of the project is limited to line following and basic path planning. Theoretically calculation of stress analysis is done on the base and verified with the help of simulation based analysis in Ansys Software. All the required Calculations and Methods are explained in the report along with the steps of Simulations of the base in the mentioned Software.

2. Introduction:

In the pursuit of optimizing the structural integrity and performance of our robot base for the National Engineering Robotics Contest (NERC), this report meticulously examines each hole and screw through the lens of design of machine elements principles. The theoretical calculations delve into stress analysis, ensuring that every component of the base is designed to withstand operational loads and environmental stresses. Employing established concepts and formulae from the design of machine elements discipline, our approach aims to guarantee robustness and reliability in the mechanical aspects of the robot.

Furthermore, to validate and complement the theoretical calculations, extensive simulations were conducted using ANSYS software. ANSYS provides a powerful platform for finite element analysis, enabling us to visualize and quantify the structural behavior of the robot base under varying conditions. This report seamlessly integrates the insights garnered from theoretical calculations with the results obtained from ANSYS simulations, fostering a comprehensive understanding of the base's mechanical characteristics.

Through this dual approach, we not only ensure that the robot base is theoretically sound and adheres to design standards but also verify its performance in virtual environments. The comparative analysis of theoretical calculations and ANSYS simulations serves as a robust methodology to refine and enhance the design, contributing to the overall success of our robot in the NERC competition.

3. Materials and Methods:

3.1 Base Design:

The foundation of our robot for the National Engineering Robotics Contest (NERC) is constructed using robust and durable materials to ensure structural integrity and reliability. The primary material chosen for the base is cast iron. The use of iron provides the necessary strength and rigidity required to withstand operational loads and environmental stresses. The cast iron base serves as a sturdy platform to house the essential components, including the 24 V motors, electronics, and the tree planting mechanism.

Base Material: Cast Iron

Description:

- **Type of Material:** Cast iron is a strong and brittle material known for its excellent castability, wear resistance, and damping properties.
- **Properties:**
  - **High Strength***:* Cast iron exhibits high compressive strength, making it suitable for applications where structural integrity is crucial.
  - **Wear Resistance***:* Cast iron is known for its wear resistance, reducing the impact of friction and abrasion on the material over time.
  - **Damping Capacity***:* It has good damping capacity, meaning it can absorb and dissipate vibrations, contributing to the overall stability of the structure.
  - **Heat Resistance***:* Cast iron can withstand high temperatures without losing its structural properties, making it suitable for applications where heat may be generated.

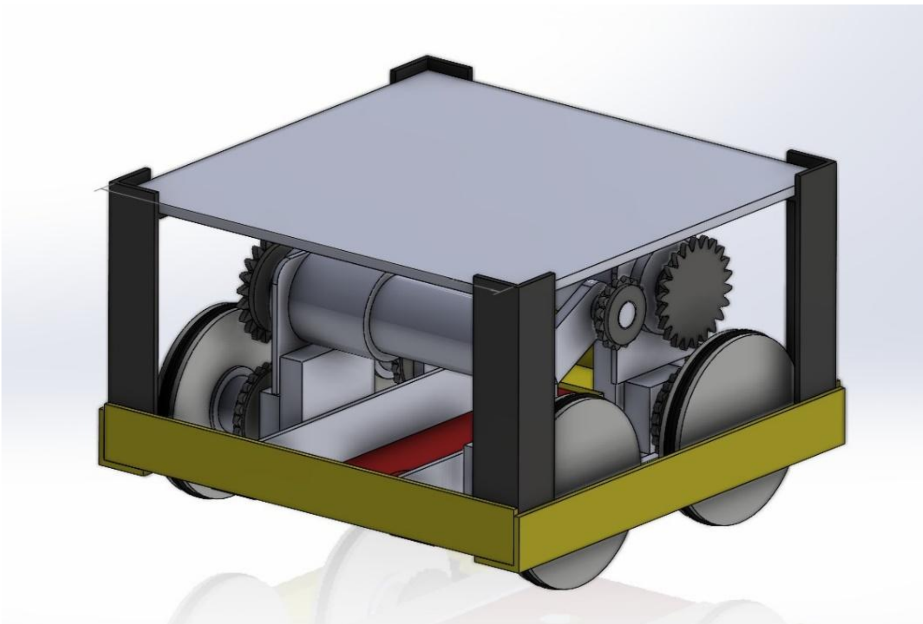


Figure 1: Base design

3.2 Motors:

The propulsion system of the robot is powered by 24 V motors, carefully selected for their efficiency and power output. The motors are a crucial component in determining the robot's mobility and performance during the competition. The choice of steel for the motor construction ensures durability and resilience, essential for withstanding the demands of varied terrains and operational conditions.

Motor Material: Steel Components

Description:

- **Motor Casing:** The casing or housing of the 24 V motors is constructed from high-quality steel. This steel casing provides protection for internal components and contributes to the motor's structural integrity.
- **Rotor and Stator Components:** Internal components, including the rotor and stator, may be made of steel or steel alloys. These materials are chosen for their magnetic properties, facilitating efficient energy conversion within the motor.
- **Shaft Material:** The shaft connecting the motor to other mechanical components is typically made of steel. Steel ensures the shaft's strength, rigidity, and resistance to bending.
- **Bearings:** Bearings within the motor, essential for smooth rotation and reduced friction, may also feature steel components for durability and efficiency.

Properties:

- **Strength and Durability:** Steel components in the motor contribute to overall strength and durability, enabling the motor to withstand operational stresses.
- **Magnetic Properties:** Steel's magnetic properties are advantageous for efficient energy conversion within the motor.

Advantages:

- **Robust Construction:** Steel components in the motor contribute to a robust and reliable power source for the robot.
- **Heat Dissipation:** Steel's ability to dissipate heat efficiently is beneficial for preventing motor overheating during extended operation.

Figure 2: 24 V Steel Motors

3.3 Wheels:

The wheels of the robot are equipped with tires made from high-quality nylon. Nylon is chosen for its excellent grip, shock absorption, and resistance to wear and tear. These properties are critical for effective traction and maneuverability, particularly in the context of tree planting where the robot may encounter uneven or challenging terrains. The nylon tires also contribute to minimizing vibrations, enhancing the overall stability of the robot during operation.

Wheel Material: Nylon

Description:

- **Type of Material:** Nylon is a synthetic polymer belonging to the polyamide family, known for its excellent mechanical properties, wear resistance, and low coefficient of friction.
- **Properties:**
    - **High Strength and Toughness***:* Nylon exhibits a combination of high tensile strength and toughness, making it suitable for applications where mechanical durability is essential.
    - **Low Friction***:* Nylon's low coefficient of friction allows for smooth and efficient movement, particularly crucial for wheels where minimizing resistance is beneficial.
    - **Abrasion Resistance***:* Nylon is resistant to abrasion, ensuring that the wheels can withstand wear and tear over time.
    - **Chemical Resistance***:* It possesses good resistance to various chemicals, enhancing its durability in diverse environmental conditions.

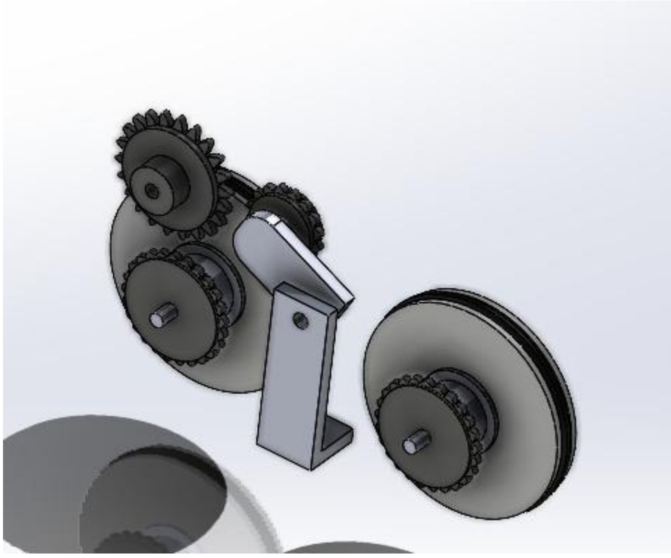


Figure 3: Rubber Wheels

3.4 Fastening Components:

Various screws and fasteners are employed in assembling the different parts of the robot base. The choice of appropriate fastening components is essential to ensure the structural integrity of the entire system. High-strength steel screws are utilized, aligning with the material properties of the base and providing a secure and reliable connection between components.

Fastening Components Material: High-Strength Steel Screws and Fasteners

Description:

- **Material Grade:** High-strength steel screws and fasteners are chosen to match the material properties of the base. Common grades include stainless steel or alloy steel, depending on the specific requirements of the application.
- **Properties:** High-strength steel fasteners offer excellent tensile strength, durability, and corrosion resistance. These properties are essential for maintaining the structural integrity of the robot by securely fastening various components.
- **Size and Type:** The size and type of screws and fasteners are carefully selected based on the design specifications to ensure proper assembly and stability.

3.5 Design of Machine Elements Calculations:

The materials used in the construction of the robot base are subjected to theoretical calculations based on design of machine elements concepts. Stress analysis is performed to evaluate the adequacy of the selected materials and ensure that they meet the required safety factors and design standards. These calculations serve as a foundation for the subsequent simulations and optimizations.

3.6 ANSYS Simulations:

To validate and refine the theoretical calculations, simulations are conducted using ANSYS software. Finite element analysis within ANSYS allows for a detailed examination of the stress distribution, deformation, and overall structural behavior of the robot base under different loading conditions. The simulations aid in identifying potential areas of improvement and ensuring that the design meets performance expectations.

The combination of carefully selected materials, adherence to design of machine elements principles, and thorough simulations using ANSYS forms a comprehensive approach in the development of a robust and high-performance robot base for the NERC competition.

4.Analysis and Results:

The comprehensive study on the design and analysis of the NERC robot base has yielded significant insights, combining theoretical calculations and ANSYS simulations to assess the structural integrity and performance of the robot under various conditions.

4.1.Theoretical Calculations:

The theoretical calculations, grounded in design of machine elements principles, played a crucial role in determining the suitability of the chosen materials, particularly high-strength steel for the base and steel components for the motors. Stress analysis ensured that these materials meet safety factors and design standards, providing confidence in the structural robustness of the robot.

The analysis based on the chapters we've covered so far includes screws, rivets, acrylic in the center, panel on top and their deflections and the pillars screws in the corners.

- **SCREWS:**

The screws calculations include: bearing stress, bearing stress at the root of the threads, transverse shear stress, Von mises using all the stresses. The force per newton area is calculated by checking the distances to the center of the screw over the distributed load applied above which is converted to point load. The other approach includes tracing the way from top to bottom, the forces, and then calculating the stresses, we used the distributed load instead.

→ **CALCULATIONS :-**

i) 4 screws on the steel at bottom of the base having diameter 1.1 cm (round-head)

For our ease, we've converted 1.1cm into inches and selected the parameters accordingly.

IMPERIAL :-

Nominal bolt size = $\frac{7}{16}$ inch

Threads per inch = 20 (UNF)

Min. shank diameter = 0.4305 in

Max. shank diameter = 0.4375 in

Min. head thickness = 0.272 in

Max. head thickness = 0.291 in

For this specific bolt, nut thickness = 0.365 in (minimum) and 0.385 in (maximum).

Actual head size = 7/16 in

Min. counter-bore diameter = 7/16 in

Screw shank / Hole size = 7/32 in

Screw size (gauge) should be 1/2 12.

By doing some research, we found out that the minimum tensile strength for such a design, having diameter 7/16 in and 20 threads per inch, is equal to 120 kpsi for SAE Grade 5 and 150 kpsi for SAE grade 8. These values were obtained from fastener torque charts.

For SAE Grade 5 :-

Proof load = 9050 to 10,100 lb

Figure 4

Clamp load = 6,780 to 7,570 lbs
Torque (dry) = 50 to 55 ft lbs
Torque (lubricated) = 35 to 40 ft lbs

→ It is always better to use a lubricant and use lubed torque values. However, in our case we haven't lubricated it.

Screw - 12 :-
Root diameter = 0.149

Finding Stresses :-

7/16 in 20 UNF

Nominal size : $\frac{7}{16}$ ⇒ Major diameter = 0.438 in
Pitch diameter = 0.435 in
Minor diameter = 0.383 in
Pitch = 20

Equivalent Metric thread = M11
Nominal diameter = 11 mm
Pitch = 1.5 mm
Pitch diameter = 10.026 mm
Root diameter = $d_r = d - p = 11 - 1.5 = 9.5$ mm

⇒ Finding bearing stress :-

$$\therefore \sigma_B = \frac{-2F}{\pi d_m n_t p}$$

Finding "d_m" :-

$$\therefore d_m = d - \frac{p}{2} \Rightarrow 11 - \frac{1.5}{2}$$

$$\boxed{d_m = 10.25 \text{ mm}}$$

Figure 5

Assuming the force to be equal to the point force that is being applied at that point. In this case, it is uniformly distributed load $\Rightarrow F = 11.76$ N/cm

$\therefore F = (11.76\,N/cm) \times (0.9\,cm)$

$F = 10.584\,N$

Now,

$$\sigma_B = \frac{-2\,(10.584)\,(0.38)}{(3.14)(10.25)(1)(1.5)}$$

$$\boxed{\sigma_B = -0.1666\ MPa}$$

⇒ The bending stress at the root of the thread :-

$$\therefore \sigma_b = \frac{6F}{\pi d_r n_t p}$$

$$\sigma_b = \frac{6\,(0.38F)}{\pi d_r n_t p}$$

$$\sigma_b = \frac{6\,(0.38)(10.584)}{(3.14)(9.5)(1)(1.5)} \Rightarrow 0.5393\ MPa$$

$$\boxed{\sigma_b = 0.5992\ MPa}$$

⇒ The transverse shear stress "τ" at the center of the root of thread due to load F is :-

$$\therefore \tau = \frac{3 \times F}{\pi d_r n_t p}$$

$$\tau = \frac{(3)(10.584)}{(3.14)(9.5)(1)(1.5)}$$

$$\boxed{\tau = 0.7096\ MPa}$$

VON MISES:- $\boxed{\sigma' = 1.051\ MPa}$

$(\sigma_x = 0.599\ MPa \quad ; \quad \tau_{xy} = 0$ X

$\sigma_y = -0.487\ MPa$ X $; \quad \tau_{yz} = 0.788$!

$\sigma_z = 0\ MPa$ X $; \quad \tau_{zx} = 0\,)$ X

Figure 6

$$\therefore \sigma' = \frac{1}{\sqrt{2}}\left[(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)\right]^{1/2}$$

$$\sigma' = \frac{1}{\sqrt{2}}\left[(1.086)^2+(-0.487)^2+(-0.599)^2+6(0.6209)^2\right]^{1/2}$$

$$\boxed{\sigma' = 1.6584 \text{ MPa}} \; X$$

4297

) 10 screws at base having diameter 0.8 cm (flat-head)

Converting cm into inches and selecting parameters :-

IMPERIAL :-

Nominal bolt size = 5/16 in
Threads per inch = 18 (UNC)
Max. shank diameter = 0.3125 in
Min. shank diameter = 0.3065 in
Max. head thickness = 0.243 in
Min. head thickness = 0.226 in
Nut thickness (maximum) = 0.273 in
Nut thickness (minimum) = 0.256 in

→ Actual head size = 5/16 in
Min. counterbore diameter = 5/16 in
Screw shank / Hole size = 5/32 in
Screw size (gauge) should be 7. The recommended size is 9/8.

- Tensile strength :-

	Grade 5	Grade 8
Proof Load	4450 lbf	6300 lbf
Clamp Load	3338 lbf	4725 lbf

Figure 7

FINDING STRESSES:-

5/16 in 18 UNC

Nominal diameter = 0.313 in

Pitch diameter = 0.275 in

Minor diameter = 0.245 in

Pitch = 18

- Equivalent Metric thread = M8

Nominal diameter = 8 mm

Pitch = 1.25 mm

Pitch diameter = 7.188 mm

Root diameter = $d_r = d - p = 8 - 1.25 = 6.75$ mm

Mean diameter = $d_m = d - \frac{p}{2} = 8 - \frac{1.25}{2} = 7.375$ mm

⇒ Finding bearing stress :-

$$\therefore \sigma_B = \frac{-2F}{\pi d_m n_t p}$$

The force F will be same as case - I.

$$\sigma_B = \frac{-2(78.79)(0.38)}{(3.14)(7.375)(1)(1.25)}$$

$$\boxed{\sigma_B = -2.0686 \text{ MPa}}$$

⇒ The bending stress at the root of thread :-

$$\therefore \sigma_b = \frac{6F}{\pi d_r n_t p}$$

$$\sigma_b = \frac{6(0.38)(78.79)}{(3.14)(6.75)(1)(1.25)}$$

$$\boxed{\sigma_b = 6.78 \text{ MPa}}$$

Figure 8

⇒ Transverse shear stress "τ" :-

$$\tau = \frac{3F}{\pi d_r n_t p}$$

$$\tau = \frac{3(7879)}{(3.14)(6.75)(1)(1.25)}$$

$$\boxed{\tau = 8.921 \text{ MPa}}$$

VON MISES :-

$\sigma_x = 6.78$ MPa ; $\tau_{xy} = 0$ MPa

$\sigma_y = -(2.0686)$ MPa ; $\tau_{yz} = 8.921$ MPa

$\sigma_z = 0$ MPa ; $\tau_{zx} = 0$ MPa

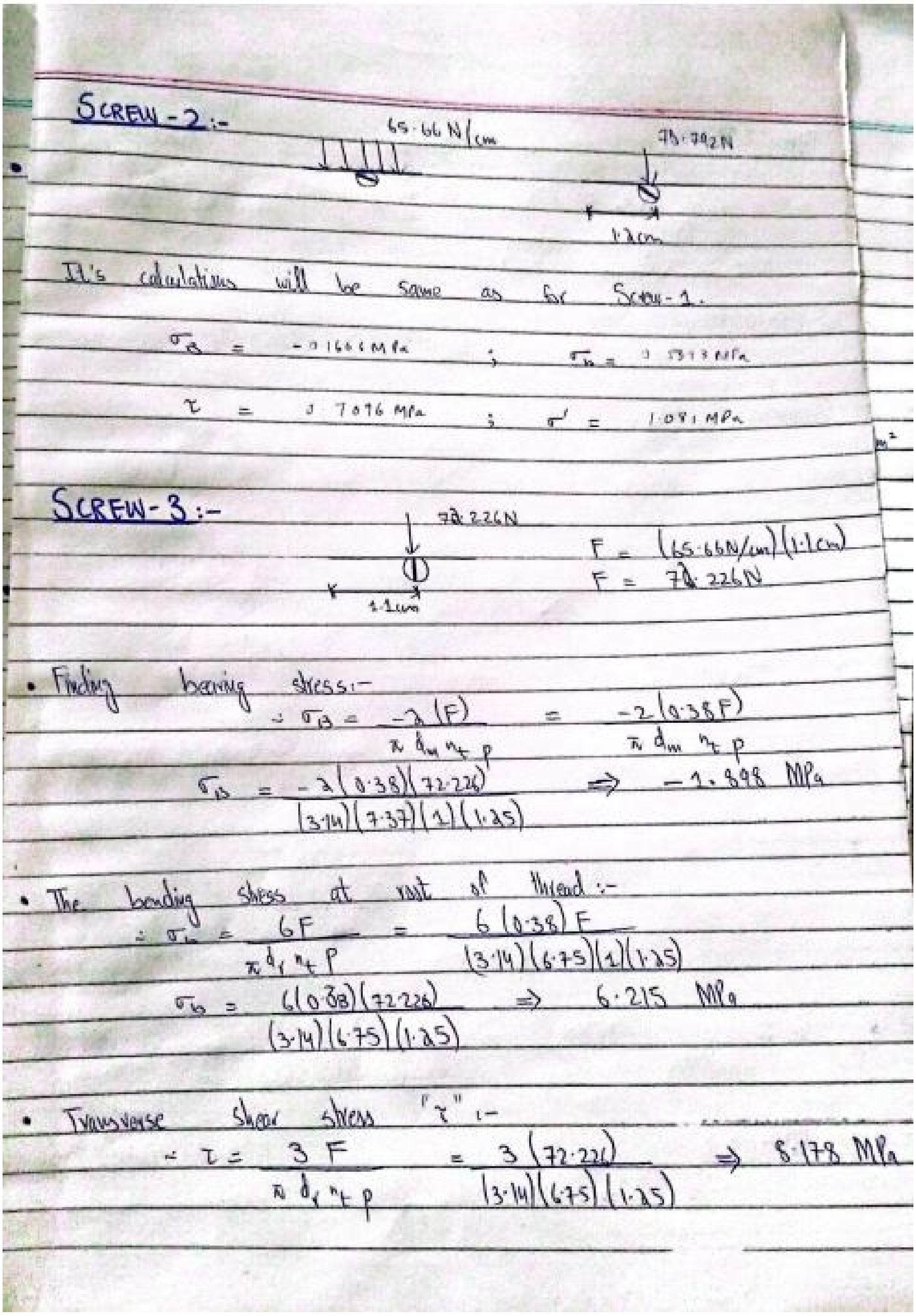
$$\therefore \sigma' = \frac{1}{\sqrt{2}}\left[(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)\right]^{1/2}$$

$$\sigma' = \frac{1}{\sqrt{2}}\left[(3.06+6.78)^2 + (2.0686)^2 + (-6.75)^2 + 6(8.921)^2\right]^{1/2}$$

$$\sigma' = \frac{1}{\sqrt{2}}(22.965)^{1/2}$$

$$\boxed{\sigma' = 135.09 \text{ MPa}}$$

Figure 9



SCREW-2:-

It's calculations will be same as for Screw-1.

$\sigma_B = -0.1606\ MPa$; $\sigma_b = 0.5313\ MPa$

$\tau = 0.7096\ MPa$; $\sigma' = 1.081\ MPa$

SCREW-3:-

$F = (65.66 N/cm)(1.1 cm)$
$F = 72.226 N$

- Finding bearing stress:-

$$\therefore \sigma_B = \frac{-2(F)}{\pi d_m n_t p} = \frac{-2(0.38F)}{\pi d_m n_t p}$$

$$\sigma_B = \frac{-2(0.38)(72.226)}{(3.14)(7.37)(1)(1.25)} \Rightarrow -1.898\ MPa$$

- The bending stress at root of thread:-

$$\therefore \sigma_b = \frac{6F}{\pi d_r n_t p} = \frac{6(0.38)F}{(3.14)(6.75)(1)(1.25)}$$

$$\sigma_b = \frac{6(0.38)(72.226)}{(3.14)(6.75)(1.25)} \Rightarrow 6.215\ MPa$$

- Transverse shear stress "τ":-

$$\therefore \tau = \frac{3F}{\pi d_r n_t p} = \frac{3(72.226)}{(3.14)(6.75)(1.25)} \Rightarrow 8.178\ MPa$$

Figure 10

Von Mises :-

$$\sigma' = \frac{1}{\sqrt{2}}\left[(\sigma_x-\sigma_y)^2 + (\sigma_y-\sigma_z)^2 + (\sigma_z-\sigma_x)^2 + 6(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)\right]^{1/2}$$

$$\boxed{\sigma' = 116.07 \text{ MPa}}$$

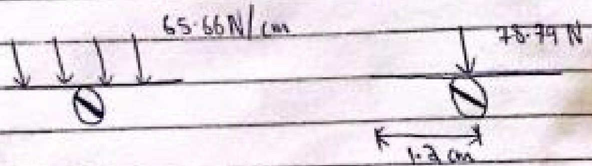
SCREW-4 :-

Same calculations as already done for screw-3.

SCREW-5 & 6 :-

Taking the distance as 1.1 cm, we get e same results as that of screws 3 and 4.

SCREW-7 :-



$$\sigma_B = \frac{-2(0.38F)}{\pi d_m n_t p}$$

$$\sigma_B = \frac{-2(0.38)(78.79)}{(3.14)(7.375)(1)(1.25)} \Rightarrow -2.0686 \text{ MPa}$$

- $$\sigma_b = \frac{6F}{\pi d_r n_t p} = \frac{6(0.38)F}{\pi d_r n_t p}$$

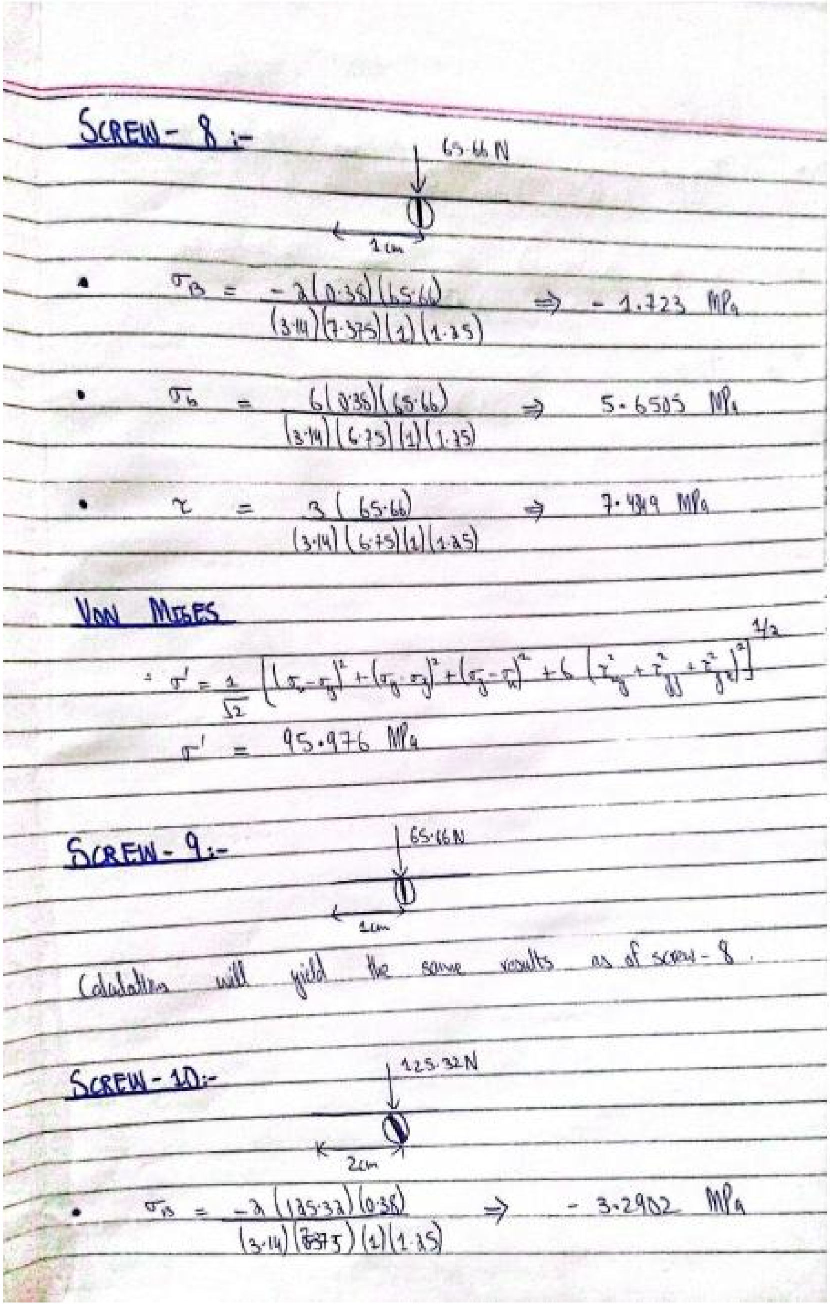
$$\sigma_b = \frac{6(0.38)(78.79)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 6.7805 \text{ MPa}$$

- $$\tau = \frac{3F}{\pi d_r n_t p} = \frac{3(78.79)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 8.92 \text{ MPa}$$

Von Mises

$$\sigma' = 138.046 \text{ MPa}$$

Figure 11



SCREW- 8 :-

- $\sigma_B = \dfrac{-2(0.38)(65.66)}{(3.14)(7.375)(1)(1.25)} \Rightarrow -1.723$ MPa
- $\sigma_b = \dfrac{6(0.38)(65.66)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 5.6505$ MPa
- $\tau = \dfrac{3(65.66)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 7.4349$ MPa

VON MISES

$$\sigma' = \frac{1}{\sqrt{2}}\left[(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)\right]^{1/2}$$

$\sigma' = 95.976$ MPa

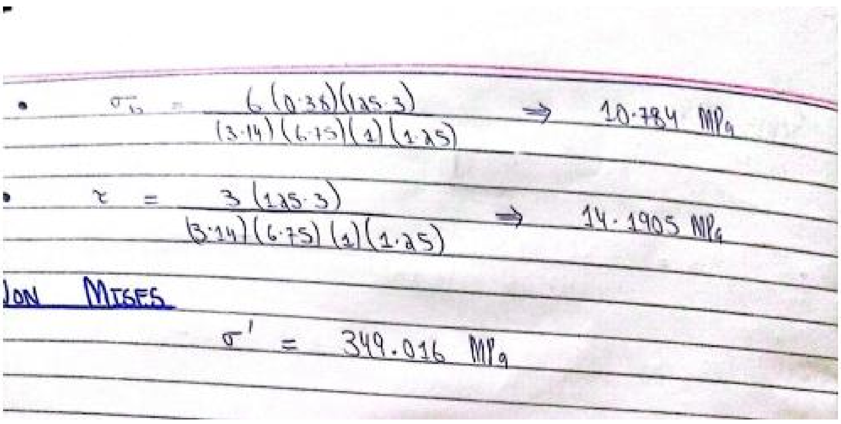
SCREW- 9 :-

Calculations will yield the same results as of screw- 8.

SCREW- 10 :-

- $\sigma_B = \dfrac{-2(125.32)(0.38)}{(3.14)(7.375)(1)(1.25)} \Rightarrow -3.2902$ MPa

Figure 12



- $\sigma_b = \dfrac{6(0.38)(125.3)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 10.784$ MPa
- $\tau = \dfrac{3(125.3)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 14.1905$ MPa

VON MISES

$\sigma' = 349.016$ MPa

Figure 13

Nominal bolt size = 5/16 ; Threads per inch = 18 UNC

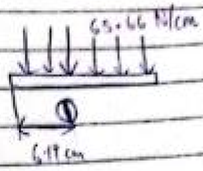
Equivalent : M8 ; Pitch dia = 1.25 mm ; diameter = 8mm

$d_r = d - p = 6.75$ mm

$d_m = d - \frac{p}{2} = 7.375$ mm

⟹ SCREWS ON SIDE :-

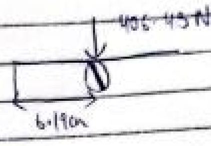
i) Distance = 2.44 in = 6.198 cm



- $\sigma_B = \dfrac{-2(F)(0.38)}{\pi d_m n_t p}$

$\sigma_B = \dfrac{-2(406.43)(0.38)}{(3.14)(7.375)(1)(1.25)}$

$\sigma_B = -10.67$ MPa



- $\sigma_b = \dfrac{6(F)(0.38)}{\pi d_r n_t p} = \dfrac{6(406.43)(0.38)}{(3.14)(6.75)(1)(1.25)}$

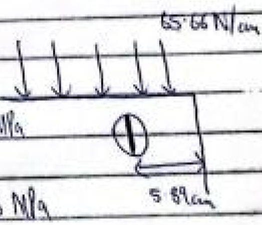
$\sigma_b = \cancel{33.73}\ 34.47$ MPa

- $\tau = \dfrac{3(406.43)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 46.021$ MPa

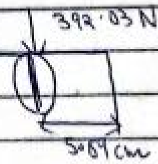
VON MISES

$\sigma' = 3668.59$ MPa

ii) Distance = 2.32 in = 5.89 cm

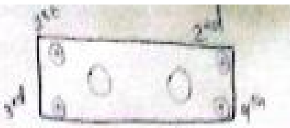


- $\sigma_B = \dfrac{-2(392.03)(0.38)}{(3.14)(7.375)(1)(1.25)} \Rightarrow -10.29$ MPa
- $\sigma_b = \dfrac{6(392.03)(0.38)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 33.75$ MPa
- $\tau = \dfrac{3(392.03)}{(3.14)(6.75)(1)(1.25)} \Rightarrow 44.39$ MPa



$\sigma' = 3413.19$ MPa

Figure 14



⇒ For the 2nd screw at distance 0.7cm :-

$$\therefore F = (11.76\ N/cm)(0.7cm)$$

$$F = 7.408\ N$$

- $$\sigma_B = \frac{-2(7.408)(0.35)}{(3.14)(10.25)(1)(1.5)}$$

$$\boxed{\sigma_B = -0.3068\ MPa}$$

-0.1165

- The bending stress at the root of thread :-

$$\therefore \sigma_b = \frac{6F}{\pi d_r n_t p}$$

$$\sigma_b = \frac{6(7.408)(0.38)}{(3.14)(9.5)(1)(1.5)}$$

$$\boxed{\sigma_b = 0.4433\ MPa}$$

0.3779

- Transverse shear "τ" :-

$$\therefore \tau = \frac{3 \times F}{\pi d_r n_t p}$$

$$\tau = \frac{3(7.408)}{(3.14)(9.5)(1)(1.5)}$$

$$\boxed{\tau = 0.4966\ MPa}$$

Von Mises :-

0.3779

$\sigma_x = 0.99$; $\tau_{xy} = 0\ MPa$

$\sigma_y = -0.1165\ MPa$; $\tau_{yz} = 0.4966\ MPa$

$\sigma_z = 0\ MPa$; $\tau_{zx} = 0\ MPa$

$$\sigma' = \frac{1}{\sqrt{2}}\left[(\sigma_x-\sigma_y)^2 + (\sigma_y-\sigma_z)^2 + (\sigma_z-\sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)\right]^{\frac{1}{2}}$$

$$\sigma' = \frac{1}{\sqrt{2}}\left[\right.$$

$$\boxed{\sigma' = 0.6183\ MPa}$$

Figure 15

⇒ 3rd screw :-

As we have taken it's distance to be same as the 1st one, so it's calculations will yield same answer.

$$\therefore \sigma_B = -0.1666 \text{ MPa}$$

$$\sigma_b = 0.5393 \text{ MPa}$$

$$\tau = 0.7096 \text{ MPa}$$

$$\sigma' = 1.061 \text{ MPa}$$

⇒ 4th screw :-

As we have taken it's distance to be same as the 2nd one, so it's calculations will give same answer.

$$\therefore \sigma_B = -0.1165 \text{ MPa}$$

$$\therefore \sigma_b = 0.3774 \text{ MPa}$$

$$\tau = 0.4966 \text{ MPa}$$

$$\sigma' = 0.6183 \text{ MPa}$$

Figure 16

The pillar screws holding the upper load are included, the base weight is added too excluding the red acrylic.

⇒ SCREWS ON THE PILLARS :-

Total screws = 8

Screw gauge number = 3

Max. head diameter = 0.199 inch

Shank diameter = $\frac{7}{64}$

Threads per inch = 29 (UNC)

Min. counterbore dia = $\frac{1}{4}$

Nominal bolt size = 1/4 inch

⇒ IMPERIAL :-

$\frac{1}{4}$ in 20 UNC

Equivalent Metric screw : M6

Nominal diameter = 6 mm

Pitch = 1 mm

Pitch diameter = 5.35 mm

Root diameter = d_r = $d - p = 6 - 1 = 5mm$

Mean diameter = d_m = $d - \frac{p}{2} = 6 - \frac{1}{2} = 5.5mm$

→ Finding bearing stress :-

$$\therefore \sigma_B = \frac{-2F}{\pi d_m n_t p}$$

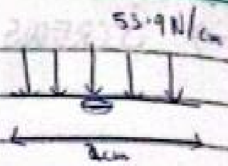
$$\sigma_B = \frac{-2(0.38F)}{\pi d_m n_t p}$$

$$\sigma_B = \frac{-2(0.38F)}{(3.14)(5.5)(2)(5)}$$

Figure 17

$$F = (5.5)(9.8)\ N/cm$$

$$F = 53.9\ N/cm$$



⇒ Finding point force :-

$$F = (53.9\ N/cm)(1cm)$$

$$F = 53.9\ N$$

Putting :-

$$\sigma_B = \frac{-2(0.38)(53.9)}{(3.14)(5.5)(5)}$$

$$\boxed{\sigma_B = -0.4743\ MPa}$$

⇒ The bending stress at the root of thread :-

$$\therefore \sigma_b = \frac{6(0.38F)}{\pi\, d_r\, n_t\, p}$$

$$\sigma_b = \frac{6(0.38)(53.9)}{(3.14)(5)(1)(5)}$$

$$\boxed{\sigma_b = 1.56\ MPa}$$

The transverse shear stress "τ" :-

$$\therefore \tau = \frac{3 \times F}{\pi\, d_r\, n_t\, p}$$

$$\tau = \frac{3(53.9)}{(3.14)(5)(1)(5)}$$

$$\boxed{\tau = 2.059\ MPa}$$

VON MISES :-

$$\therefore \sigma' = \frac{1}{\sqrt{2}}\left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)\right]^{1/2}$$

$$\boxed{\sigma' = 7.57\ MPa}$$

These calculations will be same for other 7 screws on the pillars.

Figure 18

Some screws give 0 stresses, hence are not included.

- **FAILURE ANALYSIS:**

⇒ FAILURE ANALYSIS:-

- On top acrylic sheet :-

Length = L = 22.8 cm = 0.228 m

Width = b = 7.8 cm = 0.078 m

Thickness = h = 0.3 cm = 0.003 m

Force = F = $(1.2)(9.8)$ = 11.76 N

∴ Moment = $F.d$

$$M = (11.76)(0.228) = 2.825 \text{ Nm}$$

∴ Inertia = $\frac{bh^3}{12} = \frac{(0.078)(0.003)^3}{12}$

$$I = 1.825 \times 10^{-7} \text{ m}^4$$

∴ $c = \frac{\text{thickness}}{2} = \frac{0.003}{2} = 0.0015 \text{ m}$

Finding stress :-

$$\sigma = \frac{M.c}{I} = \frac{(2.825)(0.0015)}{(1.825 \times 10^{-7})}$$

$$\sigma = 23084.94 \text{ Pa}$$

$$\boxed{\sigma = 23.08 \text{ kPa}}$$

⇒ σ_{yield} = 70 MPa :-

∴ $N = \frac{\sigma_{yield}}{\sigma} = \frac{70 \text{ MPa}}{23.08 \text{ kPa}}$

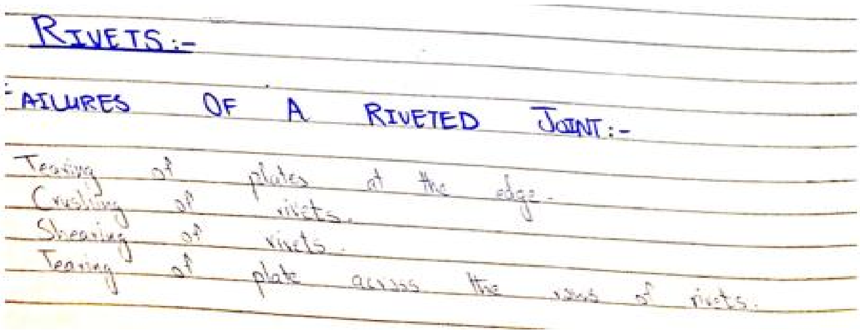
$$\boxed{N = 3030}$$

This is a significant margin of safety which indicates that at our applied load, failure will not occur.

Figure 19

- **RIVETS:**

In case of rivets, the calculations are beyond are scope so we instead explained the possible failure reasons for them.

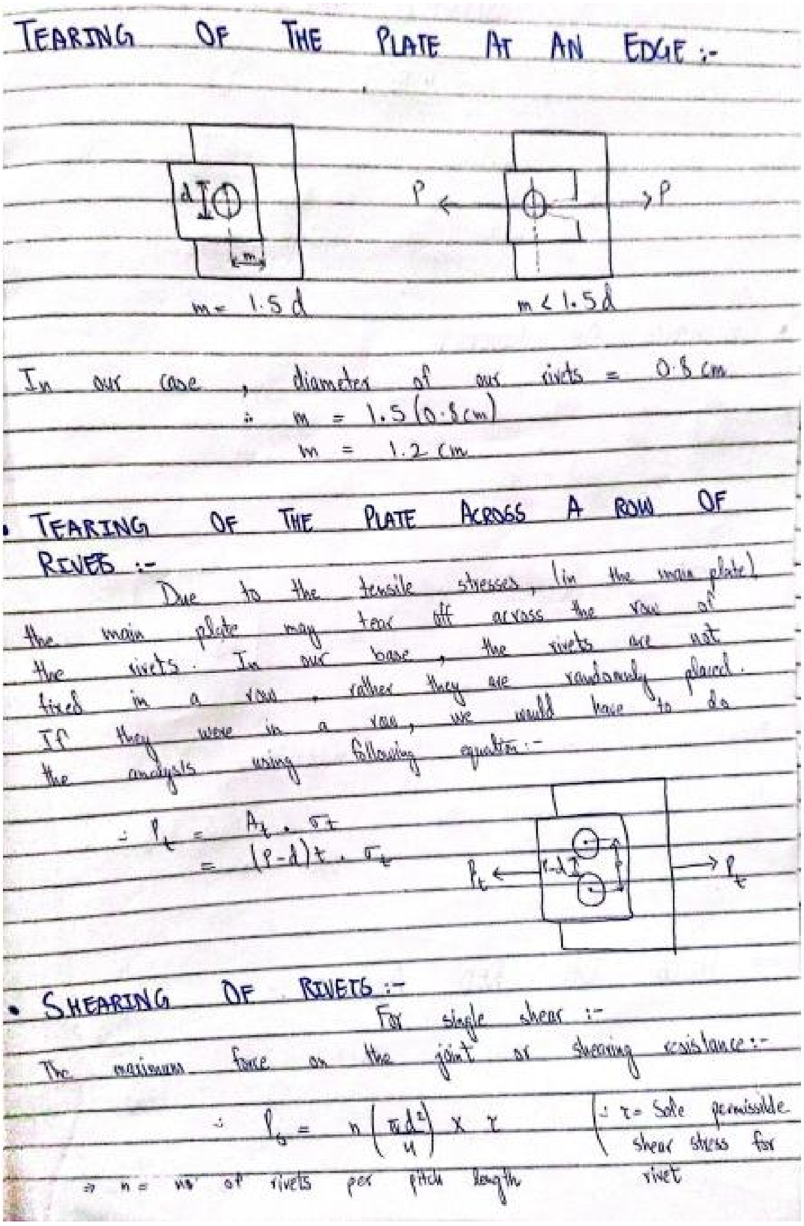


RIVETS :-

FAILURES OF A RIVETED JOINT :-

Tearing of plates at the edge.
Crushing of rivets.
Shearing of rivets.
Tearing of plate across the rows of rivets.

Figure 20



TEARING OF THE PLATE AT AN EDGE :-

$m = 1.5d$ $\quad$ $m < 1.5d$

In our case, diameter of our rivets = 0.8 cm

$\therefore m = 1.5(0.8\,cm)$

$m = 1.2\ cm$

- TEARING OF THE PLATE ACROSS A ROW OF RIVETS :-

Due to the tensile stresses, (in the main plate) the main plate may tear off across the row of the rivets. In our case, the rivets are not fixed in a row, rather they are randomly placed. If they were in a row, we would have to do the analysis using following equation :-

$\therefore P_t = A_t \cdot \sigma_t$

$= (p-d)t \cdot \sigma_t$

- SHEARING OF RIVETS :-

For single shear :-

The maximum force on the joint or shearing resistance :-

$\therefore P_s = n\left(\frac{\pi d^2}{4}\right) \times \tau$ $\quad$ ($\because \tau$ = Safe permissible shear stress for rivet)

$\Rightarrow n$ = no of rivets per pitch length

Figure 21

$$\therefore \quad P_s = \frac{(1)(3.14)(0.8\times10^{-2})^2}{4} \times (60\times10^{6}\ Nm^{-2})$$

$$\boxed{P_s = 3014.4\ N}$$

For the above calculation, we have selected the value of "τ" to be 60 MPa, it ranges from 60 MPa to 80 MPa for stainless steel.

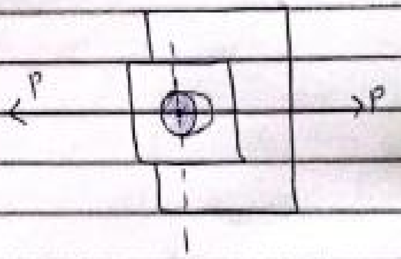
- **CRUSHING OF RIVETS :-**

Sometimes, the rivets do not actually shear off under tensile stress but they are crushed off. Due to this, the rivet hole becomes like an oval shape and therefore, it becomes loose.

σ_c = safe permissible crushing shear stress

t = thickness of plate

n = number of rivets



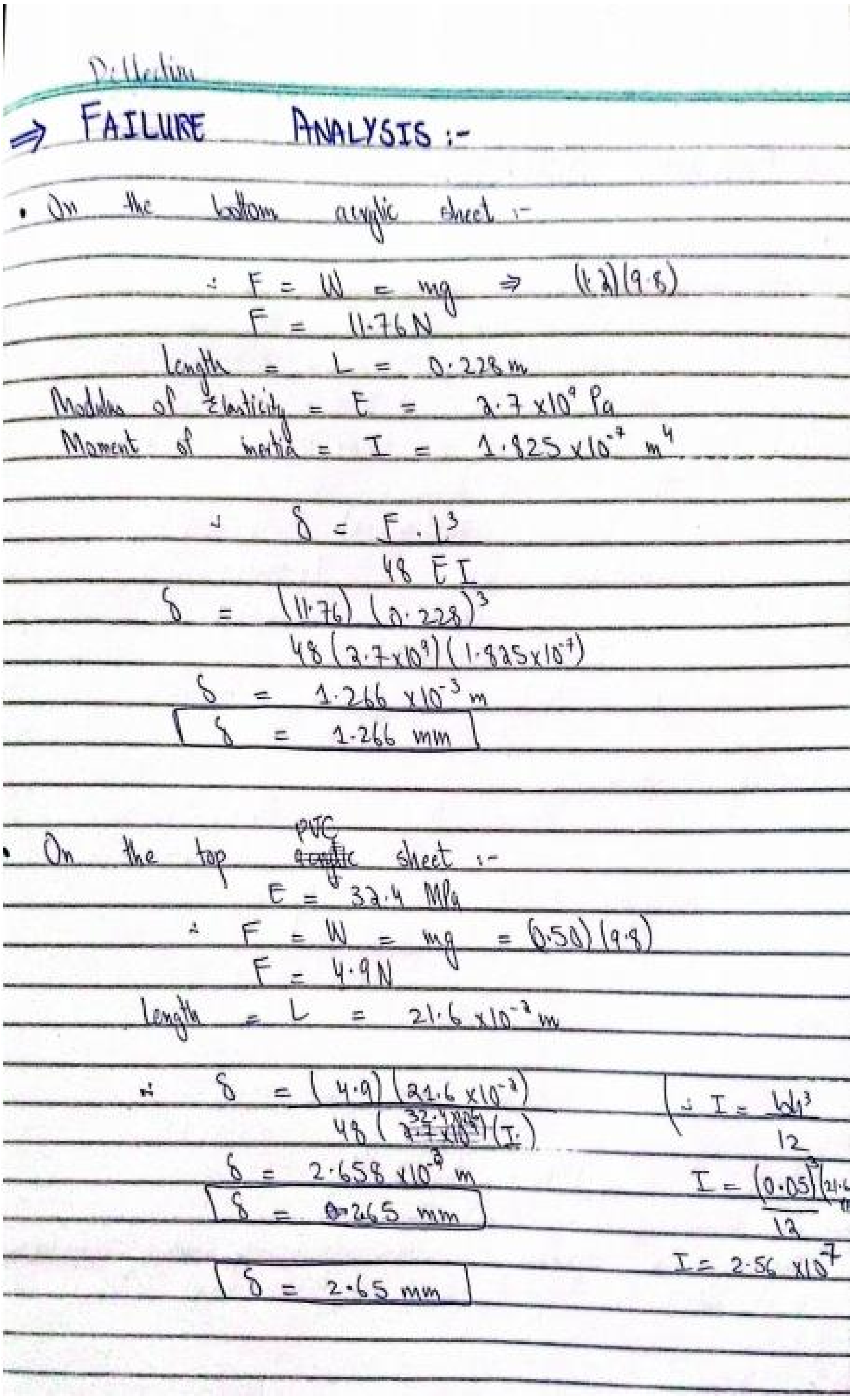
Max. crushing resistance : $P_c = n(d)(t)\,\sigma_c$

When P_c is greater than the applied load (P) per pitch length, then failure will occur.

Figure 22

- **DEFLECTION ANALYSIS:**

The deflection of the red acrylic and for the panel, using the weight of bridges and Arduino, it is calculated as:



~~Deflection~~

⇒ FAILURE ANALYSIS :-

- On the bottom acrylic sheet :-

$\because F = W = mg \Rightarrow (1.2)(9.8)$

$F = 11.76\,N$

Length $= L = 0.228\,m$

Modulus of Elasticity $= E = 2.7 \times 10^{9}\,Pa$

Moment of inertia $= I = 1.825 \times 10^{-7}\,m^4$

$\because \delta = \frac{F \cdot l^3}{48\,EI}$

$\delta = \frac{(11.76)(0.228)^3}{48(2.7\times10^{9})(1.825\times10^{-7})}$

$\delta = 1.266 \times 10^{-3}\,m$

$\boxed{\delta = 1.266\,mm}$

- On the top ~~acrylic~~ PVC sheet :-

$E = 32.4\,MPa$

$\because F = W = mg = (0.50)(9.8)$

$F = 4.9\,N$

Length $= L = 21.6 \times 10^{-2}\,m$

$\because \delta = \frac{(4.9)(21.6\times10^{-2})}{48(\cancel{2.7\times10^{9}}\ 32.4\times10^{6})(I)}$

$\because I = \frac{bh^3}{12}$

$I = \frac{(0.05)^3(21.6 \ldots)}{12}$

$I = 2.56 \times 10^{-7}$

$\delta = 2.658 \times 10^{-3}\,m$

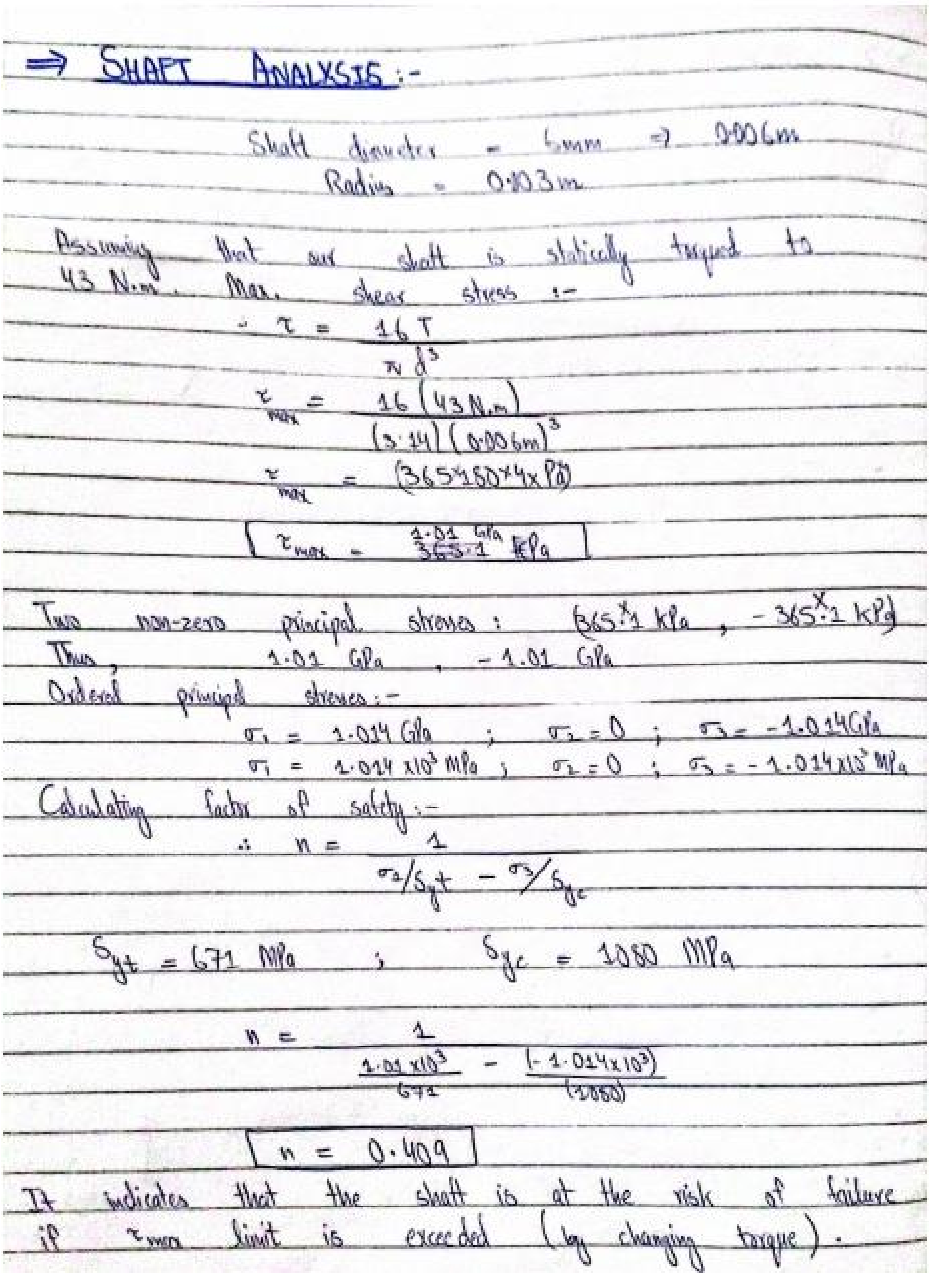
$\boxed{\delta = 0.265\,mm}$

$\boxed{\delta = 2.65\,mm}$

Figure 23

- **SHAFT ANALYSIS:**

In the shaft analysis, we have considered the shaft to be statically torqued. From here, we assumed the value of the Torque which is needed to find the maximum shear stress. Normally, a human can provide 40 to 50 Nm torque (depending on the length of the rod). In our case, we have assumed it to be 43 Nm. After calculating Maximum shear stress, the factor of safety is calculated with the help of Tensile yield strength and compressive yield strength. These values depend upon the material. Our motor has 6mm shaft diameter and is made up of stainless steel.



⇒ SHAFT ANALYSIS :-

Shaft diameter = 6mm ⇒ 0.006m

Radius = 0.003m

Assuming that our shaft is statically torqued to 43 N.m. Max. shear stress :-

$$\therefore \tau = \frac{16T}{\pi d^3}$$

$$\tau_{max} = \frac{16(43\,N.m)}{(3.14)(0.006m)^3}$$

$$\tau_{max} = (365460 \times 4 \times Pa)$$

$$\boxed{\tau_{max} = 1.01\ GPa\ \cancel{365.1\ KPa}}$$

Two non-zero principal stresses : ~~365.1 KPa , −365.1 KPa~~

Thus, 1.01 GPa , −1.01 GPa

Ordered principal stresses :-

$\sigma_1 = 1.014$ GPa ; $\sigma_2 = 0$; $\sigma_3 = -1.014$ GPa

$\sigma_1 = 1.014 \times 10^3$ MPa ; $\sigma_2 = 0$; $\sigma_3 = -1.014 \times 10^3$ MPa

Calculating factor of safety :-

$$\therefore n = \frac{1}{\sigma_1/S_{yt} - \sigma_3/S_{yc}}$$

$S_{yt} = 671$ MPa ; $S_{yc} = 1080$ MPa

$$n = \frac{1}{\frac{1.01 \times 10^3}{671} - \frac{(-1.014 \times 10^3)}{(1080)}}$$

$$\boxed{n = 0.409}$$

It indicates that the shaft is at the risk of failure if τ_{max} limit is exceeded (by changing torque).

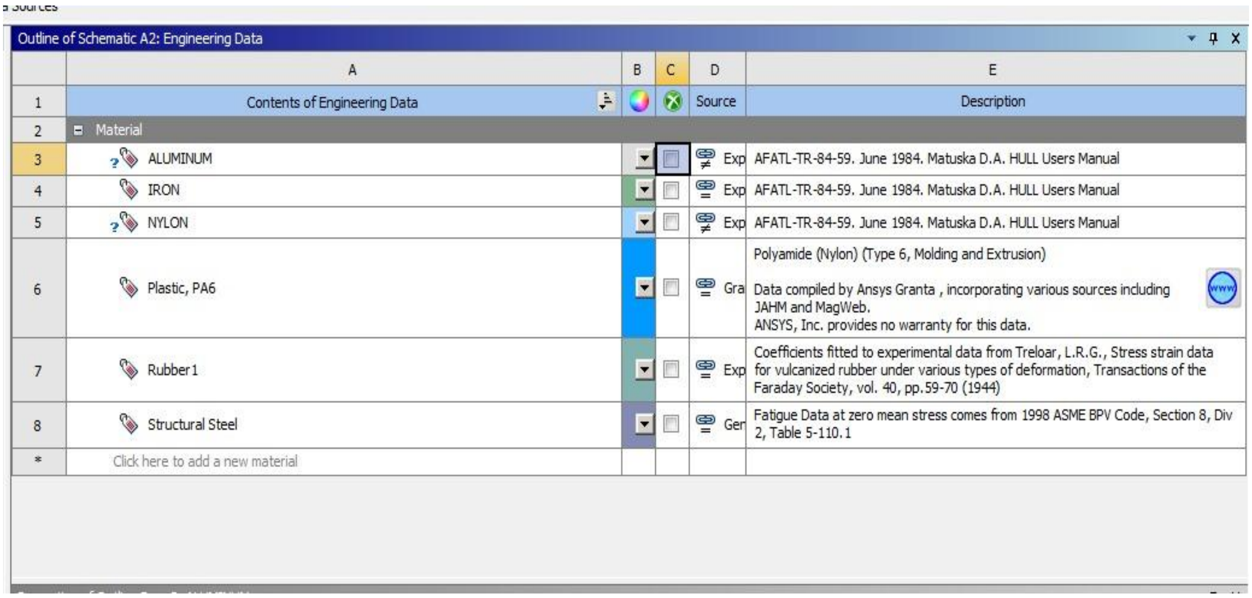
Figure 24

4.2 ANSYS Simulations:

The ANSYS simulations provided a virtual testing ground for the robot base, allowing for a detailed examination of its structural behavior under dynamic conditions. Finite element analysis revealed stress distributions, deformations, and potential weak points within the design. The simulations validated the theoretical calculations, offering a real-world perspective on how the materials and components interact under various loads. The results from ANSYS simulations allowed for fine-tuning the design, identifying areas for improvement, and ensuring that the robot base would perform reliably in the NERC competition.

4.2.1 Material Assignment:

- Access the Engineering Data tab to define the mechanical properties of the materials used in the simulation.
- Assign the appropriate materials to each part of the robot. For instance:
    - *Aluminum:* Define the Young's modulus, Poisson's ratio, and density for aluminum.
    - *Iron:* Specify the material properties, including modulus and density, for iron.
    - *Nylon:* Assign the mechanical properties of nylon, considering its elasticity and other relevant parameters.
    - *Steel:* Define the material properties for steel, including its modulus, Poisson's ratio, and density.
    - *Rubber:* Input the necessary data for rubber, considering its nonlinear, elastomeric behavior.


Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	ALUMINUM			Exp	AFATL-TR-84-59. June 1984. Matuska D.A. HULL Users Manual
4	IRON			Exp	AFATL-TR-84-59. June 1984. Matuska D.A. HULL Users Manual
5	NYLON			Exp	AFATL-TR-84-59. June 1984. Matuska D.A. HULL Users Manual
6	Plastic, PA6			Gra	Polyamide (Nylon) (Type 6, Molding and Extrusion) Data compiled by Ansys Granta , incorporating various sources including JAHM and MagWeb. ANSYS, Inc. provides no warranty for this data.
7	Rubber1			Exp	Coefficients fitted to experimental data from Treloar, L.R.G., Stress strain data for vulcanized rubber under various types of deformation, Transactions of the Faraday Society, vol. 40, pp.59-70 (1944)
8	Structural Steel			Ger	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material				

Figure 25: Material Assignment

1st Step of Static Structural is Done.

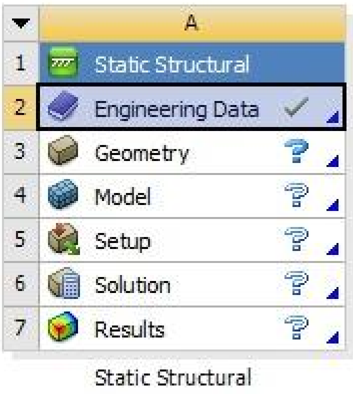


Figure 26: Static Structural Steps

4.2.2 Geometry Import:

- Begin by importing the 3D geometry of the robot base and components into ANSYS. Ensure that the model is correctly aligned and positioned.

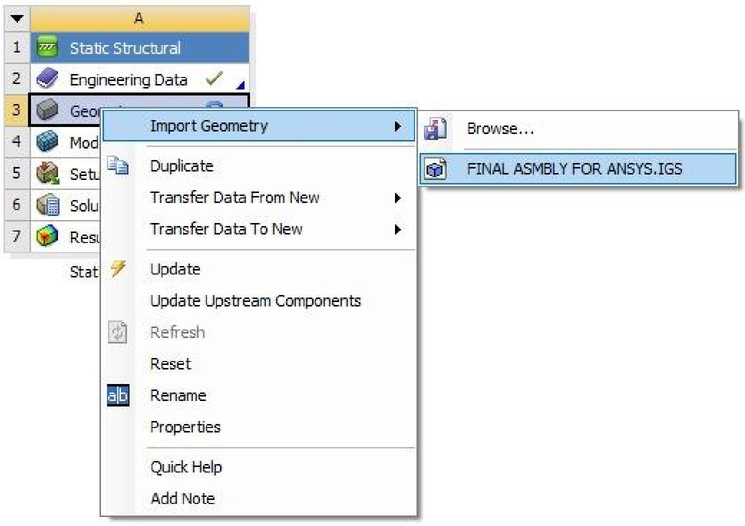


Figure 27: Geometry Import

- 2nd Step of Static Structural is Done.

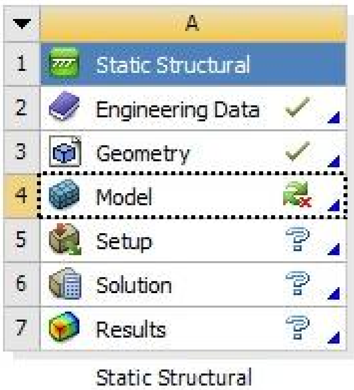


Figure 28: Static Structural Steps

4.2.2 Mesh Generation:

- Generate An Assembly in geometry tab.

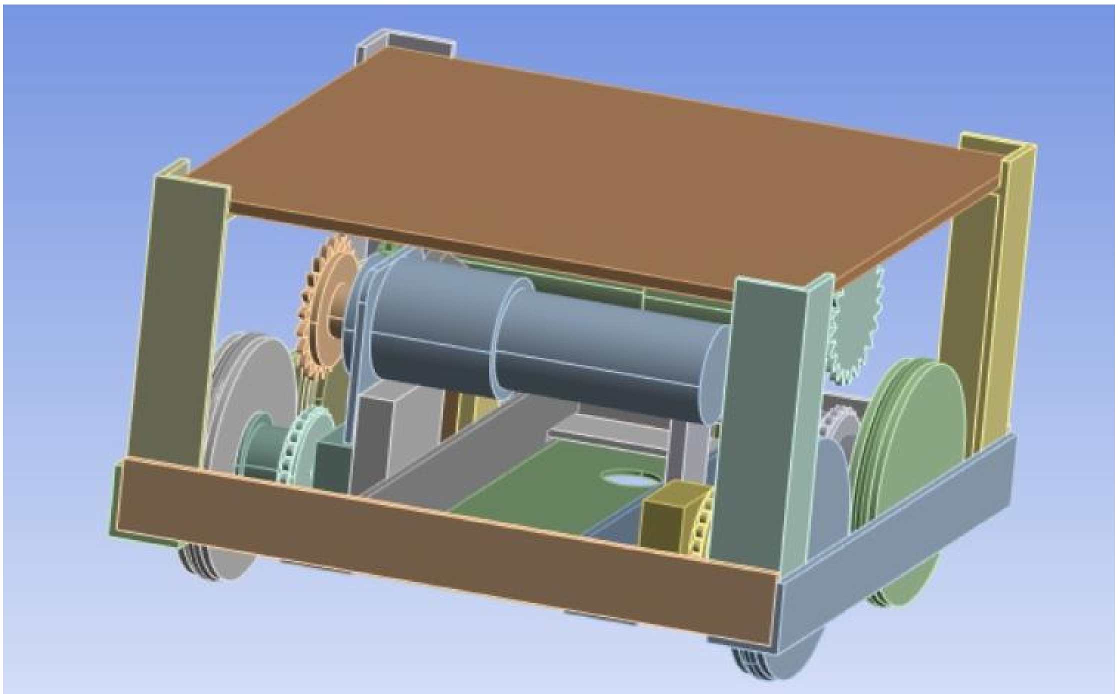


Figure 29: *Assembly in geometry tab.*

- Apply Material For Every part.

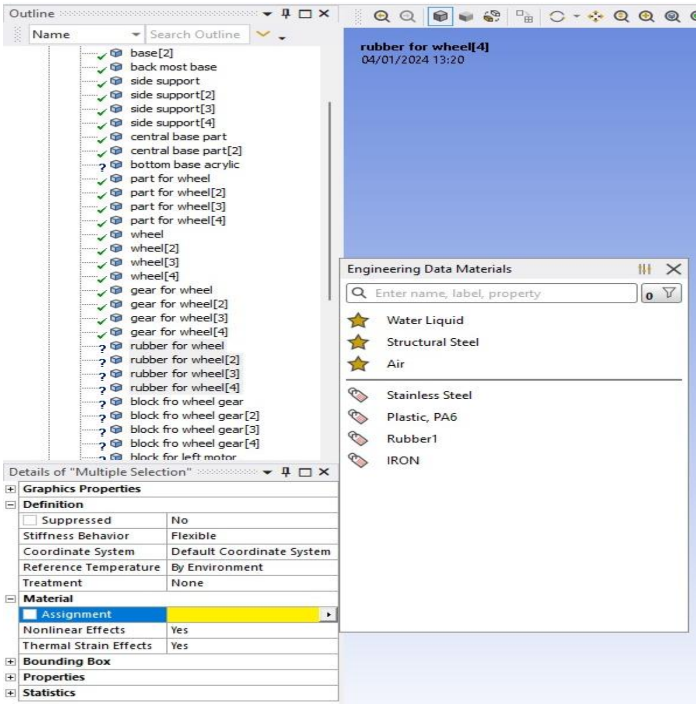


Figure 30: Applying Material

- Then Make Connections of all contacts.

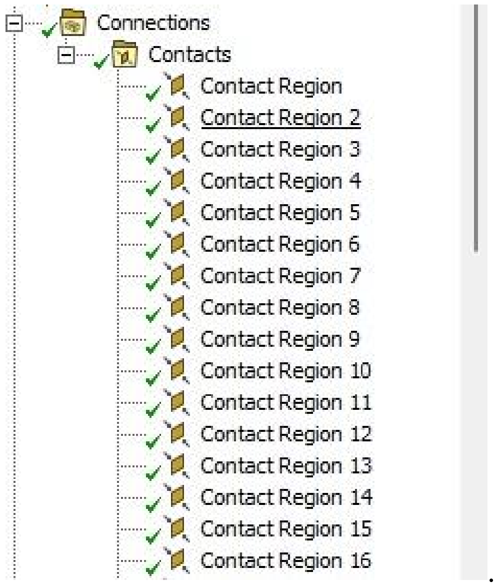


Figure 31: Making Connections

- Generate a finite element mesh for the entire model. The mesh discretizes the geometry into smaller elements, allowing ANSYS to perform calculations at discrete points.
- Adjust the mesh density based on the complexity of the geometry. A finer mesh provides more accurate results but may require additional computational resources.

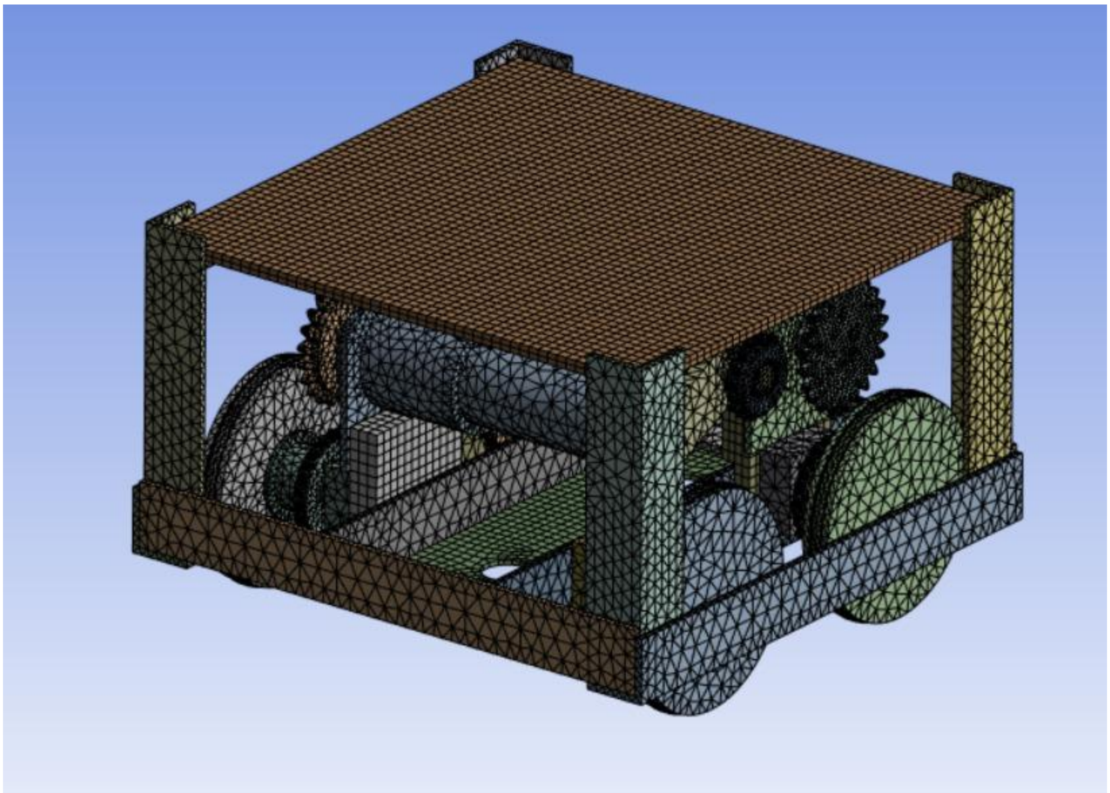


Figure 32: Generating Mesh

4.2.3 Boundary Conditions:

- Define constraints and supports to simulate real-world conditions. For example, fix any degrees of freedom at points where the robot is attached to the ground or where it interacts with other components.
- Ensure that the boundary conditions accurately represent the physical constraints on the robot.

4.2.4 Loads and External Conditions:

- Apply loads and external conditions representing operational forces and environmental factors.
- These loads could include gravitational forces, forces from the motors, or any external forces the robot might encounter during tree planting. The applied loads should mimic the actual conditions the robot will face.

4.2.5 Solver Setup:

- Configure the solver settings for a structural static analysis. Adjust parameters such as convergence criteria, time-stepping options, and other solver-specific settings.
- Choose an appropriate solver based on the nature of the analysis.

4.2.6 Solution:

- Run the simulation to obtain results. ANSYS will calculate stress, strain, and deformation across the components based on the applied loads and material properties.
- The solver iteratively solves the equations governing the structural behavior until convergence is achieved.

4.2.7 Post-Processing:

- Use ANSYS post-processing tools to review and interpret the simulation results.
- Examine stress contours, deformation plots, and other outputs to understand how different materials and components respond to applied loads.

By meticulously following these steps, the ANSYS simulation facilitates a thorough structural static analysis, allowing engineers to gain valuable insights into the performance of the robot's components made from different materials under various loading conditions. This iterative process supports the refinement of the design for optimal structural integrity and performance.

- **Total Deformation:**
    - **Definition:** Total deformation represents the overall displacement and change in shape of the structure under applied loads.
    - **Simulation Output:** ANSYS provides visualizations and numerical values for total deformation, illustrating how much each point in the structure has moved or deformed.
    - **Interpretation:** Total deformation is crucial for understanding the overall structural response to external forces. Engineers use this data to identify areas of significant deformation and assess the structural integrity of the design.

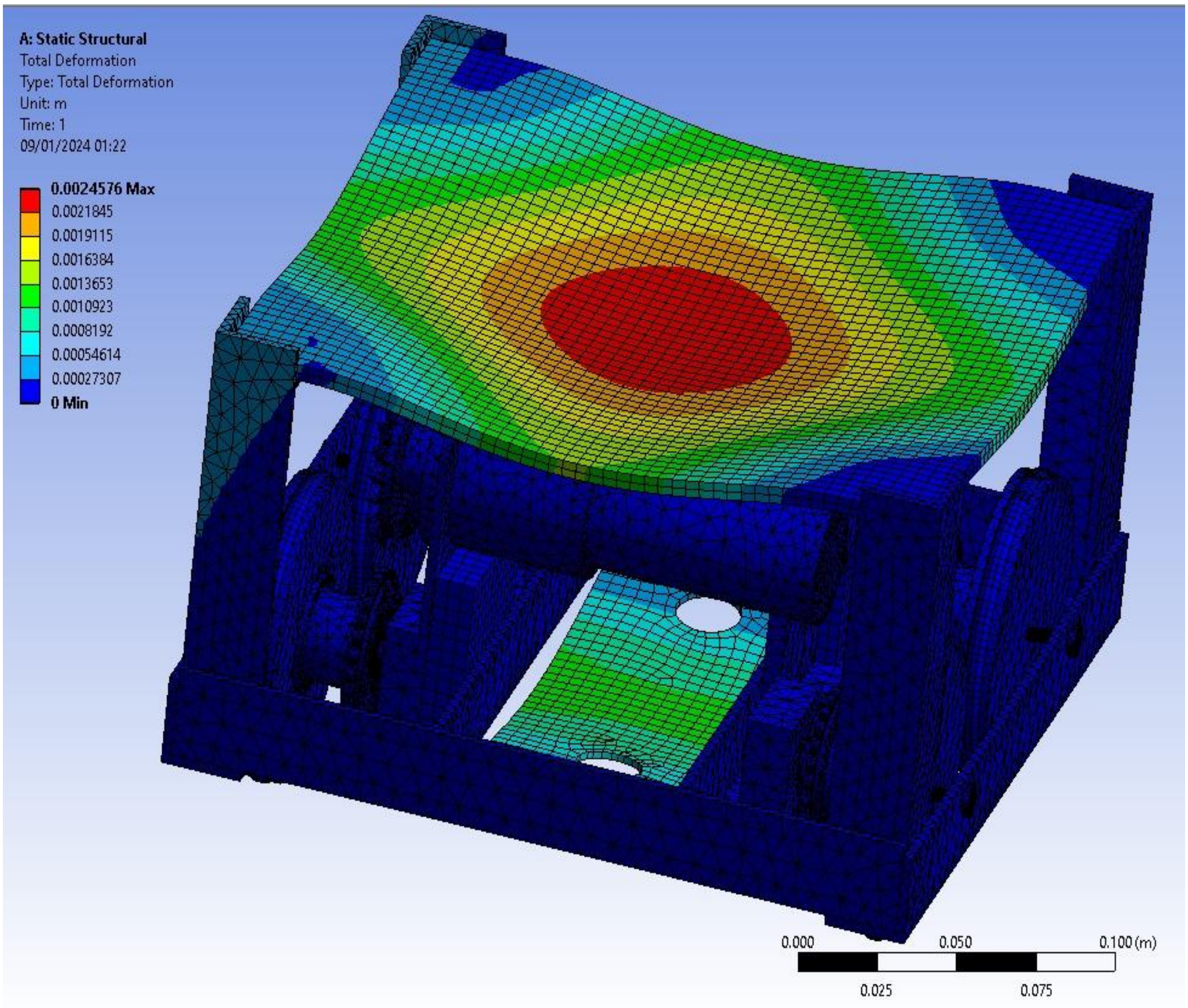


Figure 33: Total Deformation

- **Max Principle Elastic Strain:**

- **Definition:** Maximum principal elastic strain represents the highest normal strain experienced by a material, considering both tensile and compressive strains.
- **Simulation Output:** ANSYS outputs contour plots and numerical values depicting the distribution of principal strains. The highest principal strain corresponds to the maximum principal elastic strain within the structure.
- **Interpretation:** This information helps engineers assess the material's behavior under different loading conditions, ensuring that the design operates within elastic limits to avoid permanent deformation.

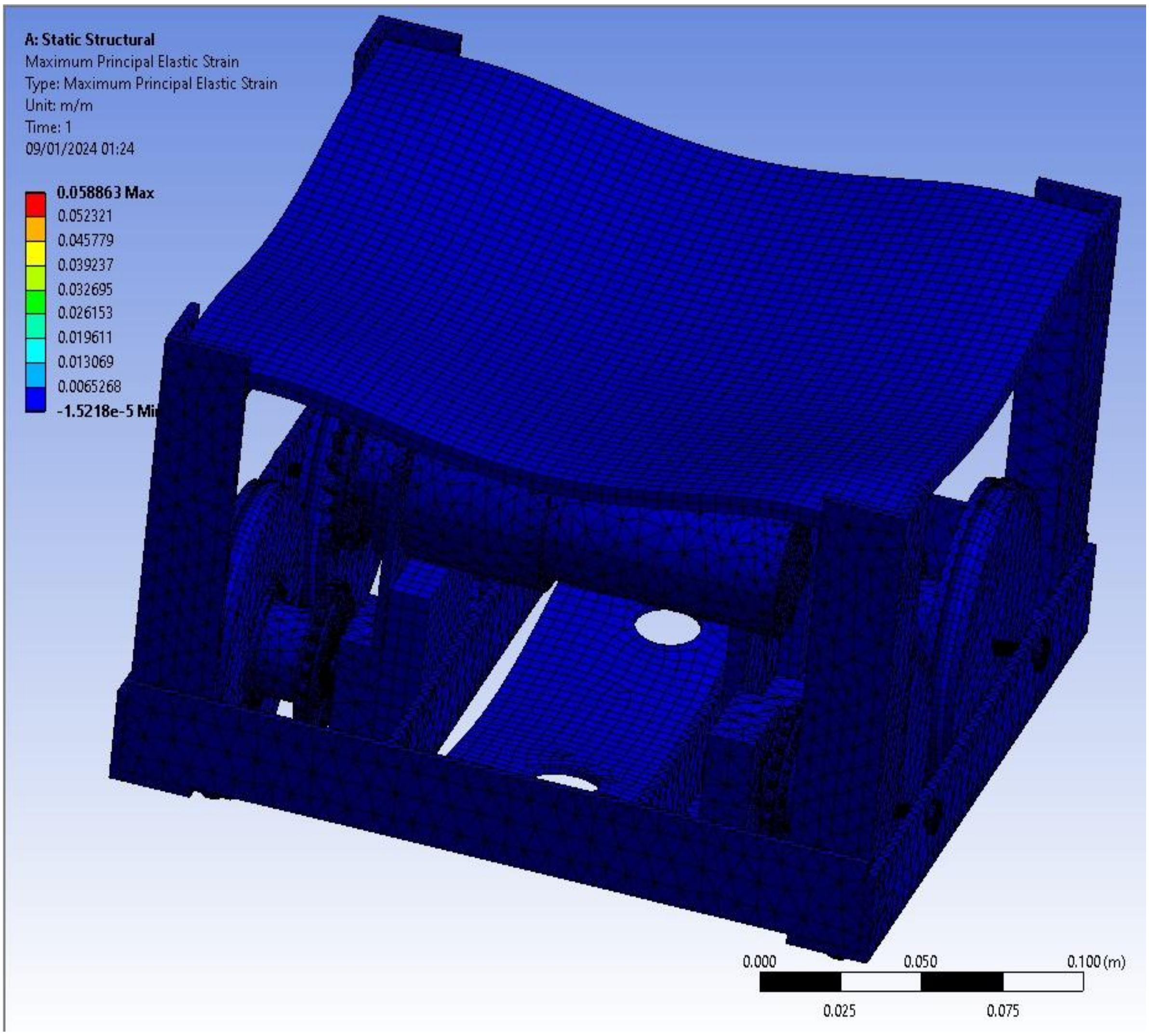


Figure 34: Max Principle Elastic Strain

- **Max Shear Elastic Stress:**

- **Definition:** Maximum shear elastic stress represents the highest intensity of internal forces within the material in a shearing direction.
- **Simulation Output:** ANSYS generates contour plots and numerical values illustrating the distribution of shear stresses. The highest shear stress corresponds to the maximum shear elastic stress within the structure.
- **Interpretation:** Evaluating maximum shear elastic stress is essential for understanding potential yielding or failure in regions prone to shearing forces.

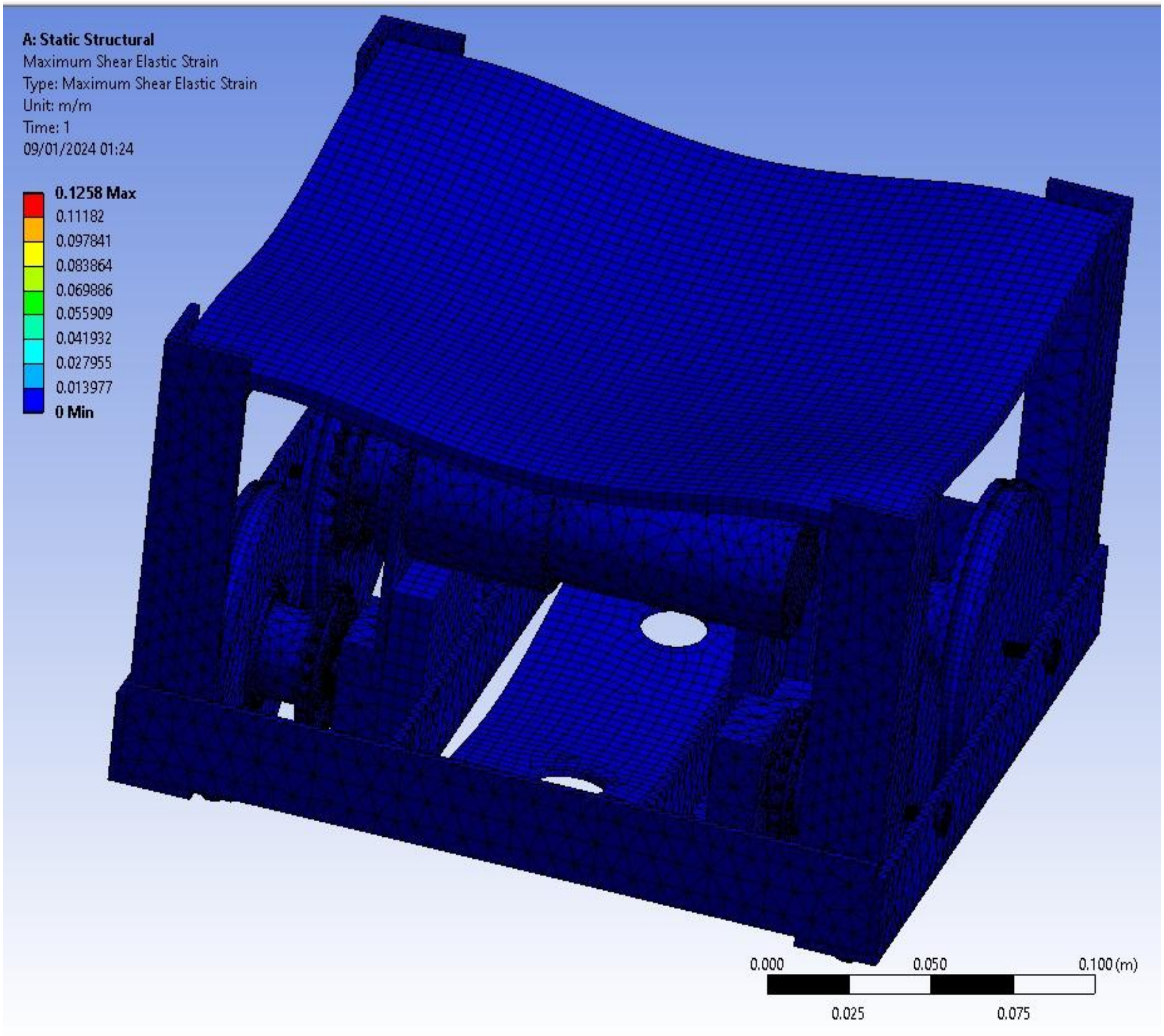


Figure 35: Max Shear Elastic Stress

Max Principle Elastic Stress:

- **Definition:** Maximum principal elastic stress represents the highest normal stress experienced by a material, considering both tensile and compressive stresses.
- **Simulation Output:** ANSYS outputs contour plots and numerical values depicting the distribution of principal stresses. The highest principal stress corresponds to the maximum principal elastic stress within the structure.
- **Interpretation:** Assessing maximum principal elastic stress helps engineers identify regions under significant tensile or compressive load, guiding design modifications to ensure structural integrity.

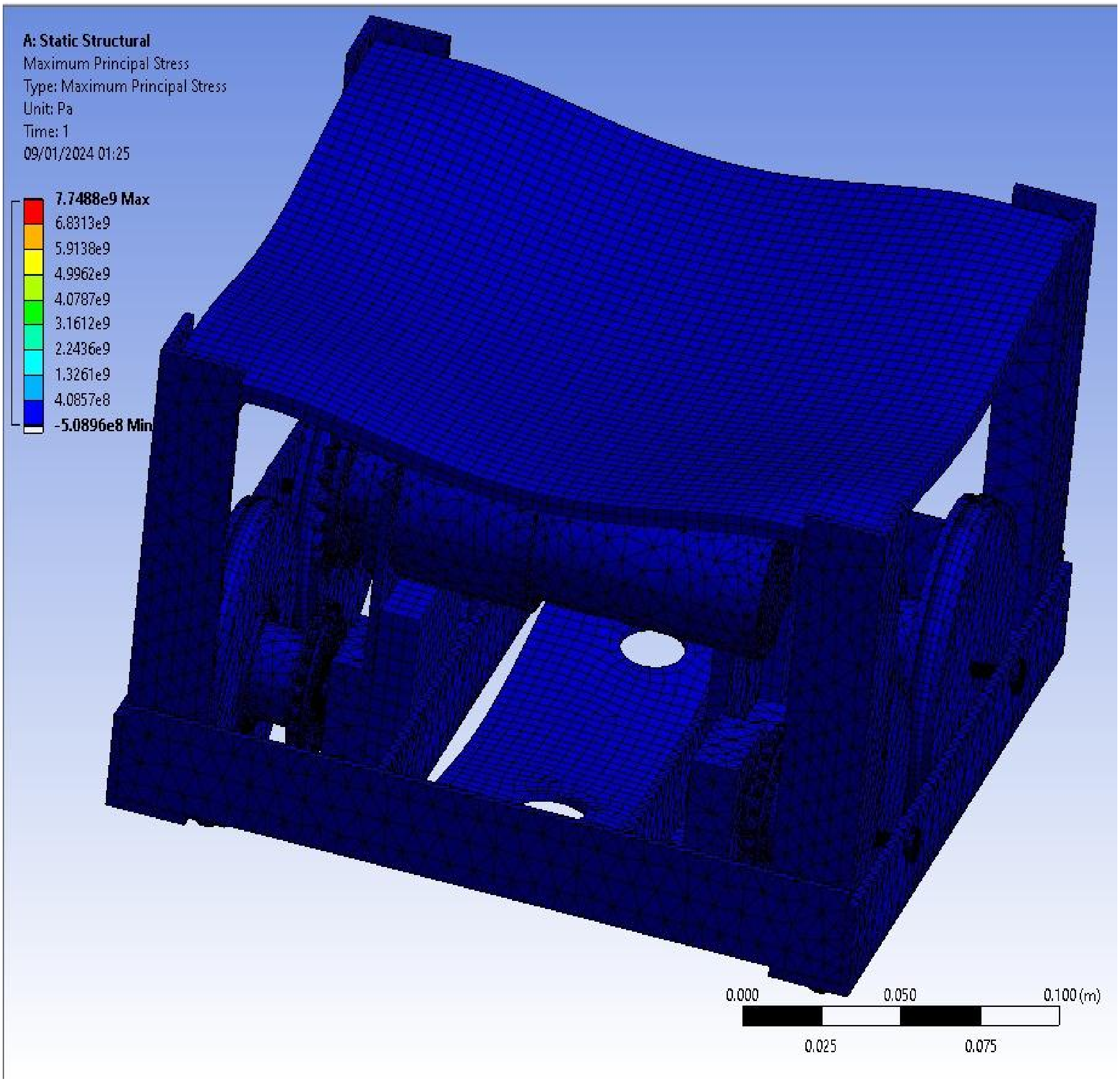


Figure 36: Max Principle Elastic Stress

Max Shear Stress:

- **Definition:** Maximum shear stress represents the highest intensity of internal forces within the material in a shearing direction, irrespective of elastic or plastic behavior.
- **Simulation Output:** ANSYS generates contour plots and numerical values illustrating the distribution of shear stresses. The highest shear stress corresponds to the maximum shear stress within the structure.
- **Interpretation:** Evaluating maximum shear stress is crucial for identifying potential failure points or areas prone to yielding, guiding design modifications for safety and reliability.

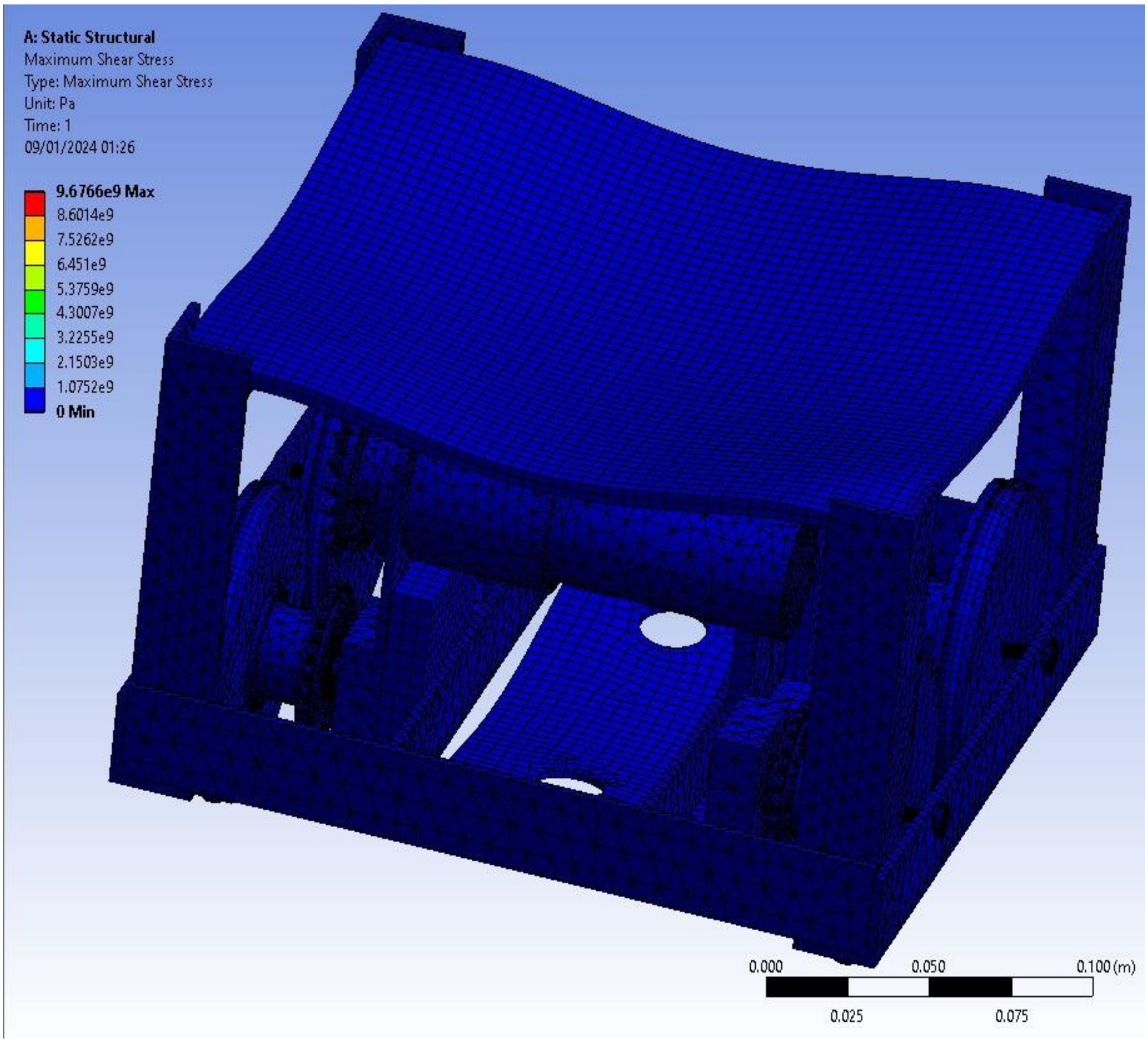


Figure 37: Max Shear Stress

Strain Energy:

- **Definition:** Strain energy is the energy absorbed by a material as it deforms under load.
- **Simulation Output:** ANSYS provides numerical values for total strain energy, indicating the cumulative energy absorbed by the structure during the simulation.
- **Interpretation:** Strain energy is useful for assessing the material's ability to absorb and dissipate energy. Engineers use this information to evaluate the resilience and performance of the structure under applied loads.

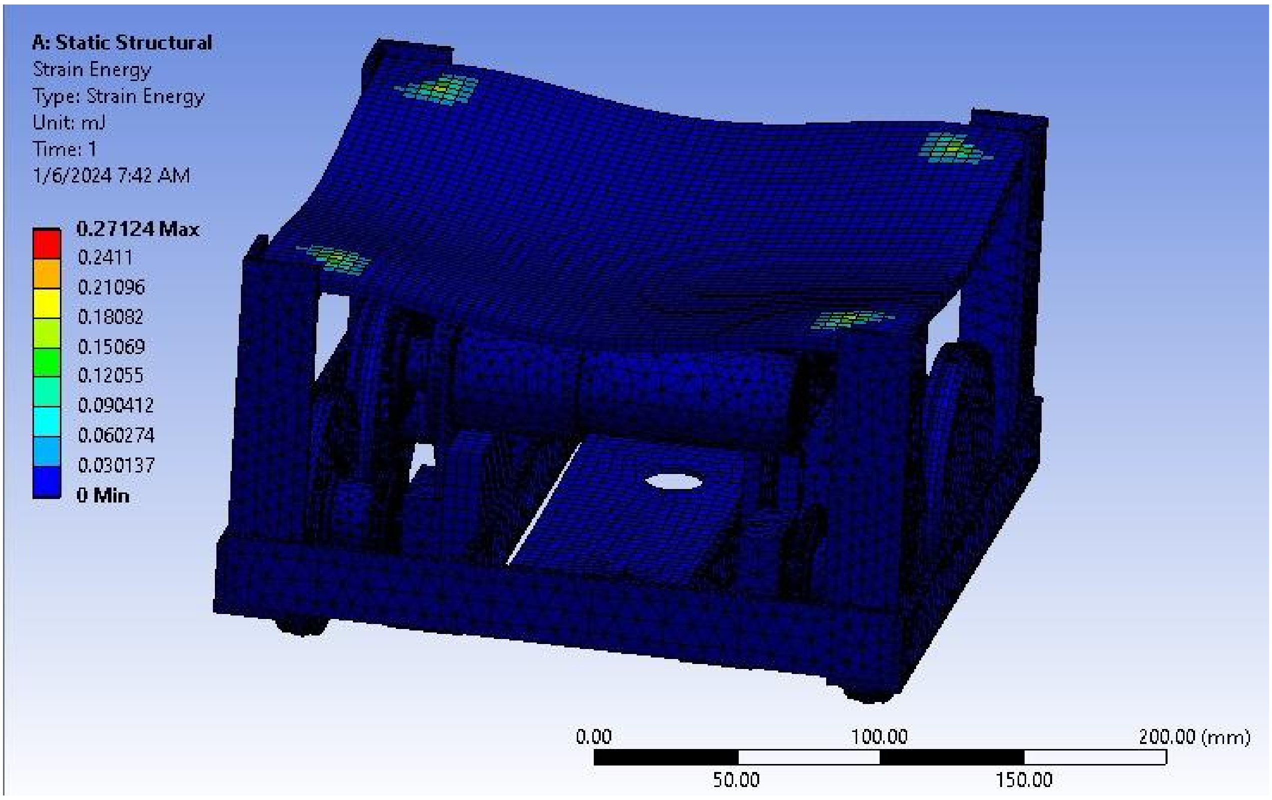


Figure 38: Strain Energy

- After All the Steps are Completed, The Analysis is Completed.

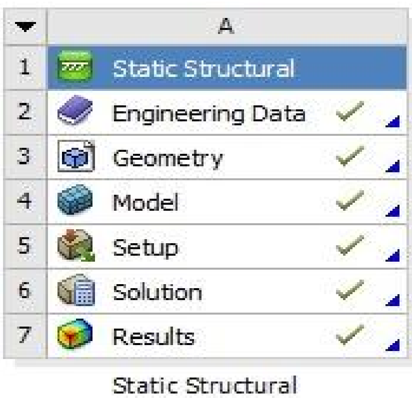


Figure 39: Analysis Completed

5. Conclusions:

Theoretical and simulation-based analysis of the National Engineering Robotics Contest (NERC) Robot were successfully completed with the help of Design of Machine Elements Concepts and Ansys Software. The comparative analysis of theoretical calculations and ANSYS simulations serves as a robust methodology to refine and enhance the design, contributing to the overall success of our robot in the NERC competition.