Design and Analysis of Braking System of a FSAE Vehicle

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***Abstract*: Brakes are one of the most important components of an automobile. The primary function of brakes is to decrease the speed of vehicle and to hold the vehicle at rest. FSAE is a student design organization which conducts various student design competition. A formula vehicle is an open wheeled open cockpit type car used for formula events. In this paper we have calculated the brake force generated for an effort of 250 N. We have used bias bar for biasing and have a pedal ratio of 4.5:1. We have studied in detail the transmission of force from the brake pedal to brake rotor. We have also performed static structural analysis of brake pedal and brake rotors in ANSYS and tried to understand the effect of applied force on brake pedal and brake rotors. We have also performed thermo-structural analysis of brake rotor. We have analyzed the forces in both numerical and analytical method. This paper aims on a detailed study of whole brake circuit and analyze the possible failure in them.**

***Index Terms*: Hydraulic brakes, Disc Brakes, Formula student, SAE, Bias bar, Solidworks, CAD, ANSYS, Numerical analysis, Analytical approach.**

I. INTRODUCTION

Braking system are one of the most crucial and important system of an automobile. The primary function of braking system is to slow down a vehicle. Mostly brakes use frictional force to stop a vehicle but in few cases like in electromagnetic braking occurs without friction. This paper is discussing about the hydraulic brakes used in a formula 3 type vehicle. Brakes are basically classified as -:

- Disc Brakes
- Drum Brakes

Moreover based on the method of actuation they are also classified as -:

- Hydraulic brakes.
- Pneumatic brakes.
- Mechanical brakes
- Electric brakes.

In this paper specifically we will be discussing about hydraulic disc brakes.

II. BRAKE COMPONENTS

Before going in detail about hydraulic disc brakes we shall be discussing the components of a hydraulic disc braking system in detail. The major components of a hydraulic disc braking system are-:

- Brake reservoir
- Brake pedal
- Bias bar
- Connecting rod
- Master cylinder
- Brake lines
- Brake calliper
- Brake Rotor.

Other than these components there are some sub components as well which constitute an essential part of the braking system they are

- Bleeder Valve
- Banjo bolt
- Brake fluid
- Brake pads.

1. **Brake reservoir**-:

As the name suggests in a brake reservoir stores brake fluid to supply it into the brake lines it also stores surplus brake fluid and supplies it into the circuit in case of a leakage in the brake lines. It is generally situated at a higher position than other components of a braking system.

Fig 1: Image of a Brake reservoir

Fig 2: Brake reservoir fitted in a car.

2. Brake Pedal-:

It is one of the most crucial part of a braking system and it is the part which bears and transmits the manual force applied on it. It works on lever principle and increases the applied force by amount of leverage in it.

Fig 3: Image of a simple brake lever

Fig 4: Image of a brake box of a FSAE car.

3. Bias bar-:

It is often observed that whenever a vehicle applies brakes due to inertia load is transferred from rear to the front. This increases the load on the front axle and hence the torque required to stop the front wheel is more. The presence of single brake pedal makes us to think of a way to generate two outputs from a single input. Most commonly two different ways are used for this task. Either a bias bar or a proportionating valve is used for the task. In our vehicle we would be using bias bar for distribution of force. It uses the concept of moment equilibrium for distribution of forces.

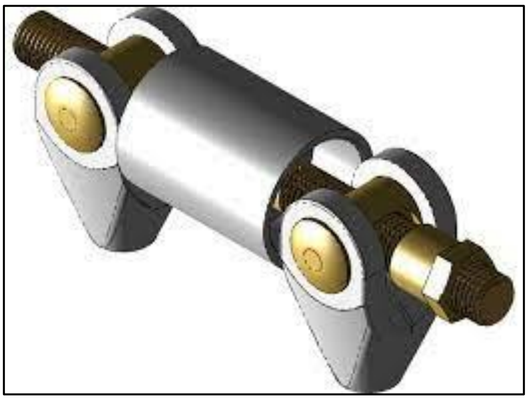

Fig 5: CAD of a brake bias bar.

4. Connecting Rod and Master Cylinder Assembly-:

Master cylinder is a device which converts the mechanical energy applied on the pedal to equivalent pressure on the brake lines. The pressure is then transmitted undiminished to the brake calipers. It is cylinder piston like arrangement. Whenever force is applied on the brake pedal that is transmitted to the master cylinder. The connecting rod which is connected directly to the piston of the master cylinder pushes the brake fluid out of the cylinder. This push generates a push and that travels to the brake caliper.

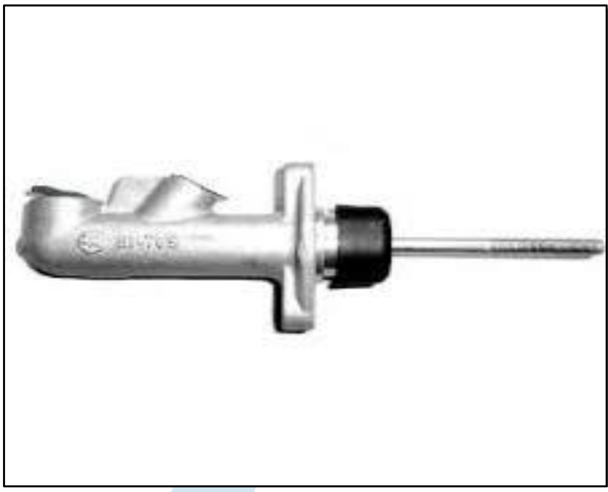

Fig 5: Image of Master cylinder.

Fig 6: Image of Master Cylinder (AP Racing)

5. Brake Lines-:

As the name suggests these are used to house brake fluid which is at pressure. It connects master cylinder with the caliper. It should be rigid enough to bear the pressure generated at the brake lines.

Fig 7: Image of a commercially used Brake line

Fig 8: Image of Braided Brake Line.

6. Brake Caliper-:

Any thing that has two jaws is called a caliper. So does a brake caliper. It has two jaws with brake pads fitted on it. Whenever brake is applied the pressure in the brake line pushes a piston inside the caliper. The piston has pads attached on the surface. The pads then rub against the walls of the rotor and restricts the motion of the rotor.

Fig 9: Image of Brake Caliper

Fig 10: Image of Brake Caliper with Rotor

7. Brake Rotor-:

It is one of the most important features of a Disc Braking system. A rotor is rigidly attached with the hub and rotates with it. It has to be light and durable to be able to bear the braking torque applied on it.

Fig 11:Image of a Brake Rotor

III. DESIGN CALCULATION

We have designed the brake system after getting certain data from suspension department. We have been provided with certain data all of this pre-requisite has been provided in the below table.

** List of all the symbols has been provided in the last page.

Pedal Force =250 N
Mass of the vehicle (m) =300 kg
Wheel base (L) = 1560mm
Track Width Front = 1280mm
Rear = 1240mm
Radius of front wheel (R) = 228.6mm
Maximum Longitudinal Acceleration (a) = 0.89g
Maximum Lateral Acceleration (Al) = 0.84g
Centre of Gravity from ground (h) = 350mm
Mass Distribution Front: Rear = 45:55 (calculated from the position of centre of gravity)
Distance of Centre of Gravity from Front Axle (L_f) = 702mm
From Rear Axle (L_r) = 858mm

- **Calculation of Mass Distribution-:**

Load on Front Axle = Mass*(Lr+h)/L
= 300*(858+350)/1560
= 232.30kg
Load on Rear Axle = Mass*(Lf -h)/L
= 300*(702-350)/1560
= 67.692kg

- **Calculation of Lateral Load Transfer**

Front = (Mass(front)*Al*h)/(g*Front Track width)
= (0.45*300*0.84*9.81*350)/(9.81*1280)
= 31.007kg
Rear = (Mass(Rear)*Al*h)/(g*Rear Track Width)
= (0.55*300*0.84*9.81*350)/(9.81*1240)
= 39.12kg

- **Calculation of The Driving Torque**

Longitudinal load Transfer (F_t) = μ*m*h*g/L (During Braking)
= (0.89*300*350*9.81)/1560 = 587.65N
Normal Force on Front Tyres (F_{nf}) = ((m*g*L_r)/L) +F_t

= ((300*9.81*858)/1560) +587.65
=2206.306N

Normal Force on Rear Tyres (F_{nr}) = ((m*g*L_f)/L)-F_t
= ((300*9.81*702)/1560)-587.65
=736.7N
So, braking force on each Front wheel (F_f)= F_{nf} * μ/2
= 2206.306*0.89/2
= 981.806N
Radius of front wheel (R) = 228.6mm= 0.228m
So, Torque required on front and rear wheel to stop (T_f) = F_f *R
= 981.806*0.228
= 223.85Nm
Similarly, braking force required on each Rear wheel (F_r)= F_{nr}* μ/2
=736.7*0.89/2
= 327.83N
So, Torque required on Rear wheel to stop (T_r)= F_r *R
= 327.83*0.228
= 74.745Nm

- **Calculation of The Braking Force Generated**

Maximum Brake Force exerted by Driver = 250N
Taking FOS = 1.1, we have Brake Force = 275N
Pedal Ratio = 5:1

So,total Force applied on Master Cylinder = 5*275 = 1375N

We have used Brake Biasing Ratio = 55:45

So,
Brake Force applied on Front Master Cylinder (F_{bf}) = 1375*0.55
= 756.25N

Rear Master Cylinder (F_{br}) = 1375*0.45
= 618.75N
Area of Master Cylinder (A_m) = 153.93mm^2

Pressure in Front Brake Line (P_{bf}) = F_{bf}/A_m
= 756.25/153.93
= 4.912N/mm^2
Pressure in Rear Brake line (P_{br}) = F_{br}/A_m
= 618.75/153.93
= 4.019N/mm^2

Front

Area of Front Caliper (A_c)= 1606.5mm^2
Clamping Force on Front rotor applied by Calipers (F_{clf}) = P_{bf}*A_c
= 4.912*1606.5
= 7891.128N

Coefficient of friction between rotor and pads = μ_{pad} = 0.3
Frictional Force on Front rotor applied by Calipers (F_{cf}) = F_{clf}* μ_{pad}
= 7891.128*0.3
= 2367.338N

Radius of effective force acted on region (r) = (r_a^3-r_i^3)/(r_a^2-r_i^2)
= (90^3-74.25^3)/(90^2-74.25^2)
= 123.56mm = 0.1235m

Force on rotor applied be Calipers on Front rotor (F_{cf}) = 2367.338N
So, Maximum torque can be given by rotor is = F_{cf} *r
= 2367.338*0.1235

=292.50Nm

Here, Driving torque (223.85Nm) < Braking torque (292.50Nm)
So, the rotor design is satisfactory for front braking circuit.

IV. CAD MODELLING OF BRAKE COMPONENTS

Fig 9:CAD of a Brake Pedal

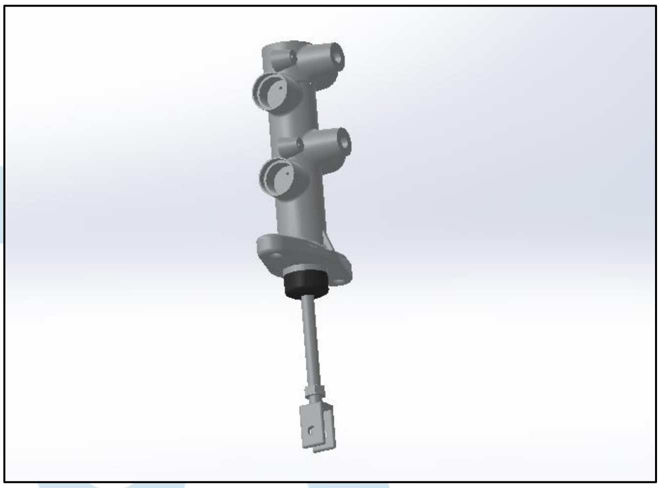

Fig 10:CAD of a Master Cylinder

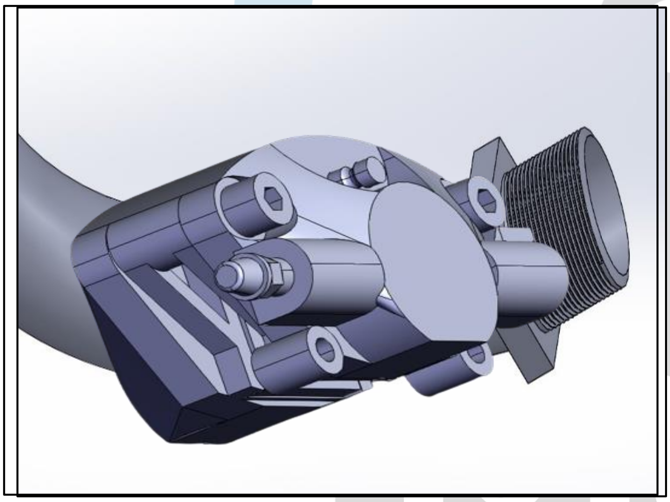

Fig 11: CAD of a Brake Line

Fig 12: CAD of a Caliper

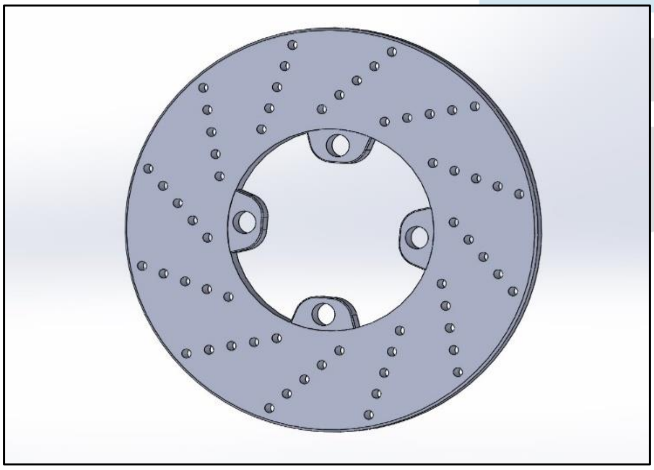

Fig 13: CAD of a Brake Rotor

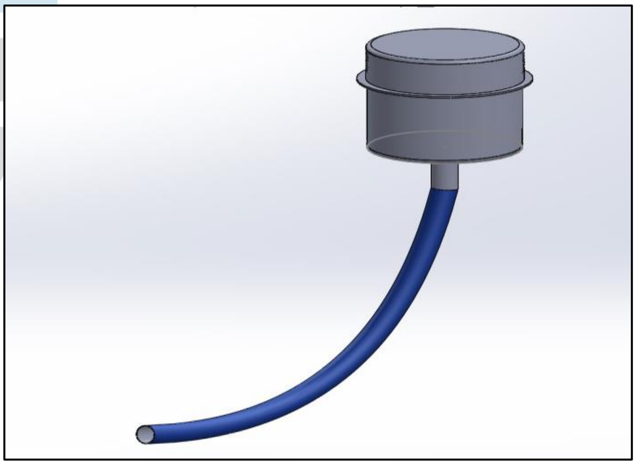

Fig 14: CAD of a Brake Reservoir

V. Finite Element analysis of designed components

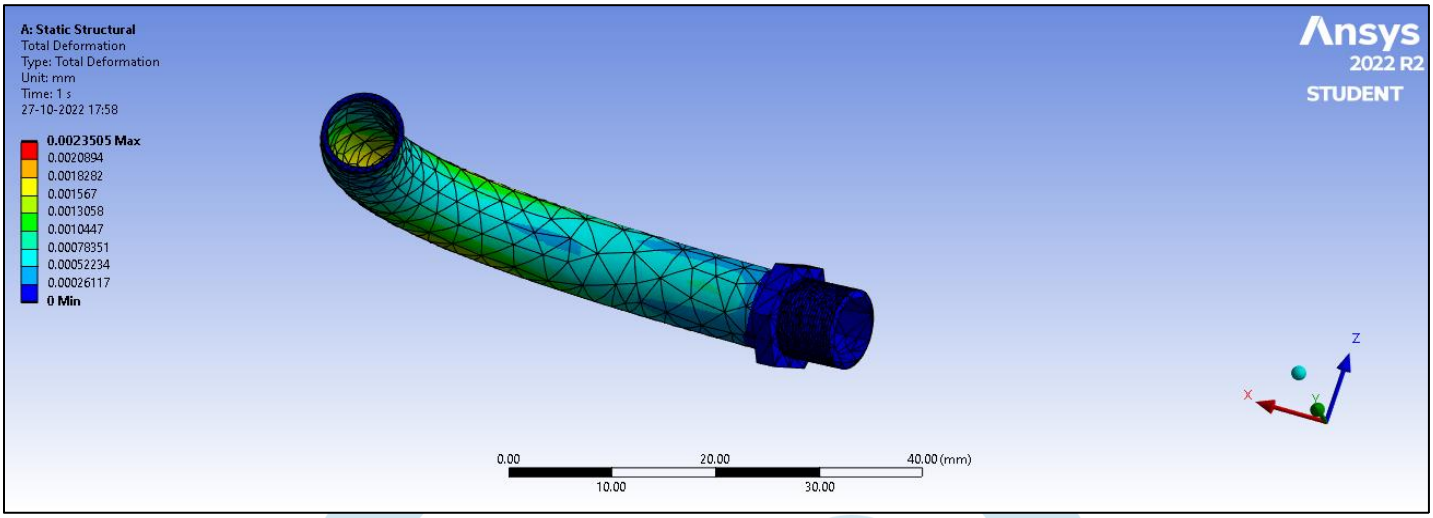

Fig 14: Total Deformation of Brake Line Under an Internal Pressure of 4.912 N/mm²

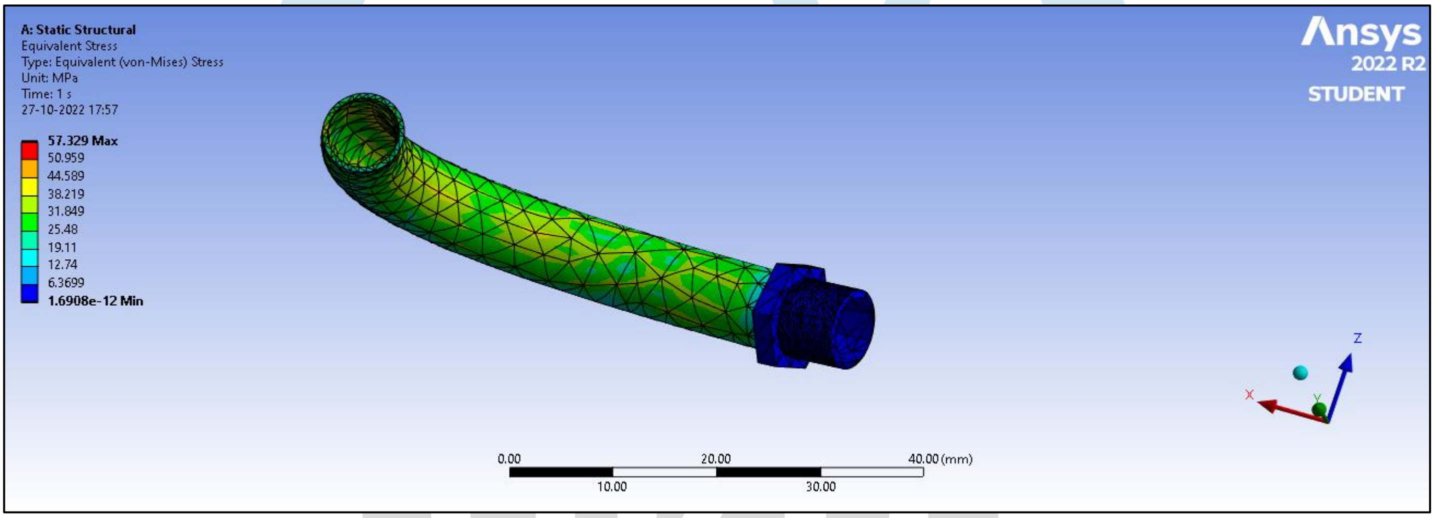

Fig 15: Equivalent Stress of Brake Line Under an Internal Pressure of 4.912 N/mm²

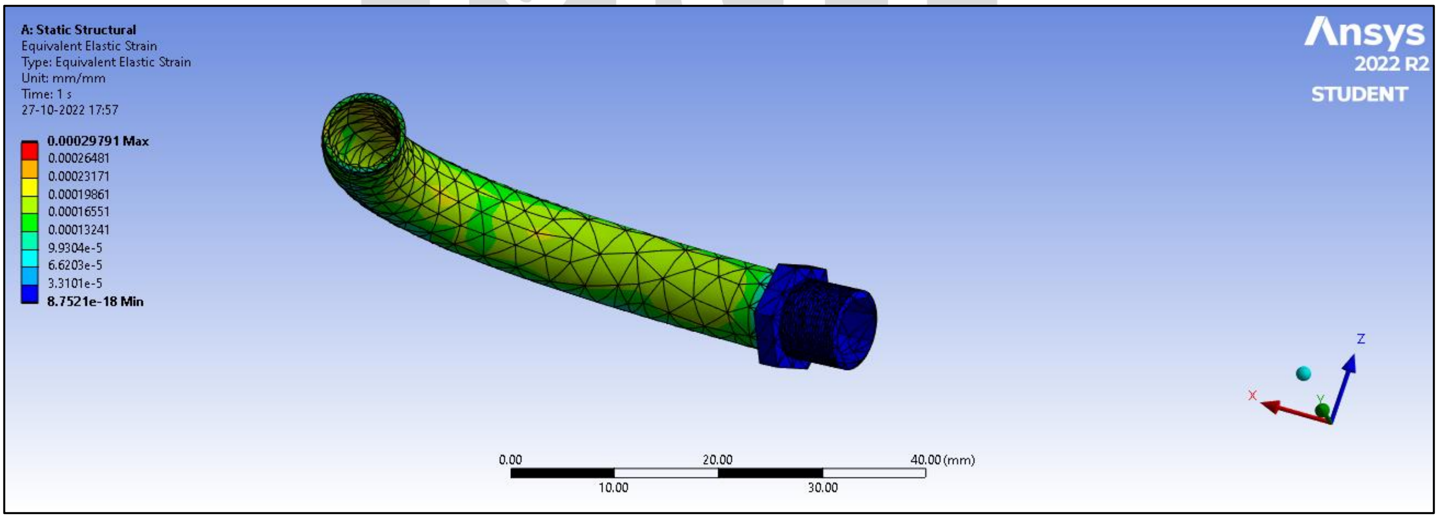

Fig 16: Equivalent Strain of Brake Line Under an Internal Pressure of 4.912 N/mm²

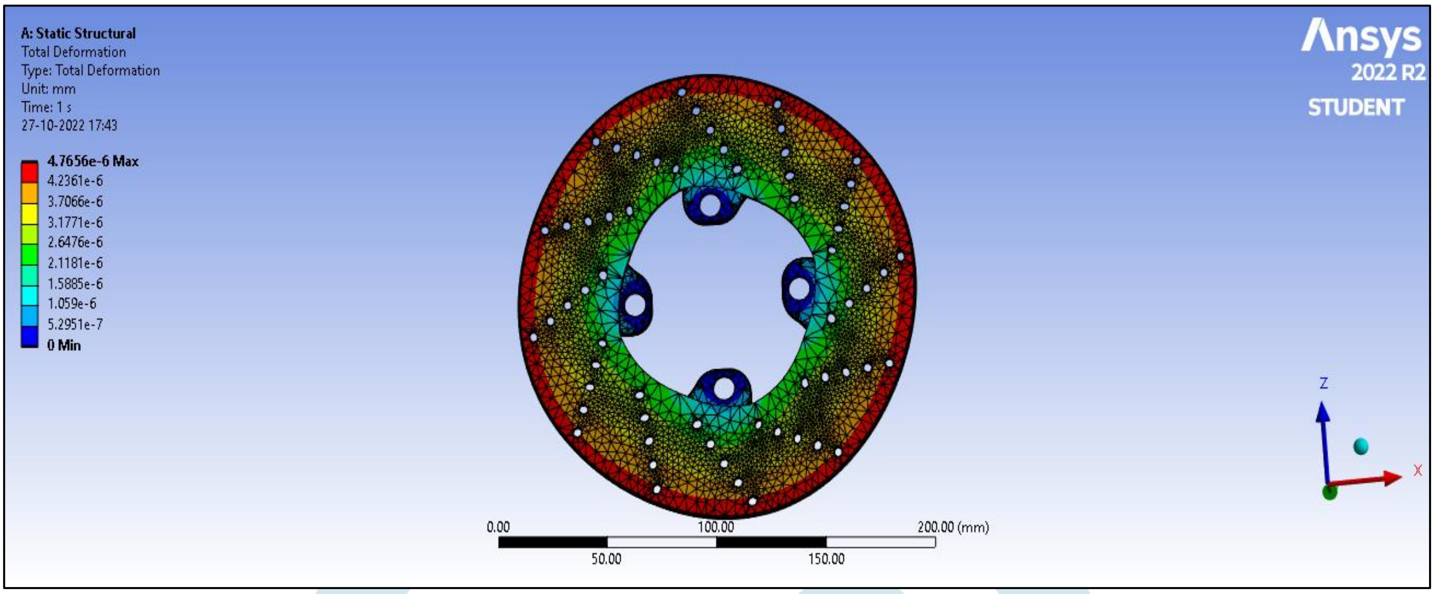

Fig 17: Total Deformation of Brake Rotor Under Braking Torque of 291.2 N/mm

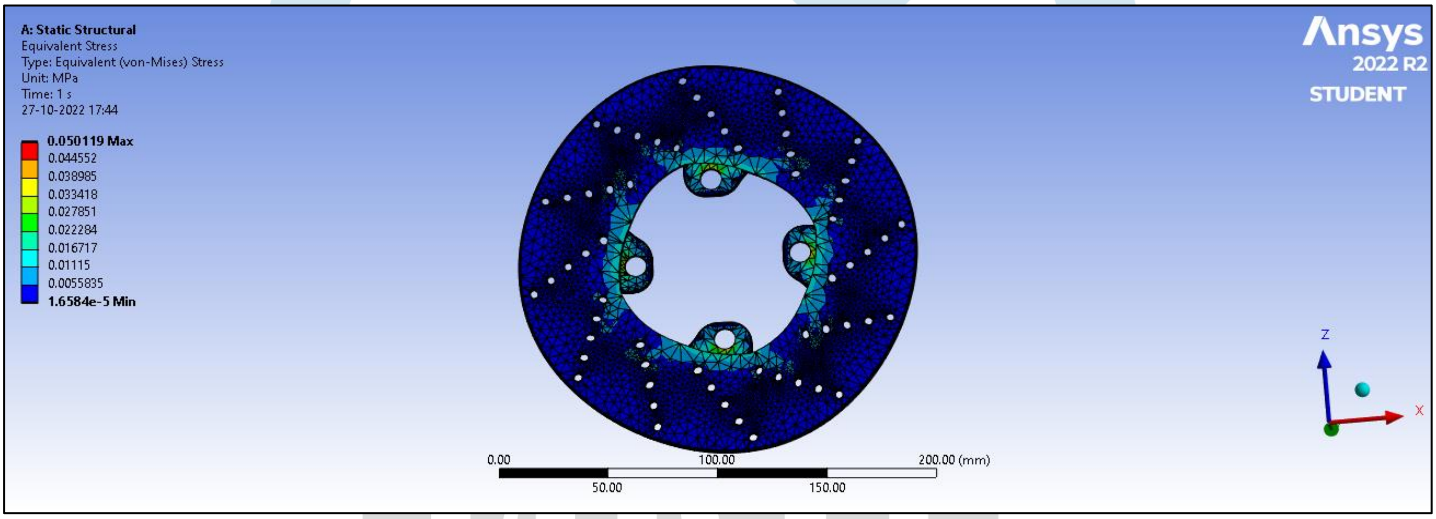

Fig 18: Equivalent Stress of Brake Rotor Under Braking Torque of 291.2 N/mm

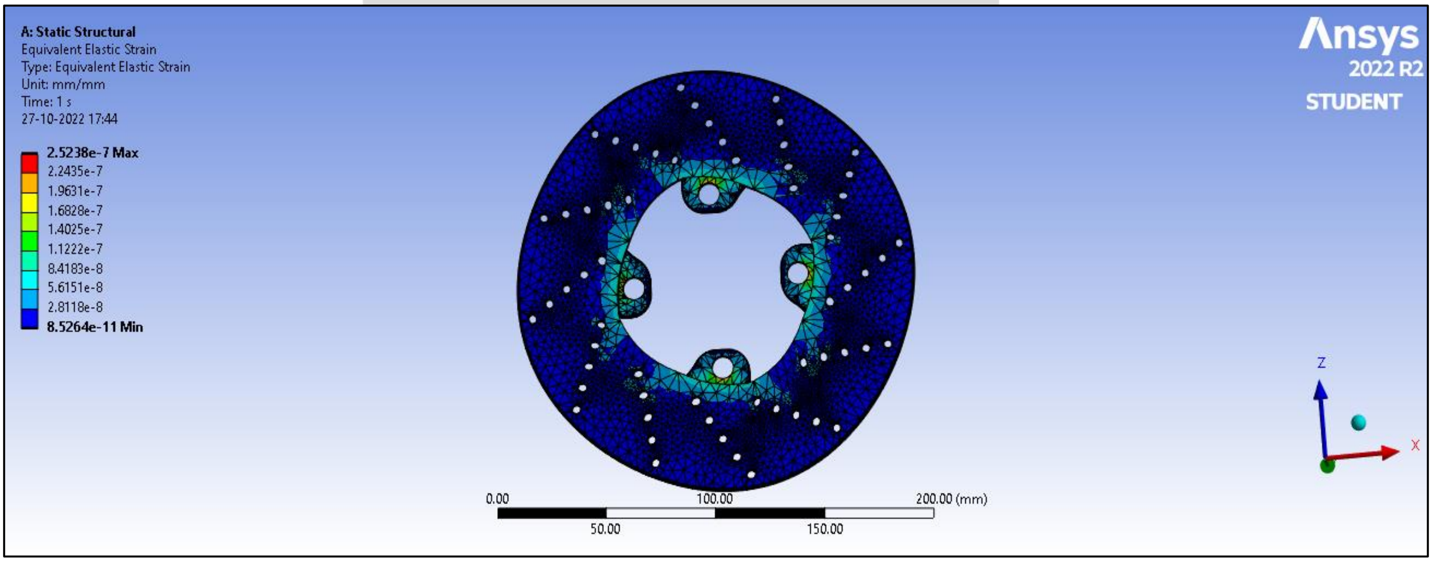

Fig 19: Equivalent Strain Brake Rotor Under Braking Torque of 291.2 N/mm

VI. Conclusion

We can conclude from our calculation is that even a pedal force of 250 N is enough to lock the tires. In this paper we have made a detailed study on how a braking system works. The braking system studied in this paper was a hydraulic disc braking system with a bias bar used for biasing and H-Split system. We have analyzed the system in both ways i.e., Numerical method and Analytical method and both have been proved the design is satisfactory.

References

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