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Performance Evaluation of Shock Absorbers Using Composite Materials

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Abstract: This project evaluates the performance of shock absorbers using composite materials like Carbon Fiber and Glass Fiber Reinforced Polymer (GFRP), applied as a coating to a primary spring steel structure. The study compares an original spring steel design with a modified version featuring an increased coil diameter and composite coating to enhance ride quality and comfort by reducing disturbance amplitudes. Designed in CATIA and simulated in ANSYS Workbench 2024, the analysis includes structural evaluation of equivalent and principal stresses under varying loads, vibrational analysis of frequency and acceleration changes, and modal analysis of mode shapes and natural frequencies. The objective is to propose a modified shock absorber design that ensures the maximum principal stress remains within the yield stress limit, making it a safer and more efficient solution

Keywords: *Shock absorbers, Composite Materials, Structural & Vibrational Analysis, CATIA & ANYSYS, Equivalent stress*

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I. INTRODUCTION

➢ *Shock Absorbers*

The primary function of a shock absorber is to absorb or dis- sipate energy, with one key design consideration being the di- rection in which this energy is managed. In most dashpots, en- ergy is converted into heat within a viscous fluid, while in hy- draulic cylinders, the hydraulic fluid heats up, whereas air does not. Typically, heated air is vented into the atmosphere from cylinders. Some types of dashpots, such as electromagnetic ones, allow dissipated energy to be conserved and reused. The term ”shock” broadly refers to various impact-related events, and shock absorbers play a crucial role in enhancing vehicle stability and comfort when driving over uneven roads.

Shock absorbers minimize the impact of driving over uneven terrain, improving ride quality and comfort by reducing distur- bance amplitudes. Without them, the vehicle would bounce as energy stored in the spring is released, potentially exceeding the suspension’s allowable movement range. Uncontrolled sus- pension movement would require stiffer springs, leading to a rougher ride. Shock absorbers allow the use of softer springs while maintaining vehicle stability by regulating the suspen- sion’s response to bumps, ensuring a smoother and more con- trolled driving experience.

- Shock Absorber Types: There are various methods to transform an impact or collision into a smoother surface con- tact.

✓ Metal Spring
✓ Rubber Buffer
✓ Hydraulic Dashpot

Fig 1Rear shock absorber and spring of a motorcycle.

✓ Collapsing safety Shock Absorbers
✓ Pneumatic Cylinders
✓ Self-compensating Hydraulic

This study focuses specifically on metal spring shock ab- sorbers, a type of dashpot designed to soften shock impulses and dissipate kinetic energy. In spring-based shock absorbers, coil or leaf springs are commonly used, while torsion bars are utilized in torsional shock absorbers.

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However, ideal springs alone do not function as shock absorbers since they only store energy rather than dissipating it. Automobiles typically incor- porate hydraulic shock absorbers alongside springs or torsion bars, where the shock absorber acts as a hydraulic piston to ab- sorb and dissipate vibrations. The primary purpose of a shock absorber is to absorb and disperse as much kinetic energy from impacts as possible. Shock absorbers are generally classified based on the type of spring used—either solid springs made of steel or rubber or fluid springs utilizing gas, oil, or a combina- tion of both, known as oleo-pneumatic systems. A key design consideration when developing or selecting a Preprint submitted to Elsevier March 18, 2025
shock absorber is determining how the energy will be managed. In most dashpots, energy is dissipated as heat within a viscous fluid. In hydraulic cylinders, the hydraulic fluid heats up, while in air cylinders, hot air is typically vented into the atmosphere. Some dashpots, such as electromagnetic ones, can store and later reuse the dissipated energy. Shock absorbers play a cru- cial role in cushioning vehicles on uneven roads and are widely used in automotive and motorcycle suspensions, aircraft land- ing gear, and industrial machinery supports.

Large shock absorbers are utilized in structural engineering to minimize a structure's sensitivity to earthquake damage and resonance. In vehicles, they help absorb the impact of uneven terrain, ensuring a smoother ride and improved comfort. While shock absorbers primarily control excessive suspension move- ment, their main function is to dampen spring oscillations. Shock absorbers utilize oil and gases to absorb excess energy from springs.Manufacturers determine spring rates based on the vehicle's weight, both loaded and unloaded.While some attempt to use shocks to modify spring rates, this is not their in- tended function. Along with tire hysteresis, shock absorbers help dampen the energy generated by the up-and-down mo- tion of the unsprung weight. Effective wheel bounce damping may require fine-tuning the shocks to achieve the desired re- sistance. In spring-based shock absorbers, coil or leaf springs are commonly used, while torsion bars are utilized in torsional shocks. However, ideal springs alone do not function as shock absorbers, as they only store energy without dissipating it..

II. COMPOSITE MATERIALS

This project is about the current developments in autos and material advancements. Shock absorbers are nothing more than suspensions, and the objective is to compare suspensions con- structed of composite materials, and it has been proven that composite suspensions are stronger than other materials. As a result, suspension materials should be robust, and compos- ite materials should be employed. Because composite materials have a high stiffness, they are chosen and blended with vari- ous chemicals, minerals, and other components to make them strong, and numerous tests are performed.

Suspensions today require high performance and must be highly sturdy to be used. For this reason, suspension systems are composed of composite materials such as S-glass fibre and carbon fibre. These are blended with epoxy glue and formed into the shape of a helical spring, after which different tests, both practical and theoretical, are performed. We picked two distinct composite materials as an alternative to structural steel in order to lower the weight of the suspension system and boost its efficiency. The two materials are as follows:

- Carbon Fiber [Material combination of 2 composite mate- rials (Carbon fiber 395Gpa (B) 60per+ Epoxy carbon Fi- bre UD 395Gpa(R) 40 per)].
- Glass Fiber Reinforced Polymer(GFRP) also known as glass fiber reinforced plastic is a composite material weav- ing fiber E-glass and polyester material together. Glass fiber composition: E- Glass of 60 percent + Epoxy resin of 40 percent in unidirectional fiber-reinforced polymer.

carbon combination		
Density	1696	kg/m³
Structural		
Orthotropic Elasticity		
Young's Modulus X direction	3.206e+11	Pa
Young's Modulus Y direction	7.38e+09	Pa
Young's Modulus Z direction	7.38e+09	Pa
Poisson's Ratio XY	0.228	
Poisson's Ratio YZ	0.4	
Poisson's Ratio XZ	0.228	
Shear Modulus XY	7e+09	Pa
Shear Modulus YZ	2.8457e+09	Pa
Shear Modulus XZ	7e+09	Pa

Fig 2 Technical Specification of Carbon Fiber

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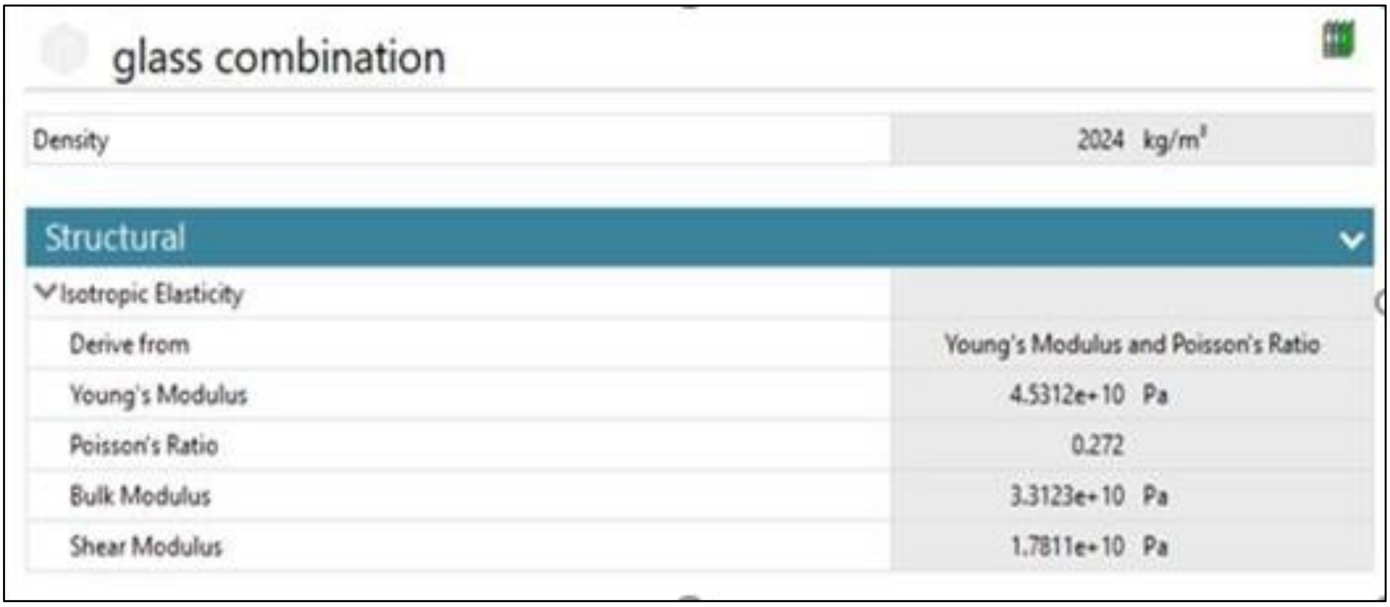


Fig 3 Technical specification of Glass fiber

III. TECHNICAL SPECIFICATION OF STRUCTURAL STEEL AND LOAD CALCULATION:

Structural steel is a subset of steel. It is utilised in the build- ing industry. Steel is commonly used in constructions due to its stiffness and high strength-to-weight ratio. Structural steel is utilised in buildings such as houses, warehouses, aeroplane hangars, educational institutions, bridges and stadiums. Struc- tural steel is steel that has no more than 2.1% carbon. Carbon steel is another name for structural steel, which normally has a carbon percentage of less than 0.6%.

Properties of Structural Steel (S460):

- Material: Structural steel.
- Density: 7850 kg/m3.
- Coefficient of thermal expansion: $1.2e^{-05} 1/^{o}C$.
- Tensile yield strength: $2.5e^{+08}$ pa.
- Young's modulus: $2e^{+11}$ pa.
- Bulk Modulus: $1.6667e^{+11}$ pa.
- Poisson's Ratio: 0.3.

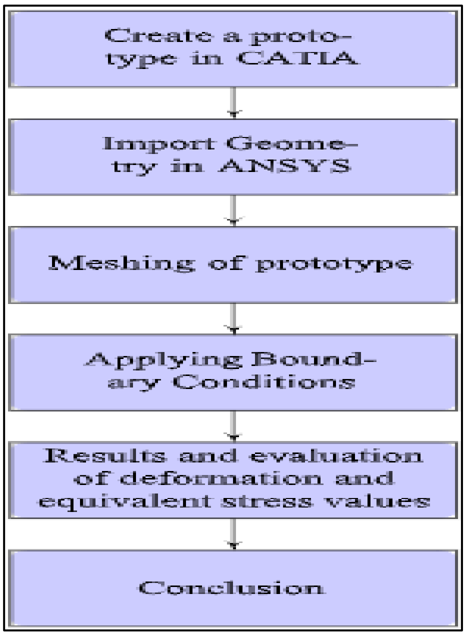
Table 1 Chemical Composition of S460

Element	Manganese(Mn)	Silicon(Si)	Ph.osphorus(P)	Carbon(C)
%	1.60 max	0.50 max	0.025 max	0.12 max

➢ *Load Calculation:*

- Weight of the bike (w) = 120kgs.
- Let the weight of one person be = 70 kg.
- Let the weight of two people be = 2 * 70 kg = 140 kg.
- Weight (wt) of the bike + the people = 260kg s.
- Assume that 65% load was taken by rear suspension: 65% of 260=169kg s. Considering dynamic loads it will be doubled (factor of safety)
- W (wt.) I=338kgs=3316 N.
- For single shock absorber weight (wt.) = (w/2) =1657N.
- Effected load (L) = 1600N

IV. METHODOLOGY



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➤ *Design Approach and Details in CATIA*

The entire model was constructed by designing and creating each component feature by feature.

➤ *Design-1(Initial coil with optimal dimension)*

- Coil diameter = 8mm.
- Pitch of the coil spring = 15mm.
- Mean diameter of the coil = 42mm.
- Free length of the spring = 200mm.

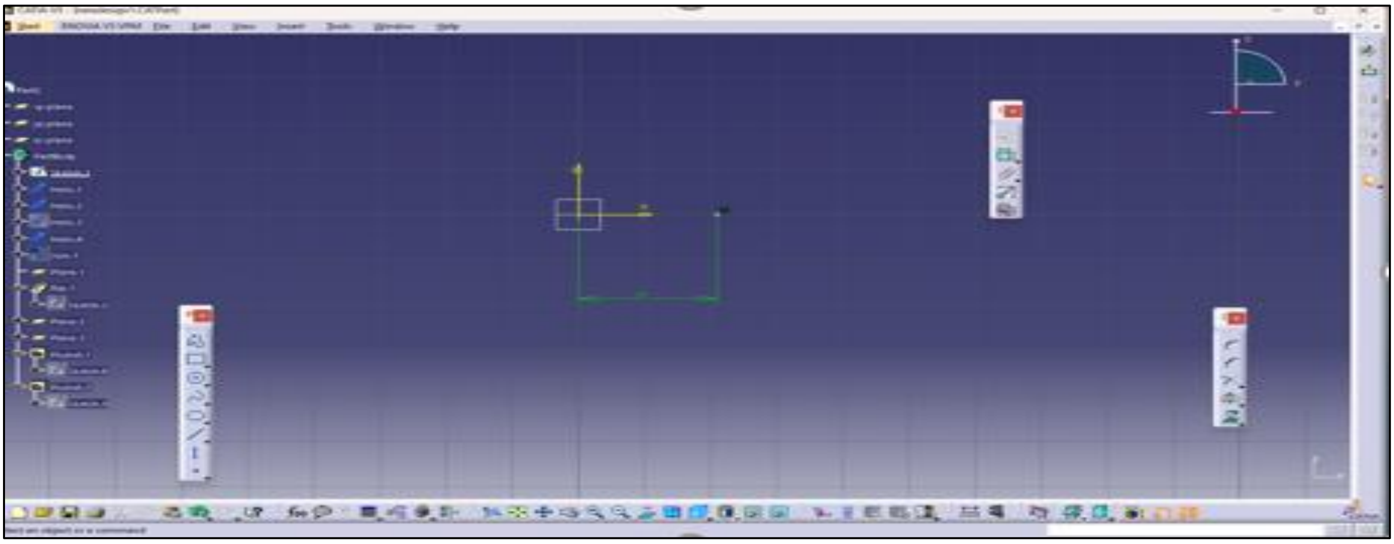

Fig 4 Mean Radius of coil Indicated with a Point for the Origin

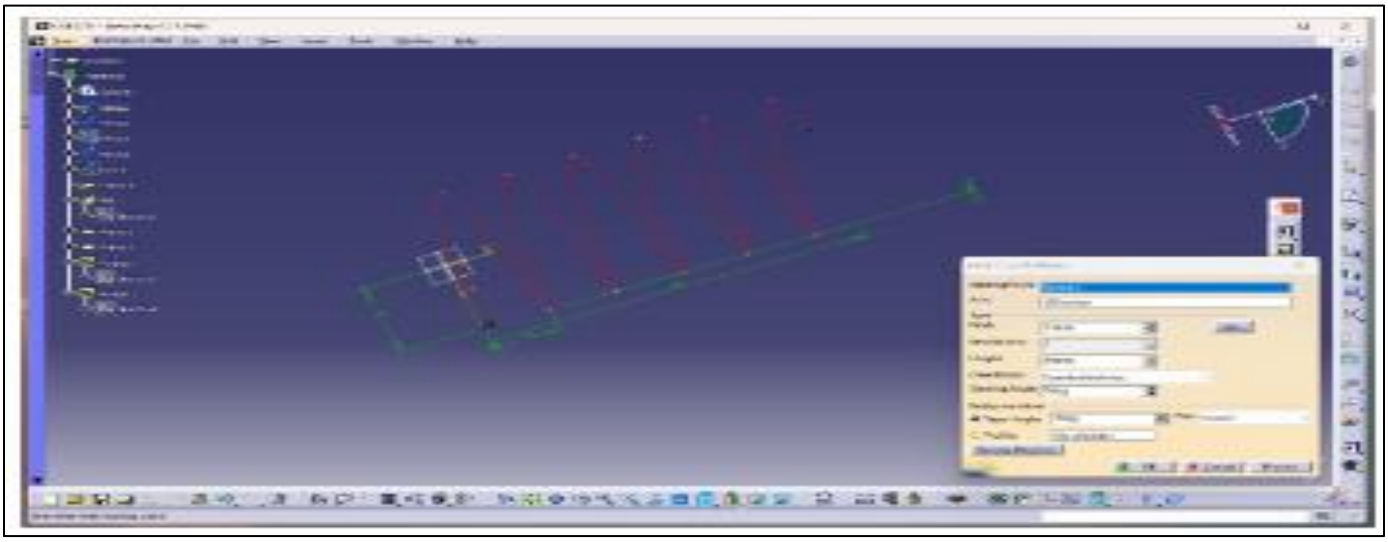

Fig 5 Helix Coil Definition for Half-Length with Uniform Pitch.

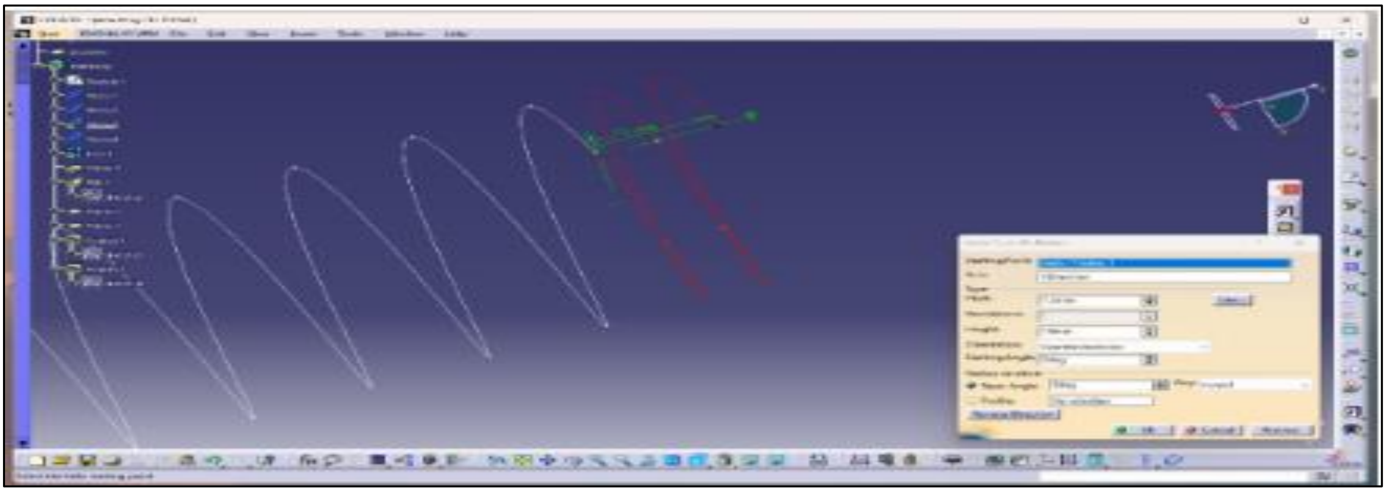

Fig 6 Extension of Helix Coil Definition with Compressed End.

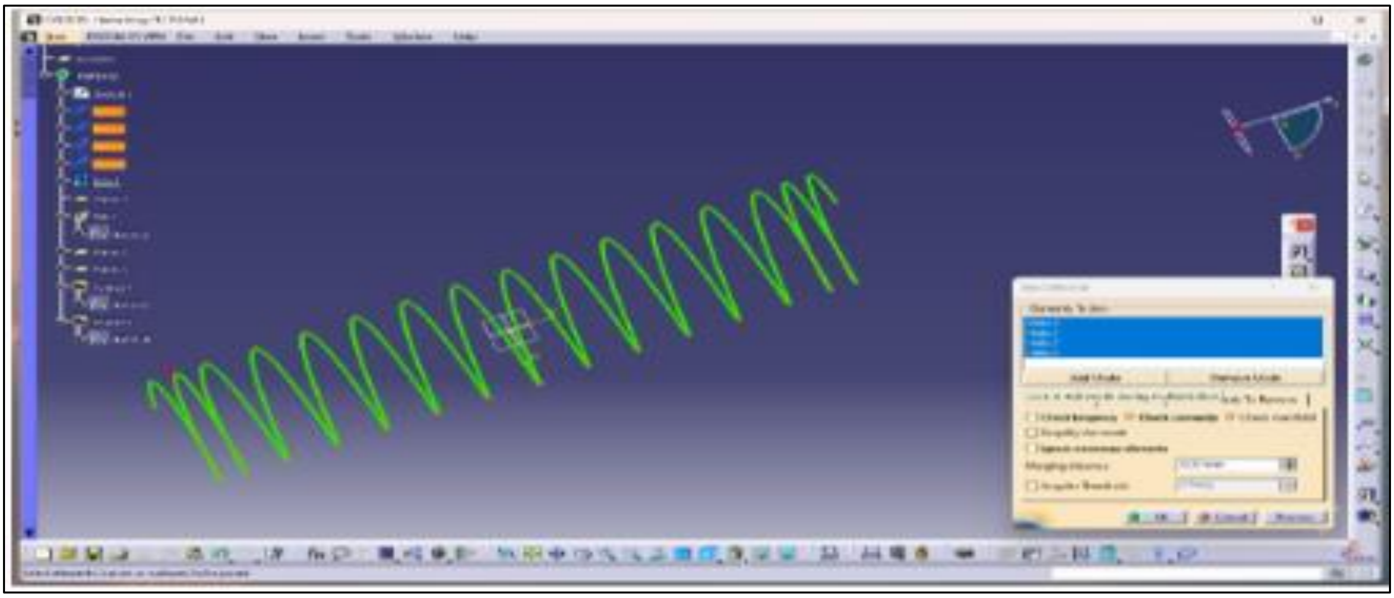

Fig 7 Helix Curve Mirror to Other End and Joined Together.

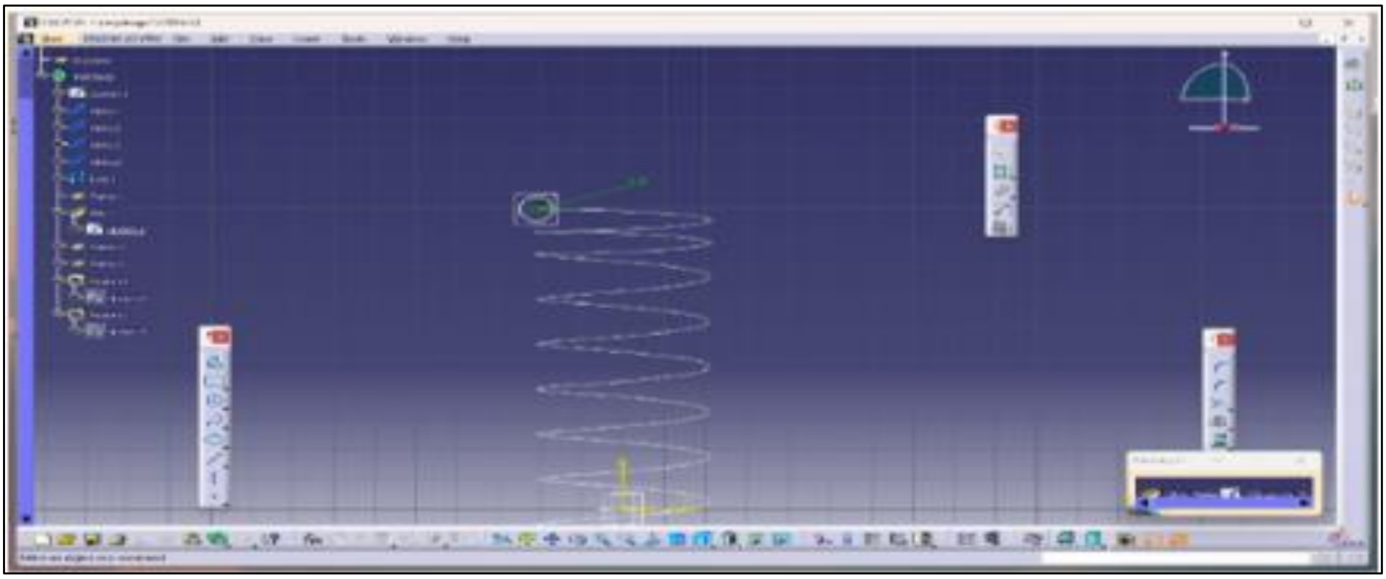

Fig 8 Plane Drawn Perpendicular to Curve and Circle of Mean Diameter of 8mm.

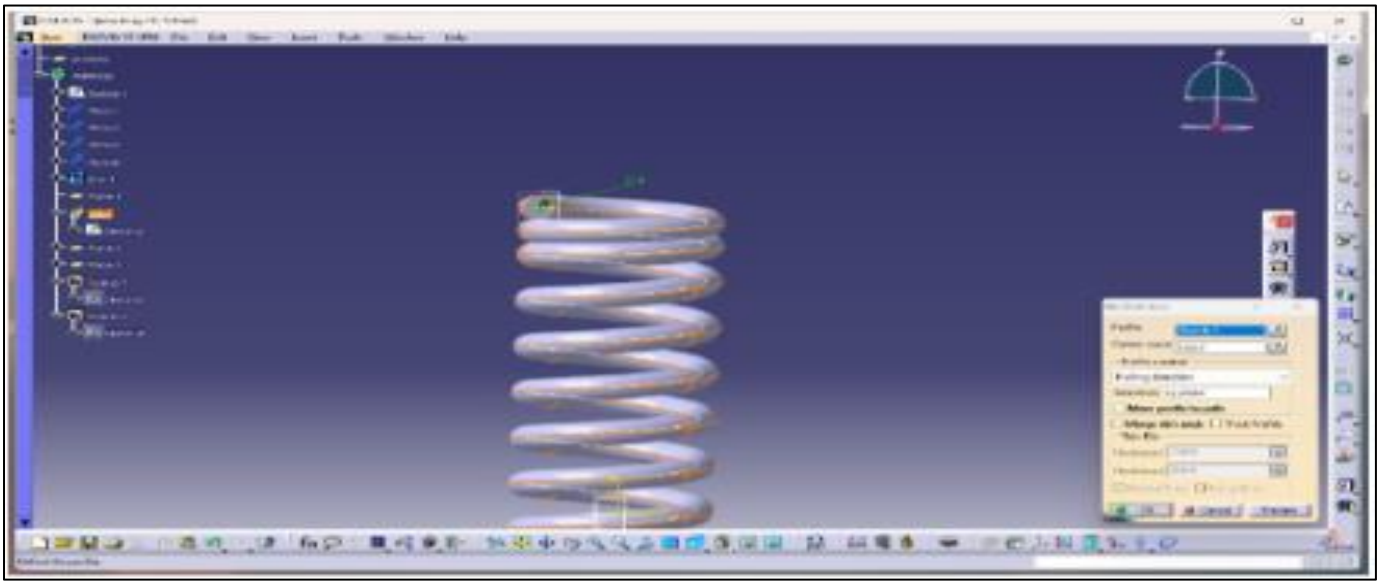

Fig 9 Rib Operation Applied to Circle Throughout the Helix.

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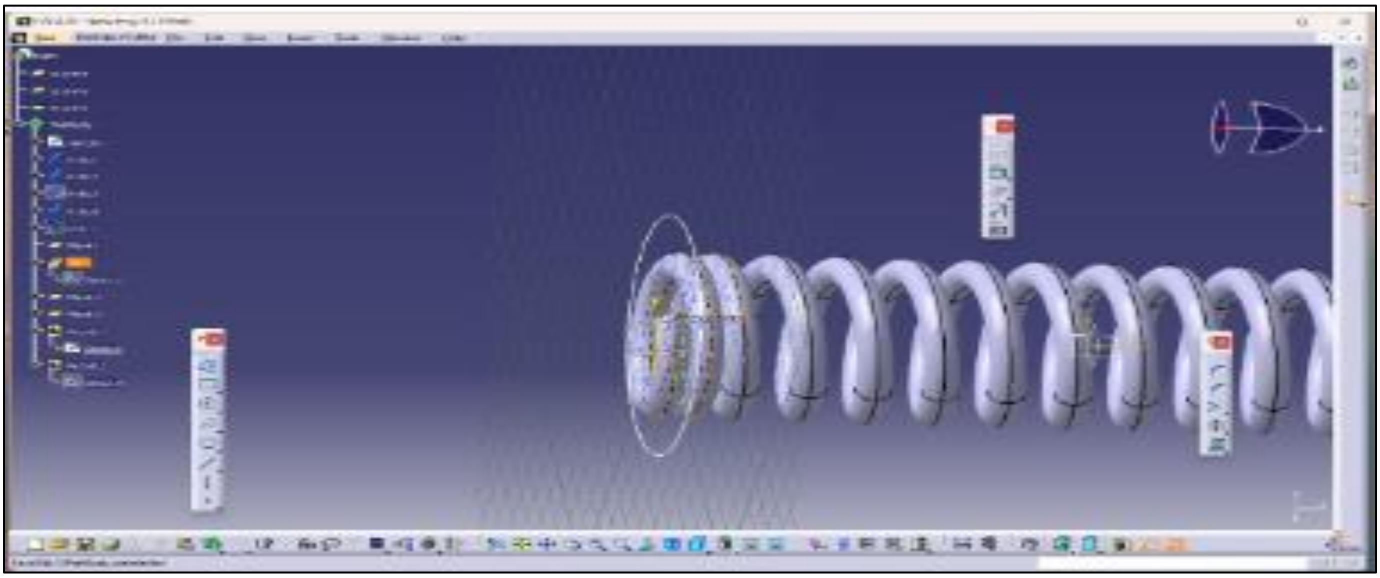

Fig 10 Both Ends of Coil Spring Extruded up to 10mm

➢ *Design-2 (With Modified Dimensions)*

From the previous design with modified the following men- tioned parameters and we introduced the hollow cavity through- out the coil for better stress distribution.

- Coil diameter = 10mm.
- Pitch of the coil spring = 18mm.
- Mean diameter of the coil = 50mm.
- Free length of the spring = 240 mm.

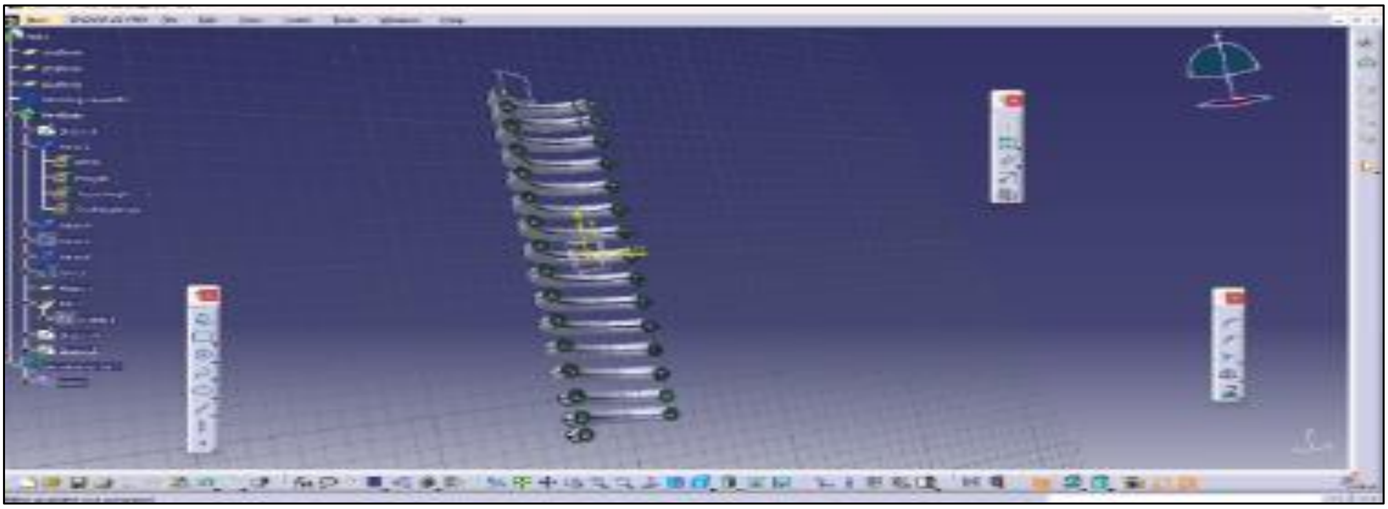

Fig 11 Coil Spring with Hollow Inside.

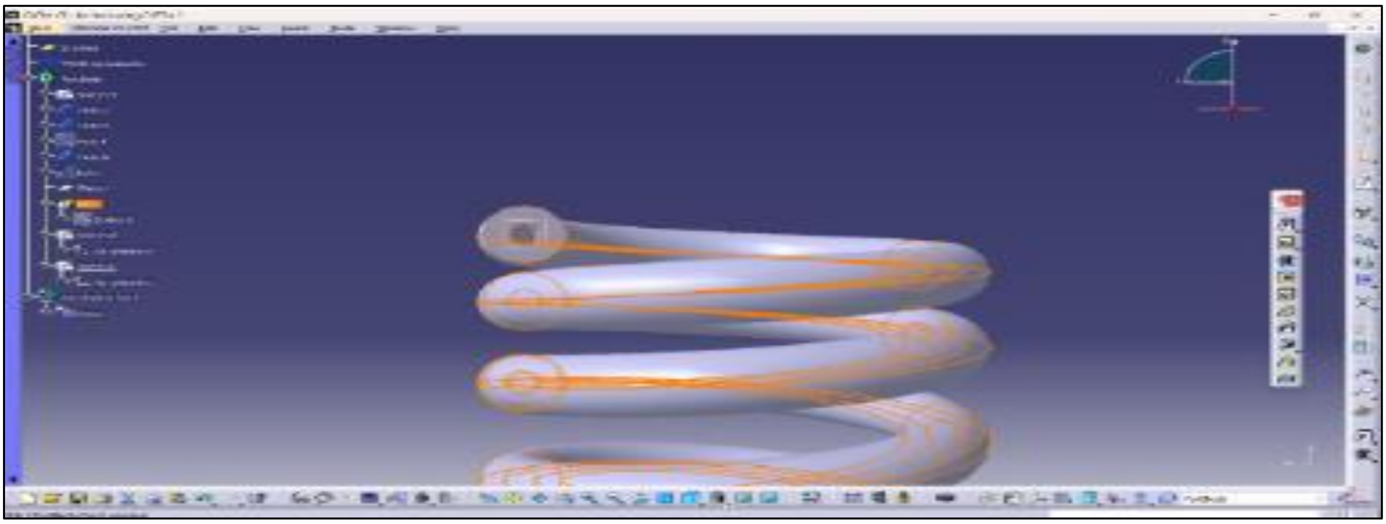

Fig 12 With Hole of 4mm

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- These two design are used in static structural analysis with the specified loads at end and to evaluate the deformation and equivalent stress

➢ *Design-3: Shock Absorber Assembly*

Figure 4.10 represents the complete shock absorber assembly with the initial dimensions of the coil(Figure 4.7) chosen for design-3 and upper and lower hinges added on both sides. The lower hinge was fixed with the chassis of two wheeler vehicle and one the other hand load was excited axially downwards.

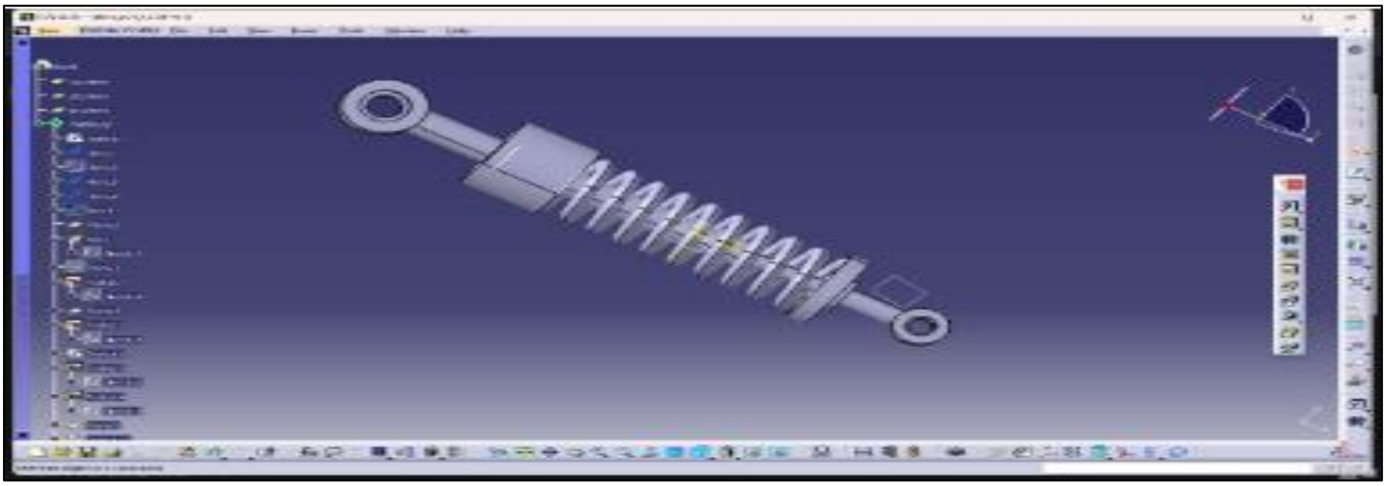

Fig 13 Normal Shock Absorber Assembly with Similar Coil Dimension of Design-1.

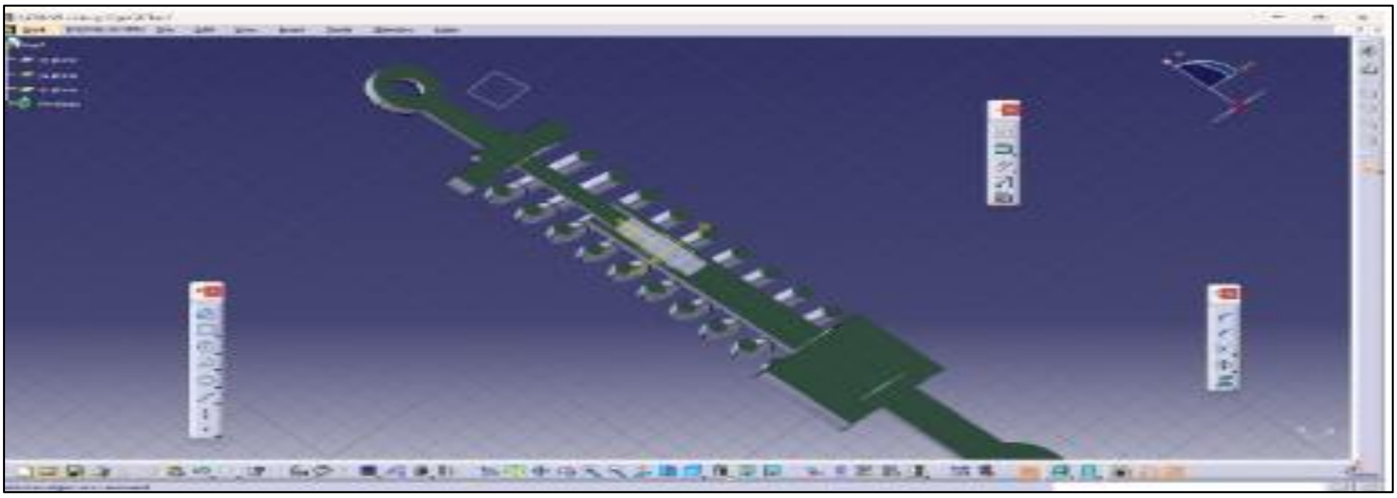

Fig 14 with Section of Solid Coil Spring

➢ *Design-4:*

By increasing the coil diameter and the distance between the oil pads of the shock absorber from the original design. design-2 was inserted into the assembly

Fig 15 Overall Shock Absorber Assembly

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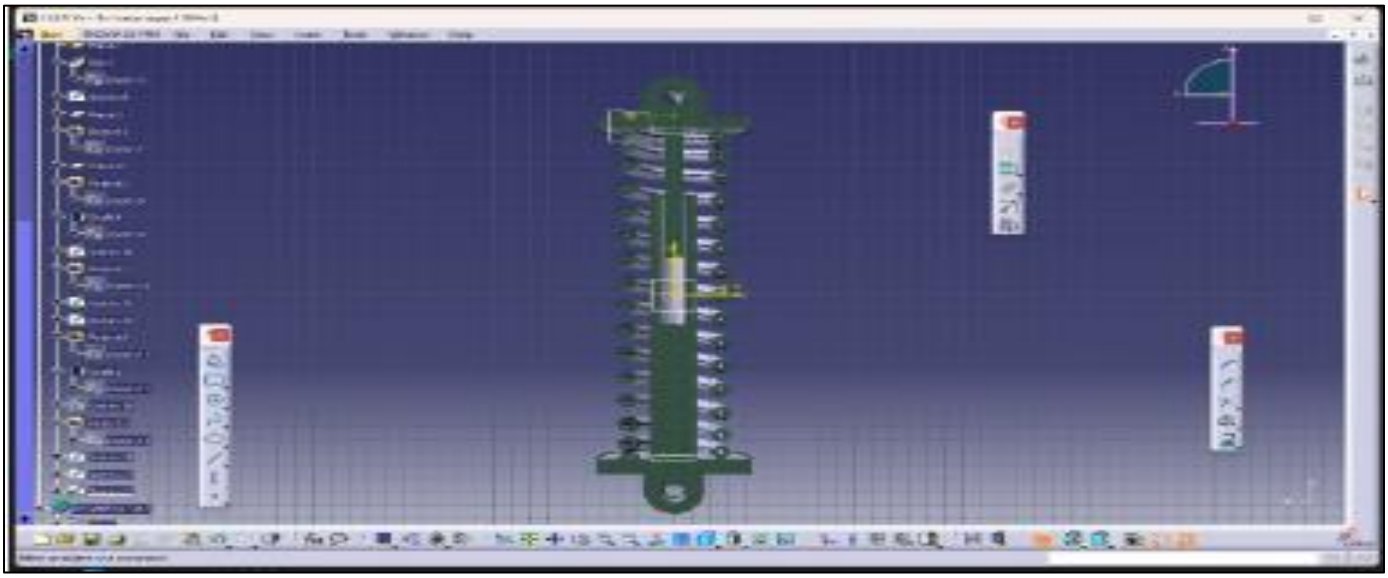

Fig 16 An Section View of Assembly with Hollow Coil.

➢ *Structural Analysis for design-1 with Different Materials*

The analysis is performed using ANSYS Workbench 2022 (R1). The Static Structural module is utilized to calculate total deformation and equivalent stress, with a 1600N force applied to one side of the shock absorber while the other end is fixed. The Mesh tool is used for meshing the shock absorber. Modal analysis is conducted to determine total deformation without applying force, while the Random Vibration module is used to obtain PSD acceleration and directional deformation. Each de- sign is modeled in CATIA V5R21.

➢ *Performing Structural Analysis Between Structural Steel Vs Carbon Fibre Vs Glass Fibre.*

- In ansys we are using the static structural analysis to calcu- late the deformation and equivalent stress.In Engineering Data the different materials added

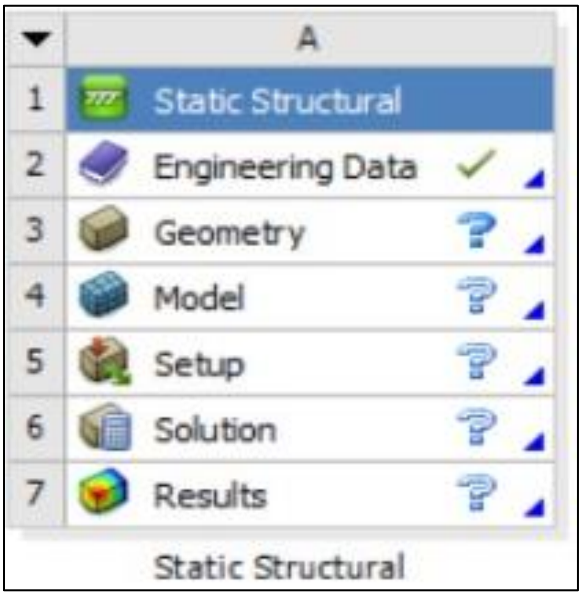

Fig 17 Static Structural Skeleton

- Importing the CATIA part file into IGES format and in- serted in the design modular or the Geometry part of An- sys workbench.
- In Model category the part imported from design modu- lar to mechanical workbench where the meshing done and boundary conditions are applied.
- In Solution the required parameters are added for example (Deformation, equivalent stress, Principal stress...).
- According to the applied conditions and different materials added to the coil the corresponding deformation and stress values are evaluated.

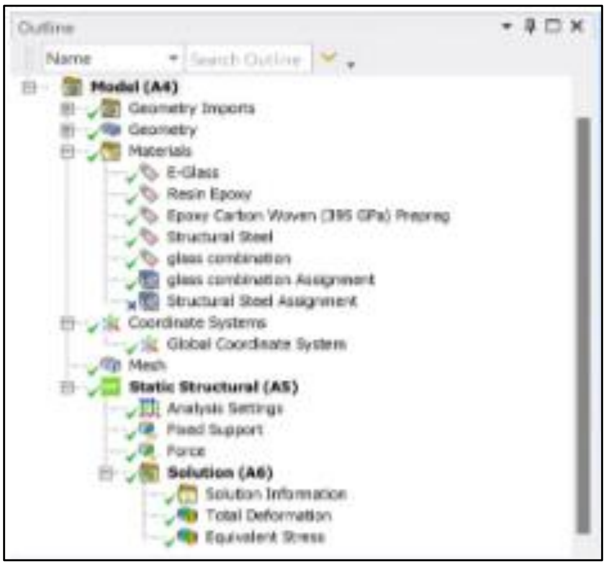

Fig 18 Static Structural Skeleton

➢ *Case-I: Structural Analysis for design-1*

These analysis has done according to the load of 1600N(compressed) applied in the one end of the coil and other end was fixed.

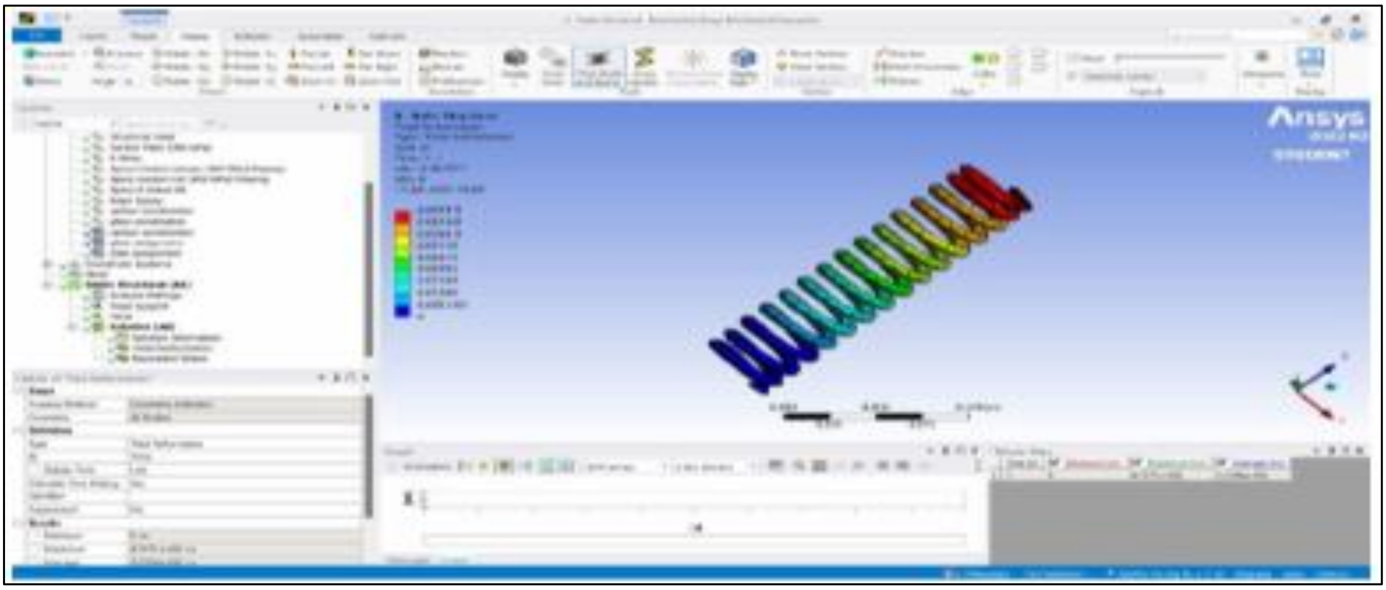

Fig 19 Deformation for Structural Steel

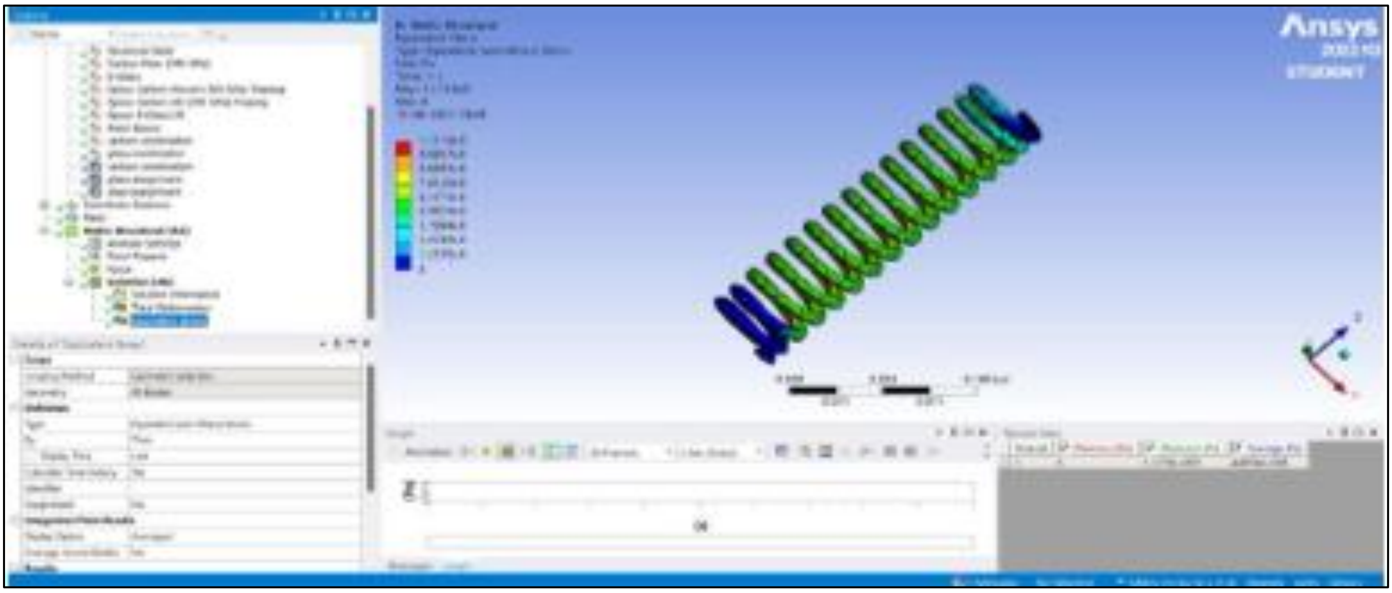

Fig 20 Equivalent Stress of Structural Steel

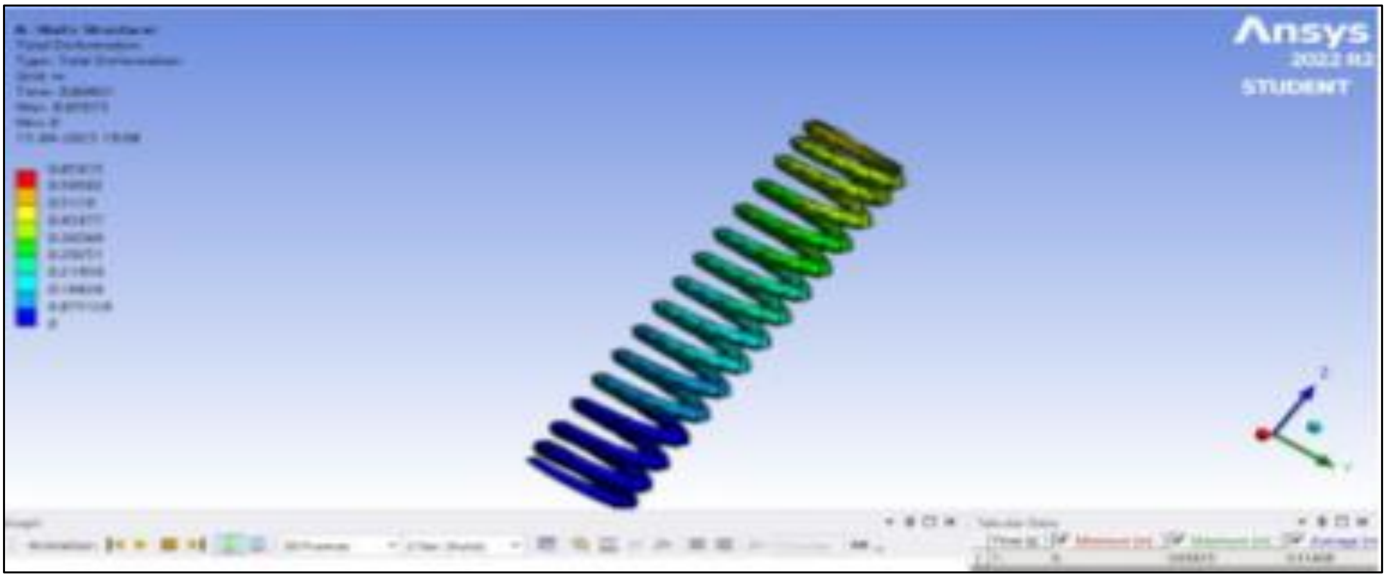

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Figure 21 Deformation Values for Carbon Fiber

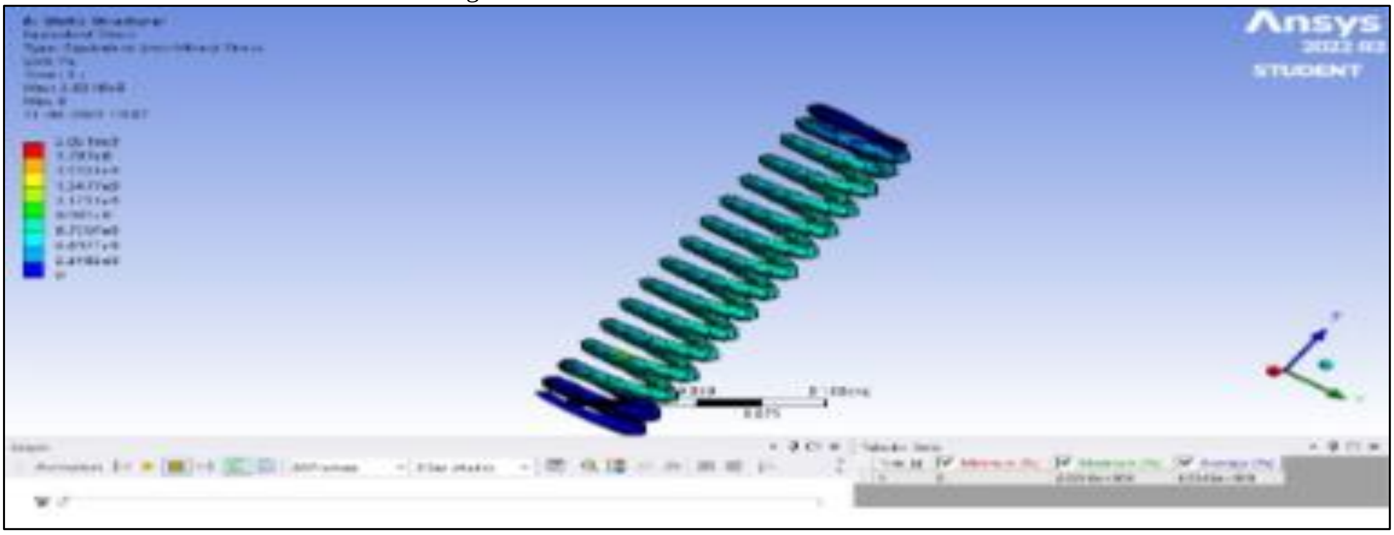

Figure 22 Equivalent Stress of Carbon Fiber

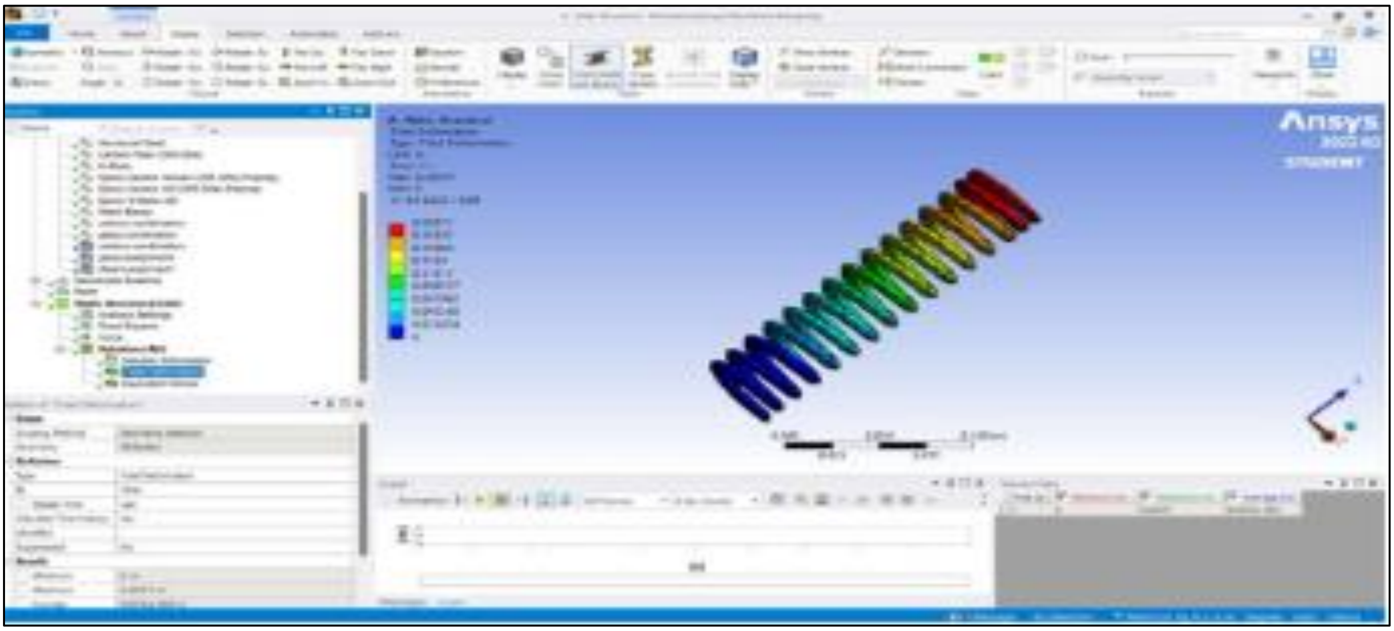

Figure 23 Deformation Values for Glass Fiber

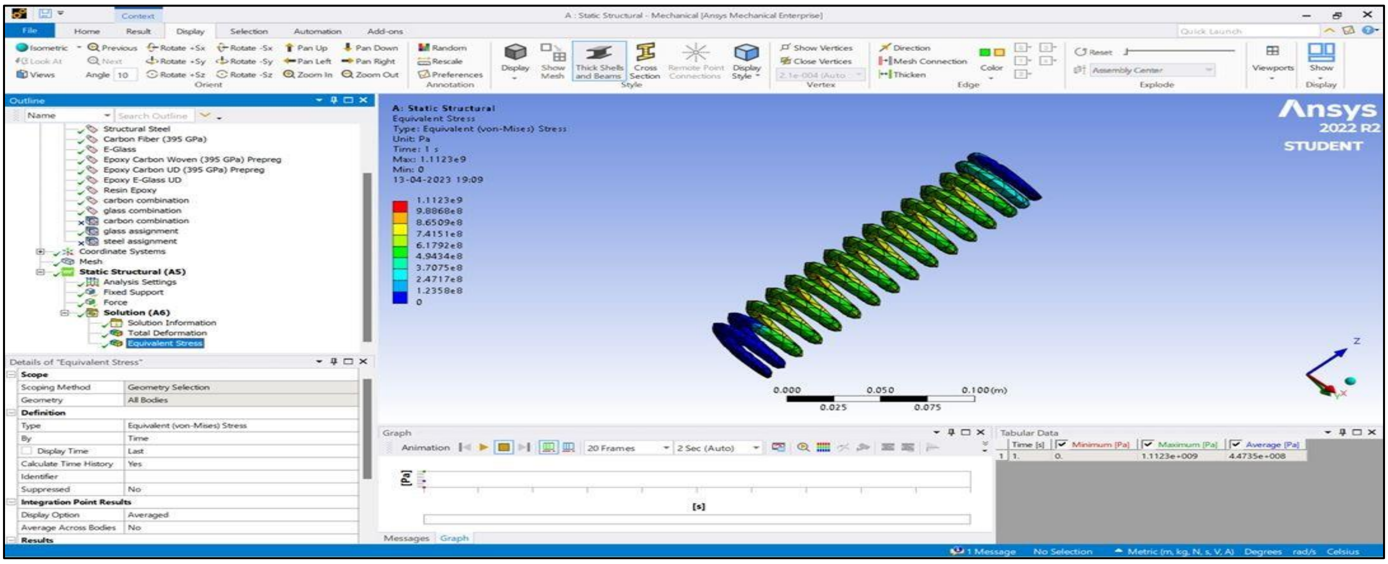

Fig 24 Equivalent Stress of Glass Fiber

➢ *By Gathering all the Values in a Tabular Form*

Table 2 Results for Case-I

Material	**Min.**	**Total deformation(m)** **Max.**	**Avg.**	**Min.**	**Equivalent stress(Pa)** **Max.**	**Avg.**
Structural steel	0	4.7071e-002	2.23e-002	0	1.1119e+009	4.46e+008
Carbon fiber	0	0.65815	0.31408	0	2.0216e+009	4.5346e+008
Glass fiber	0	0.20371	9.6535e-002	0	1.1123e+009	4.4735e+00

- *Discussion of Case-I:*

- From the values obtained as shown in the table 2, we can conclude that the equivalent stress values of both, the glass fibers and carbon fibers are nearly equal to the structural steel
- But the deformation value of carbon fibers are much larger than the structural steel when compared to the glass fibers.
- So,we are choosing glass fibers over carbon fibers for the further analysis to obtain the best designed coil with lower stress distribution which to replace the structural steel coil.
- Basically, we are going to reduce the both deformation and equivalent stress induced in the body by this we can im- prove the performance of shock absorber
- For the better reduction in the equivalent stress than the steel, we are introducing the surface coating method with a thickness of 2mm and 4mm.

➢ *Coating The Surface of Glass Fibre Coil With Epoxy Carbon Woven (395 Gpa) Prepreg.*

- For the chosen glass fiber coil, the surface is coated with the carbon woven material to enhance the equivalent stress and total deformation values.
- Stiffness behavior of coating is Membrane and Bending.
- The analysis is done in two stages with varying thickness of 2mm and 4mm respectively.

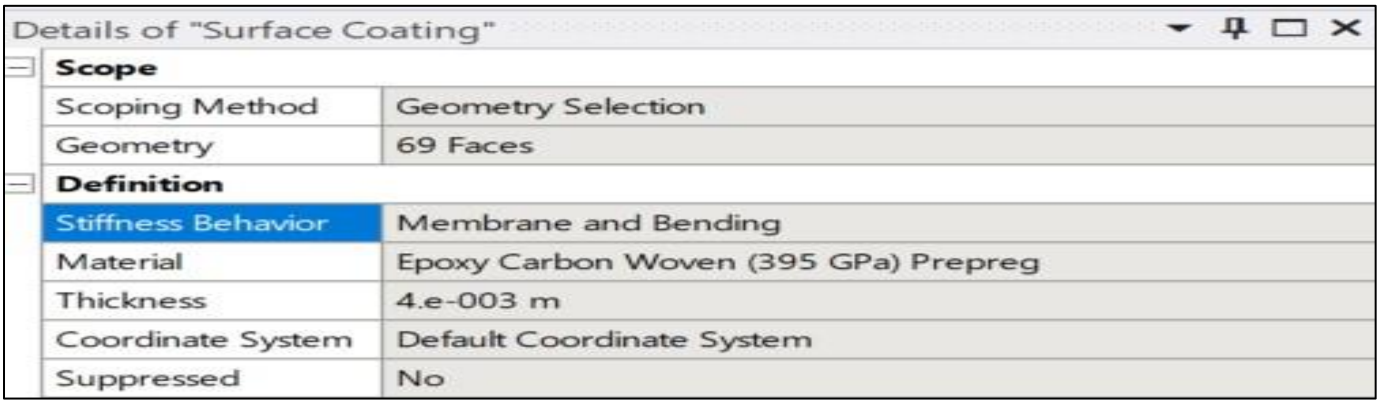

Fig 25 Surface Coating Details for the Coil Circumference.

Fig 26 Whole Body has been Selected and Coating has been Assigned.

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- *Case- II:*

  In Case II, structural analysis is conducted to compare structural steel with glass fiber coated with a composite material Epoxy

- *Woven.*

  With a two-millimeter coating:

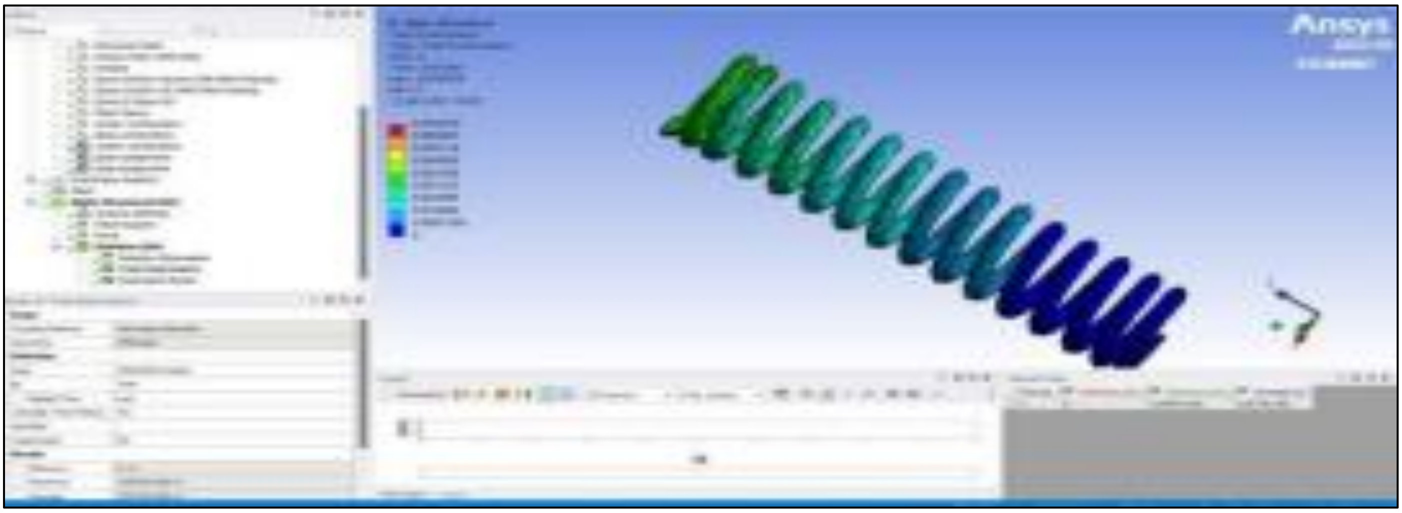

Fig 27 Deformation values of Glass Fiber with Surface Coated with 2mm

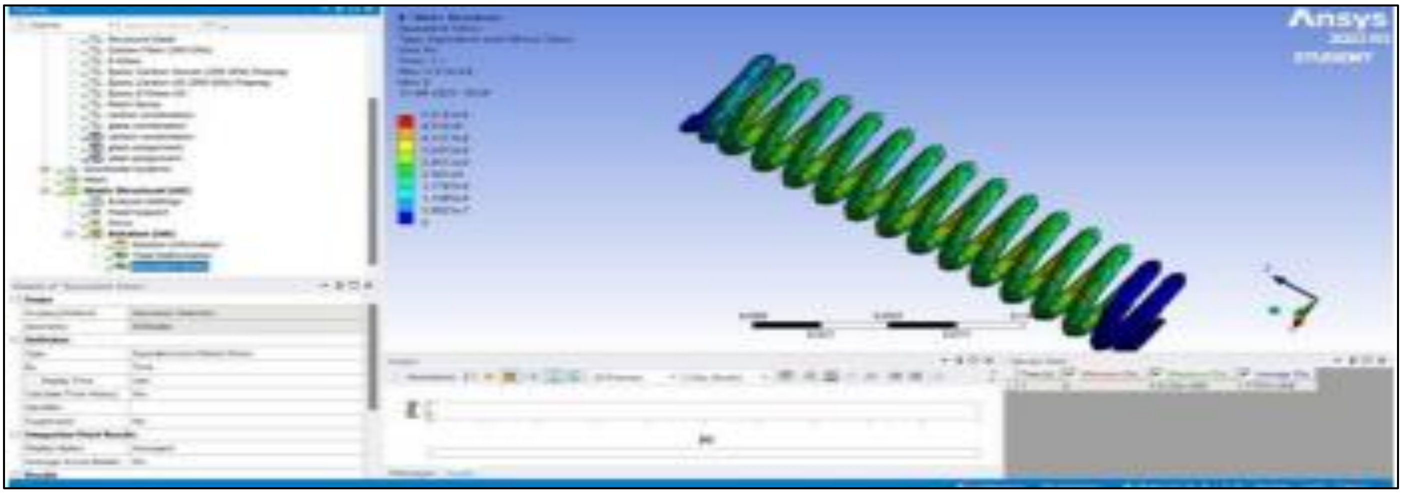

Fig 28 Equivalent Stress values of Glass Fibre with Surface Coated with 2mm.

- *With a four-Millimeter Coating:*

Fig 29 Deformation Values of Glass Fiber with Surface Coated with 4mm

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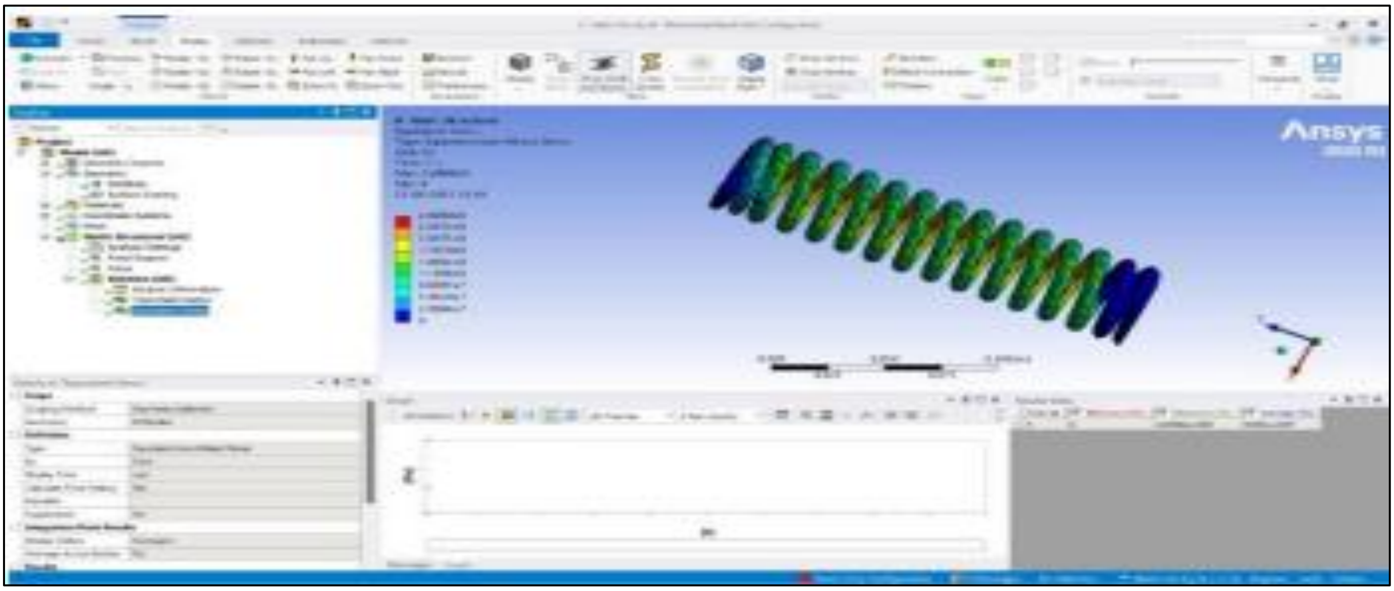

Figure 30 Equivalent Stress Values of Glass Fibre with Surface Coated with 4mm

Table 3 Comparison Between Analyzed Values of Surface Coated to Glass Fiber

Glass Fiber Coil	Total deformation(m) Min.	Total deformation(m) Max.	Total deformation(m) Avg.	Equivalent stress(Pa) Min.	Equivalent stress(Pa) Max.	Equivalent stress(Pa) Avg.
Without coating	0	0.20371	9.6535e-002	0	1.1123e+009	4.4735e+008
With 2mm coating	0	7.4978e-002	3.5579e-002	0	5.3122e+008	1.7707e+008
With 4mm coating	0	3.8943e-002	1.8484e-002	0	2.6968e+008	8.981e+007

- *Discussion of CASE-II:*

✓ We can clearly shown in table 3 a huge reduction in both the deformation and equivalent stress values
✓ So, we are choosing the 4mm coating as the optimal or the critical thickness for the coil over the 2mm.

➢ *Modified Design of Coil*

- For the next improvement in coil spring we are changing the dimension mainly the mean coil diameter which will majorly help in the reduction of deformation and induced stress.
- From the previous design with modified the following mentioned parameters and we introduced the hollow cavity throughout the coil for better stress distribution.
- The modified dimensions are mentioned in the following

✓ Coil diameter = 10mm
✓ Pitch of the coil spring = 18mm
✓ Mean diameter of the coil = 50mm
✓ Free length of the spring = 240 mm

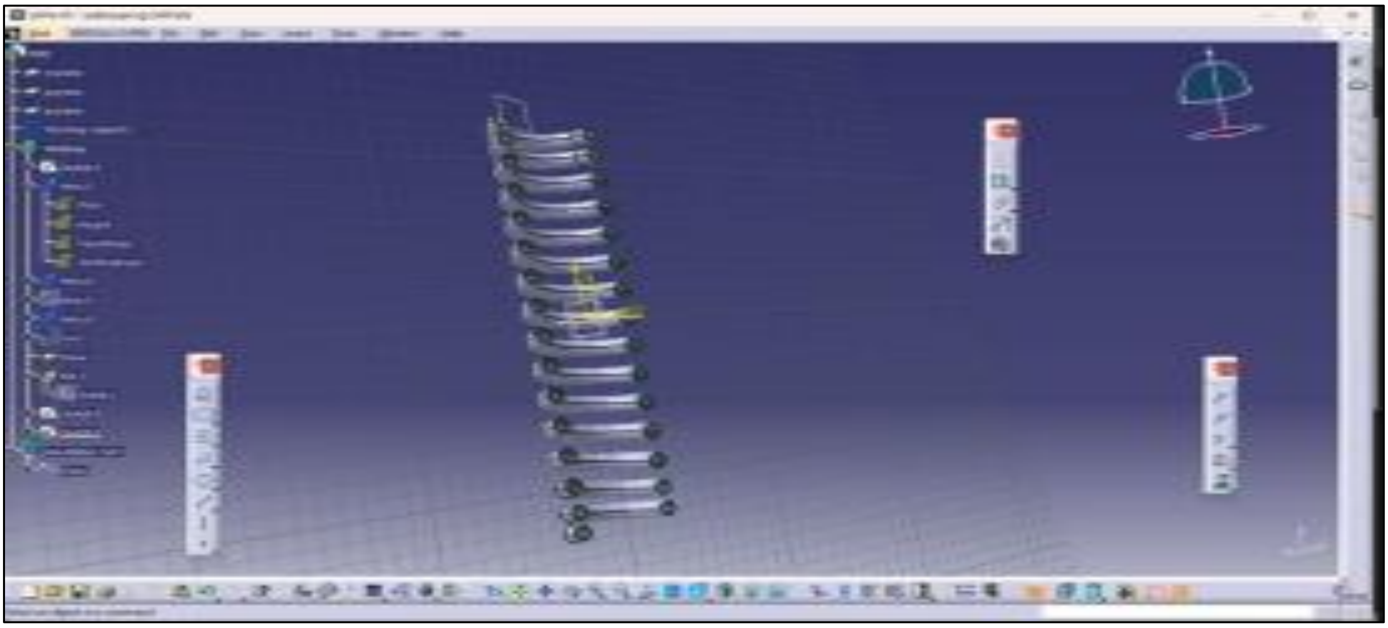

Fig 31 (a) Modified Hallow Spring(Design-2)

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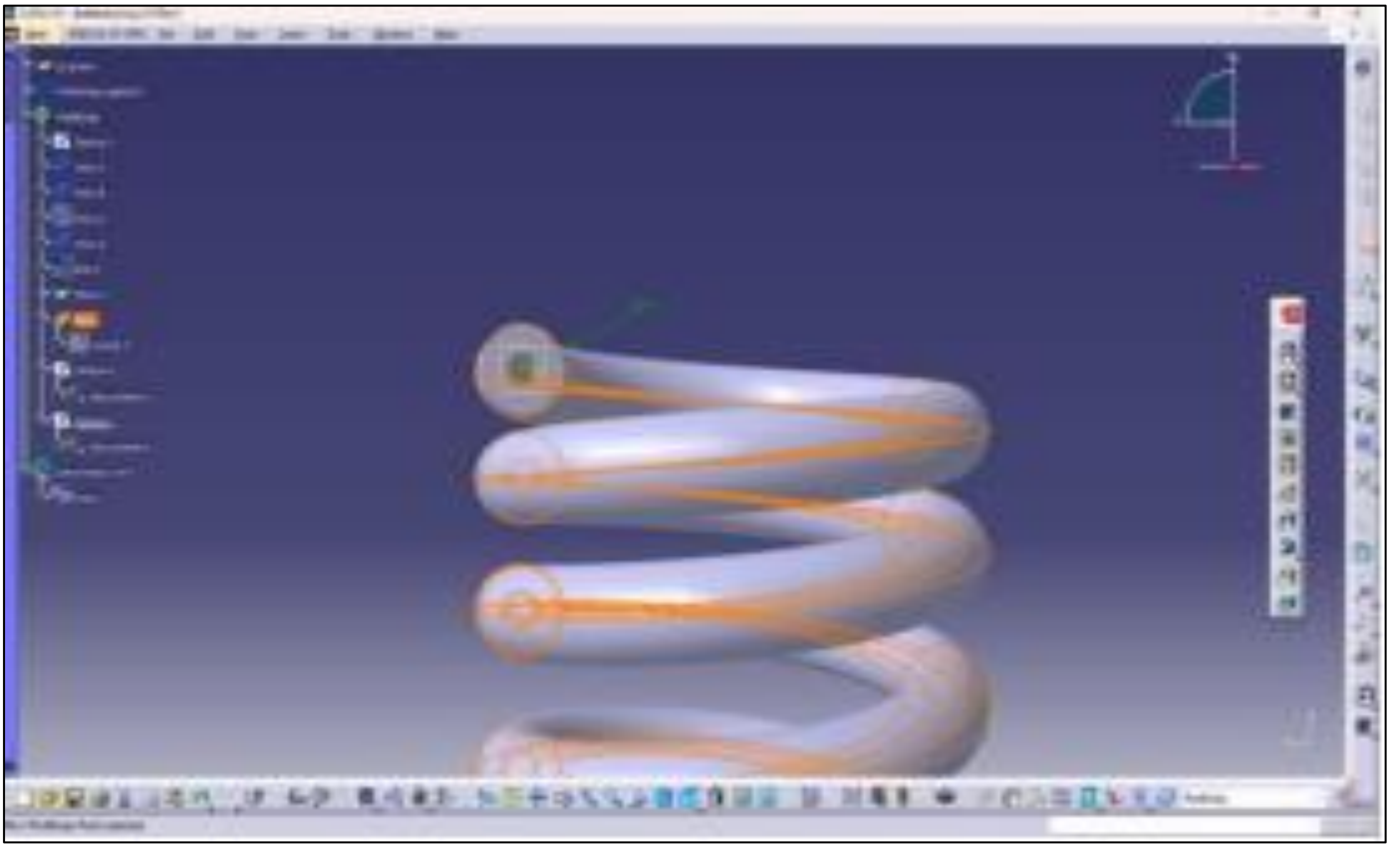

Fig 32 (b) Modified Hallow Spring(Design-2).

- Case-III: Final comparison between design-1 (Structural steel) vs Design-2 (Modified hallow spring of glass fiber with 4mm surfaced coated of epoxy woven)

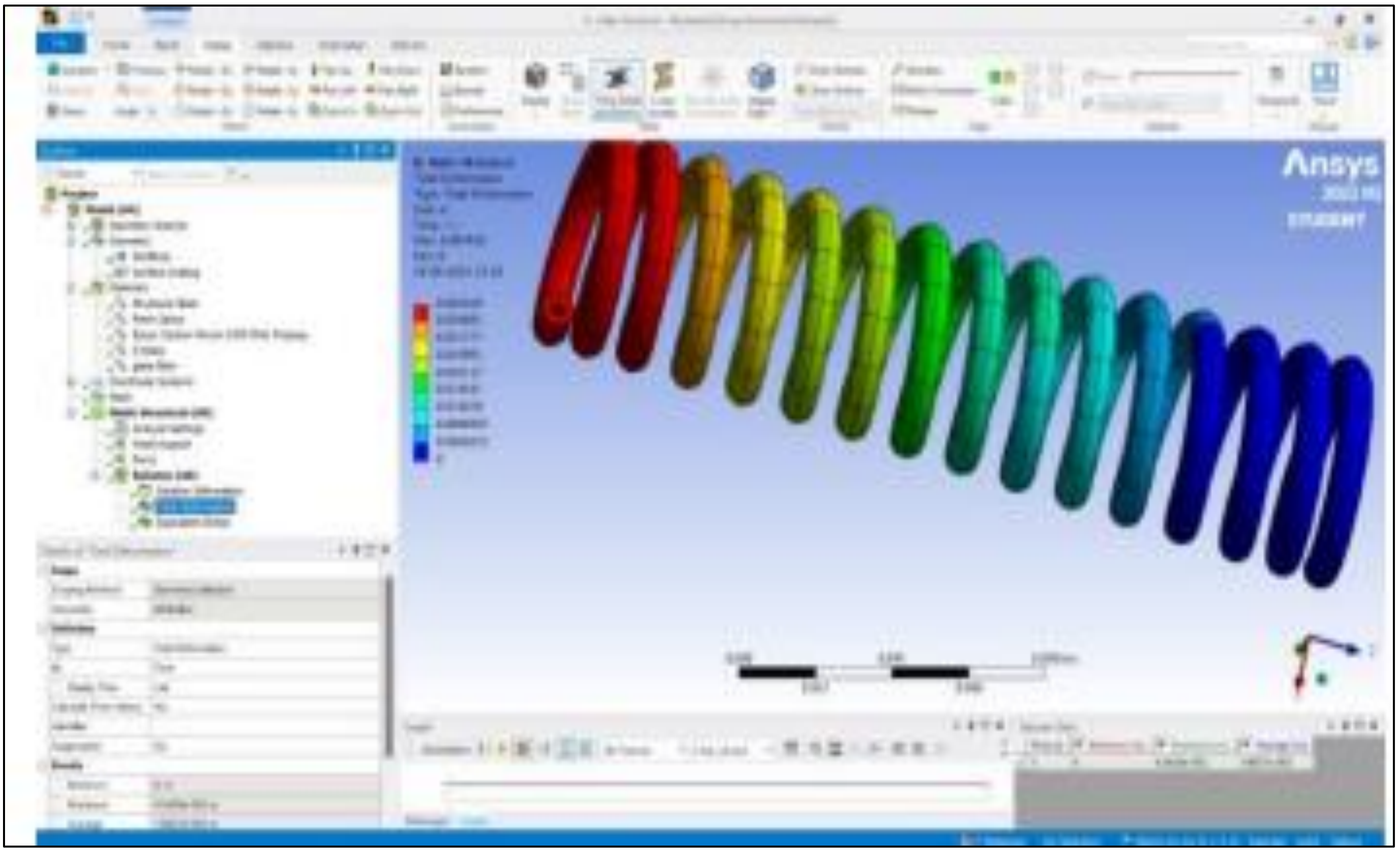

Fig 33 Deformation Values

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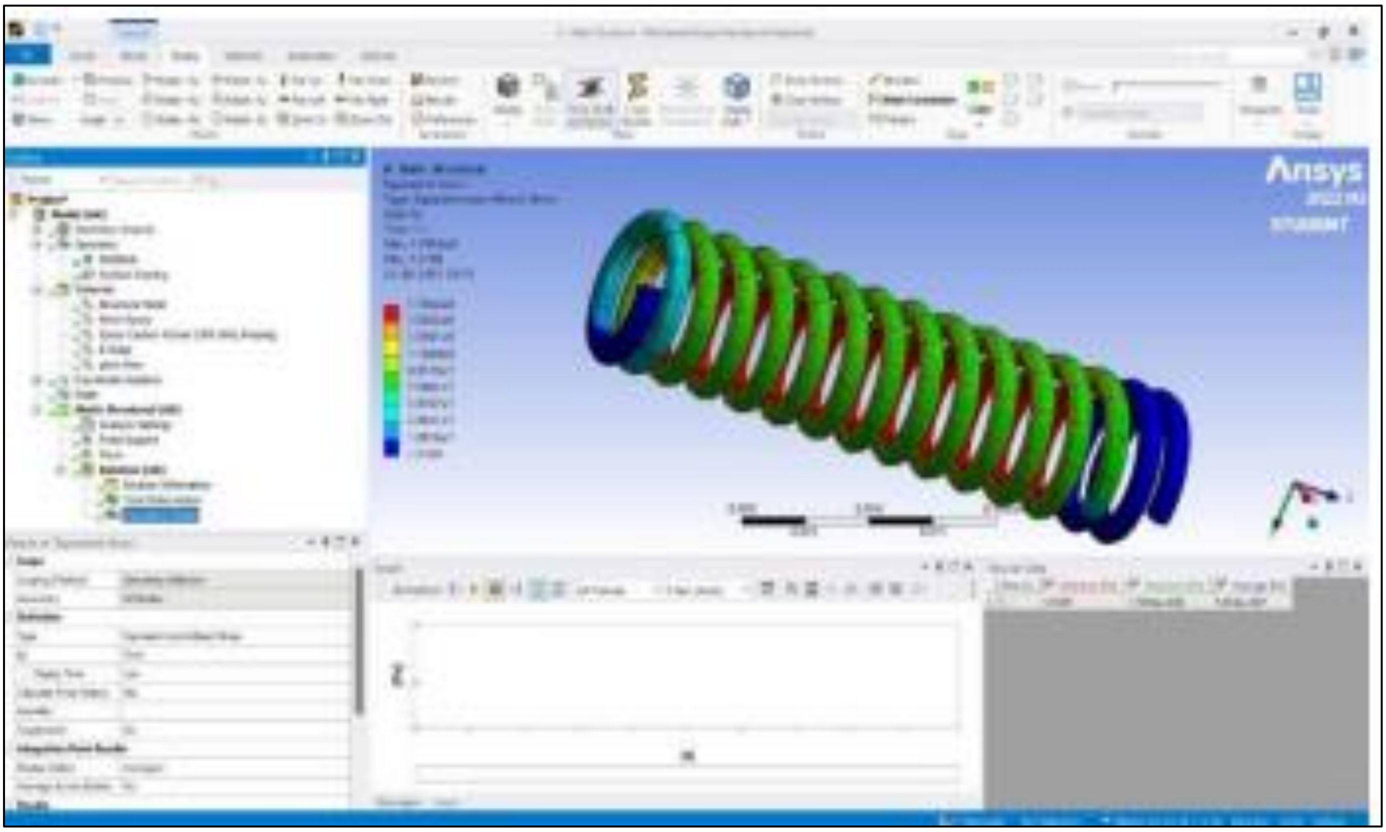

Fig 34 Equivalent Stress Values

➢ *Discussion of Case-3*

- The structural analysis indicates that the modified design exhibits lower total deformation and reduced equivalent stress compared to Design 1, as shown below. table 4.
- Thus, we can conclude that increasing the diameter of the hollow coil and the distance between the oil pads of the shock absorber enhances structural strength..
- We have reduced the total deformation by up to a certain value(2.23e-002)-(1.9827e-002). And the stress induced in the coil from (4.46e+008)-(7.653e+007).

➢ *Final Comaparisons*

Design-4 noted lesser modal frequency followed through the modal frequencies.

Table 4 Comparison Between Analyzed values of Surface Coated to Glass Fibe

No.	Material	Total deformation(m)			Equivalent stress(Pa)		
		Min.	Max.	Avg.	Min.	Max.	Avg.
Design I(solid)	Structural steel	0	4.7071e-002	2.23e-002	0	1.1119e+009	4.46e+008
Design 2 (hollow)	Glass fiber with surface coating of epoxy woven	0	4.3428e-002	1.9827e-002	1.3169	1.7924e+008	7.653e+007

➢ *Modal Analysis*

- Modal analysis is performed on a shock absorber with one end fixed and the other end free to evaluate its natural frequencies and mode shapes. is left free
- We obtain frequency for both the designs.

- *Modes vs Frequencies*

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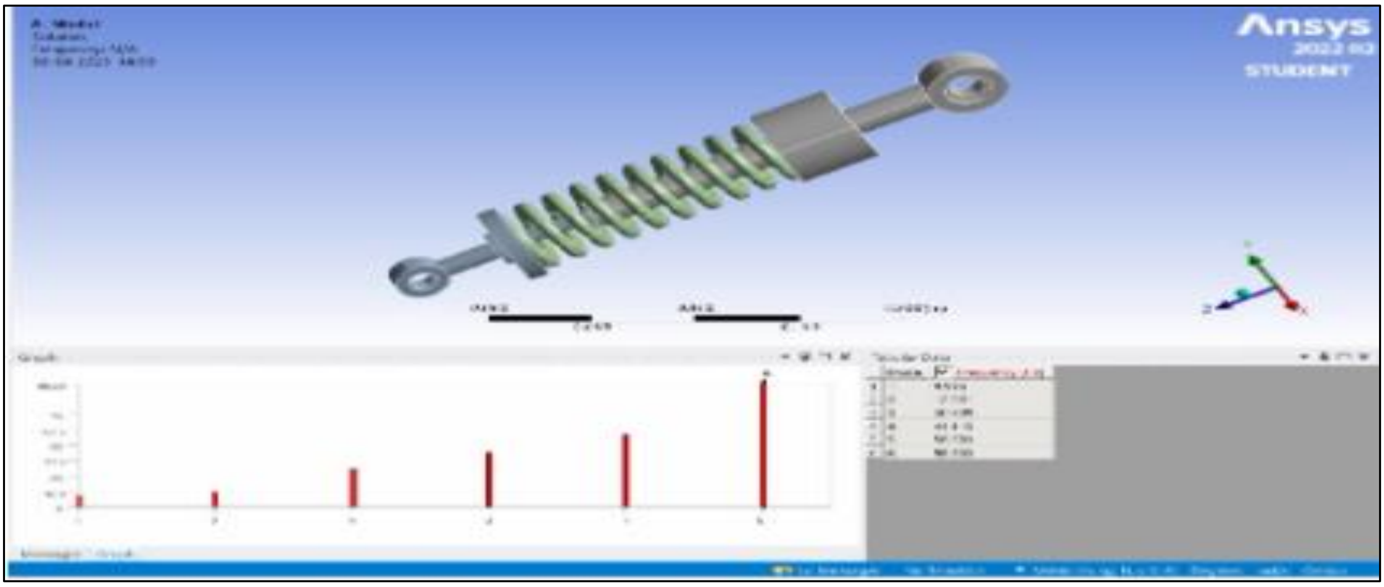

Fig 35 Frequencies obtained of design-3 at six Different Modes.

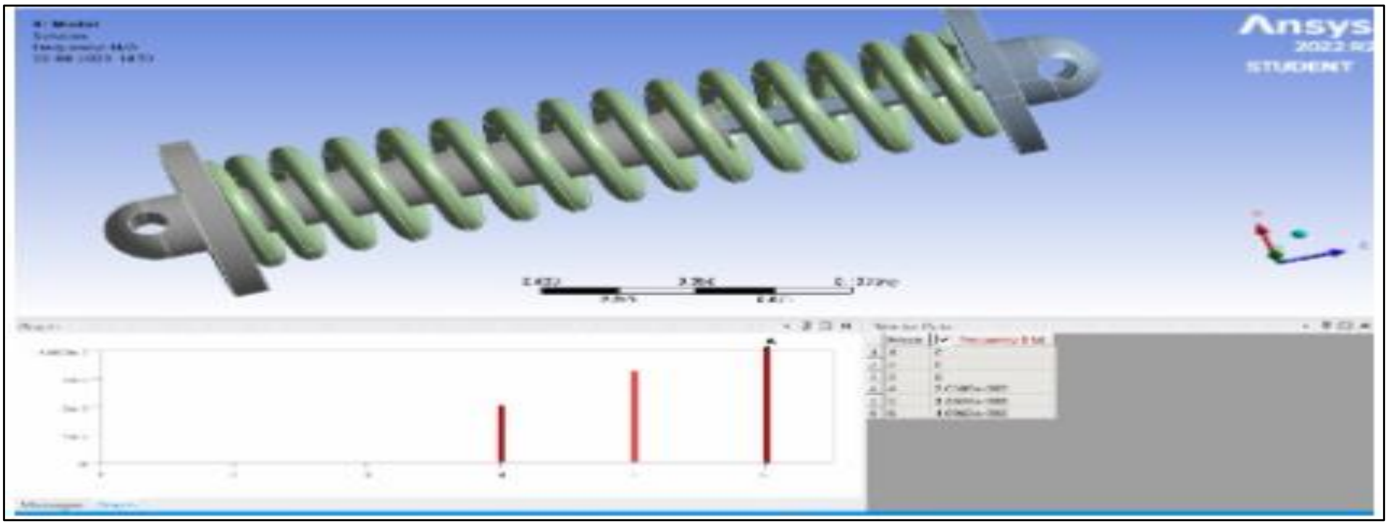

Fig 36 Frequencies Obtained of Design-4 at Six Different Modes.

- We can clearly observe that in the analysis of Design-3, a modal frequency of 9.568 Hz was recorded, whereas for Design-2, the modal frequency at Mode-1 was 0 Hz.

V. RESULTS

- Simulation is done using ANSYS software
- Structural analysis recorded total deformation and equivalent stress for two different designs and materials, namely
- structural steel and glass fiber with a composite epoxy woven/fiber glass coating.
- Modal analysis was conducted to record the values of modes and their corresponding frequencies.
- By surface coating the composite material (epoxy woven/glass fiber) on the Glass fiber with modified design. We reduce the stress impact up to 82.95% (approx.).
- And by increasing the diameter of the coil spring up to 2mm and creating a hollow coil. We reduced 11.12% of total deformation in modified design.
- We can conclude that the modified design exhibits superior structural strength compared to Design 1.

VI. CONCLUSION

- Based on the results and analysis, we can conclude that increasing the spring coil diameter and creating a hollow coil reduces stress and deflection values.
- It can be concluded that increasing the coil diameter by 2mm and replacing structural steel with surface-coated glass fiber reduces stress by 82.95% and total deformation
- by 11.12%.
- Weight reduction in the coil springs was 33.19% , the modal frequency is lower for the modified design (i.e., the second design).
- Comparing the results of the current and modified designs, the modified model shows reduced stress and deformation values.
- Based on the analysis performed on both designs, we can conclude that the modified design demonstrates superior structural and vibrational performance.

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