



Comparative Study Of Factor Of Safety Of Tunnel Segment By Adding Macro-Synthetic Fiber Using Ansys

Amey Sawant¹, Dr. Ganesh Ingle²

ABSTRACT

The fast expansion of subsurface bored tunnels in India for metro trains has raised the dilemma of how to design tunnel structures to prevent failure in an effective manner. As lining is one of the main components of a bore tunnel and its cost is directly proportional to its size, it is essential to construct the lining in an economical manner. Due to the enhanced modelling flexibility, engineering practice on these models is numerical. However, numerical models may be difficult to comprehend, in contrast to the simplicity of most empirical or analytical models. In this research, a basic model is utilized to analyze several tunnel lining design elements. Comparisons are made between these models and measurements and the findings of more intricate quantitative analysis. The objective is to demonstrate that tunnel lining behaviour may be comprehended using very basic models. Simple models have the benefit of being useful for early design and dominating mechanisms. Generally, empirical relationships and analytic solutions provide excellent insight into pertinent situations. In order to understand the interaction between the complicated geometry, geology, and building process, numerical models are required for the final design. In this work, a basic model is employed to analyses several tunnel lining design elements. The objective is to demonstrate that tunnel lining behaviour may be comprehended using very basic models. Simple models have the benefit of being useful for early design and dominating processes. In this work, a comparison was made between the traditional approach and ANSYS for the factor of security of tunnels section by introducing quantitative fiber. This study using ANSYS FEM revealed that fiber reinforcement, especially at 15%, significantly enhances tunnel lining stability by reducing deformation, elastic strain, and shear stress over time. Segments with higher fiber content demonstrated improved structural performance, underscoring the effectiveness of fiber in reinforcing tunnel linings.

I. INTRODUCTION

The macro fiber has a high fracture toughness, excellent dispersal, and a powerful build long - term relationships. The screen's increased adhesion to the cement enhances its susceptibility to shrinking and cracking(Adnan Syed, 2020). It is an ideal remedy for concrete's poor compressive properties, low ultimate elasticity, and fracture toughness. Our polymers macro fibers provide the functionality of steel fibers at lower dosing levels. The unique attachment method of each socio - economic and socio fiber and the increased area ratio (distance) result in enhanced efficiency in the hardened concrete(Soltanzadeh et al., 2022). The macro synthetic materials provide additional degrees of hardness, impact strength, and longevity to the cement. In particular, fundamentals fibers provide an additional level of fracture management without the degradation dangers involved with metal. When utilized in sprayed concrete settings, those elevated fibers boost adherence, reducing rebounding and wastage and allowing for the administration of larger coatings of concrete in a single pass. Fires concrete provides enhanced impact energy, a more effective rock segment

profile, enhanced ductility, fracture toughness, and simplified application logistics. Product description(Dridi et al., 2023): Macro-synthetic fibers are 50mm in length and are sold by the kilogram at a dose ranging between 1 5kg and 9kg per cubic meter of concrete on average. There are hundreds of thousands of individual fibers each kilogram. The fibers are placed into a concrete mixture before to pouring and provide a simple and interesting alternative to conventional reo(Van Damme, 2018). Macro-synthetic fibers provide substantially larger dose levels, resulting in concrete performance that exceeds that of conventional reinforcement. Non-corrosive macro-synthetic fibers might be regarded an alternative to steel and steel fabric fibers(S. Zainal et al., 2023). With a designed contoured profile, the fibers are effectively anchored into the concrete, therefore decreasing matrix pull-out and improving the performance of the concrete even after it has developed stress fractures(Mellios et al., 2024).

1.1 Loads On Tunnels

Earth/rock forces and pressurization are among the most potentially significant forces operating on subsurface constructions. Except if the tunnels are a snip type having a very little layer of waste, it is acceptable to disregard loading caused by surface vehicular activity(Einstein & Barvenik, 1975). It may be said essentially that tunnels segments should be dimensioned against either the overlying gravity (geostatic pressure) against of releasing stress. Earth/rock forces and water pressure are the biggest potential loads operating on subsurface constructions(Blyth & De Freitas, 2017). Unless such tunnels are a snip style with a small layer of sediment, it is acceptable to disregard live loads caused by surface vehicular activity. It may be said essentially that tunnels portions should be dimensioned either in terms of overlying gravity (take measures to ensure force) or against releasing stress. These components should be part of the strategy: Expertise, including elements of empirical predicated on an awareness of the qualities of the ground and on continual training in comparable or comparable terrain. Reasoning, employing basic or complicated mathematical answers, as the case demands, based on a complete data set on the ground circumstances. •Observation of the tube's activity throughout development, evolving into monitoring with pre-planned, methodical adjustment of supporting(Seeley, 1992).

Varieties of rock strain Underground rocks in environment are impacted by both the pressure of the layers above them their own gravity. These variables induce tensions inside the rock mass(Sainsbury, 2012). In generally, each stress results in a strain and the displacement of specific primary minerals. However, for a rock particle to be moved, vacuum must be accessible. Whereas the rock is contained, prohibiting it from moving, pressures can develop or be trapped in the material or may achieve very high levels, far over its yield point(Friedman, 1972). As soon like a rock particle, operated against by such a latent, leftover, or hidden tension, is enabled to move, a transfer takes place that, according on the information of the boulder, may appear in the form of "plastic flow" or "rock bursts" (cracking).When synthetic voids are created in rock, because gravity of the underlying geological formations would operate as an equitably spread load on the study further suggests and, therefore, on the hollow ceiling(Ulusay, 2016). The resistive passively pressures (shear strength) are hardly mobilized preparatory to the construction of the hole because the neighboring rocks limit the displacement of the laden host rock to a great extent. By digging the hollow, displacement towards the interior is made possible. Method is provided must resist the incursion of the igneous rocks in order to preserve the hollow. Rock pressure refers to the weight pressing onto the structures. Determining the amount of rock stress represents one of the most technically difficult science challenges(Ljunggren et al., 2003). This is due not only to the inherent problem of forecasting the principal tensile stresses predominant in the decor of the our past host rock, but also to the fact that, in advisement to the fracture toughness of the stones, the amplitude of supplementary pressure and expectations constructing after archaeological dig from around compartment is controlled by a number of factors, including the size of the compartment, the process of its archaeological dig, the high stiffness of its assistance, and the duration of the timeframe dug(Wylie, 2017).

1. 2 Macro Synthetic Fibers (MSFs)

Macro synthetic fibers (MSFs) have been available since the late 1990s and are defined by EN 14889 – Part 2 as The study uses short fibers with a diameter larger than 0.30 mm and a length ranging from 30 to 65 mm. Micro steel fibers (MSFs) must meet the following requirements: their elastic modulus must be at least 50,000 psi (350 MPa), their minimum thickness must be 0.3 mm, and their length must range from 13 mm

(1/2 inch) to 64 mm (2.5 inches). ASTM D7508 was reapproved in 2015. MSFs typically feature aspect ratios of 70 to 90, diameters ranging from 0.3 mm to 1 mm, tensile strengths between 350 MPa and 700 MPa, and elasticity moduli between 3 GPa and 10 GPa. MSFs are comparable in diameter to steel fibers, but they are composed of materials that have a dry density of around 0.90. Moreover, they can withstand both acidic and alkaline conditions without losing their mechanical or physical characteristics. The fibers are smooth, textured, "dented," or "striated," with a tubular form. MSFs can be either straight or distorted. Physically, a long fiber is linear but may exhibit varying degrees of roughness and texturing. The figure shows some of the widely available MSFs(Liang et al., 2018).

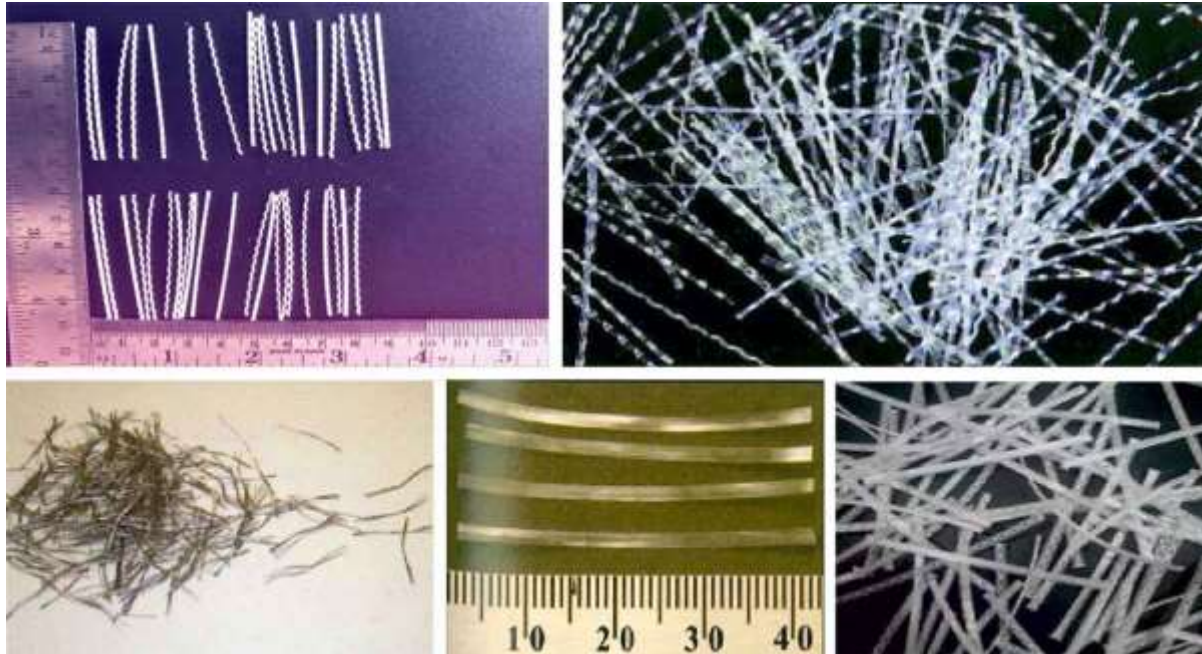


Figure 1. Commonly Available Micro Synthetic Fibers

In order to maximize troop withdrawal resistance, It is essential to carefully pick the fiber's size and geometric features to guarantee that it does not split and to obtain the required improvements in concrete properties, such as adhesion with the cement matrix and tensile strength(Reiter, 2020). The strength of the link between the fibers and the cemented polymer matrix determines how effective the fibers are. A major factor in this relationship is the physical contact that exists between the carbon surface and the mixture of hardened concrete. Furthermore, fibers may aid in repairing thermal movement- or other-related fissures in shotcrete and cementitious deck slabs. with the help of MSFs, which are used to reduce the width of fractures caused by external factors and repeated high loads. MSFs also improve the strength and durability of these materials. Additionally, MSFs may be used to a limited extent to increase the capacity of the structural concrete. Although meta reinforcing improves load stability, it is not yet feasible to fully include it into planning due to the current degree of practical implementation(Reiter, 2020).

2. RELATED WORK

R. Winterberg et.al (2022) Segmental linings made of fiber-reinforced concrete have improved mechanical performance, longevity, and economy, according to the research. Fibers are used instead of standard rebar cages, which improves fracture management and reduces carbon footprint. Research out of the University of Brescia has shown structural feasibility, and it has been successful in the field despite difficult circumstances(R. Winterberg et al., 2024). **Qingfei Li et.al (2022)** Used the strength-reduction finite element technique to study the dynamic safety considerations involved in building an underground metro station with overlapping tunnels. In order to stabilize the structure during excavation, the analysis highlighted the significance of main support and identified important damage mechanisms(Li et al., 2022). **Prajakta Nanasaheb Kenjale et al. (2022)** The fracture resistance, durability, and tensile stress resistance of macro synthetic fiber reinforced concrete were examined. The research emphasizes the advantages of using polypropylene fibers instead of steel fibers for improving the performance of structural components in tunnel linings. Insightful for engineers and designers, the article summarizes new developments(Prajakta Nanasaheb et al., 2023). **Nikhil A. Maske et al. (2018)** researched tunnel boring machines (TBMs), highlighting the advantages of pre-cast factories in creating uniform concrete segments, and the process of tunnel excavation.

Crucial improvements to structural performance and longevity have been shown by deformation analysis, which found only slight variations between EXCEL and ANSYS(Nikhil A. Maske et al. (2018). **Saber Fallah et al. (2017)** researched the effects of silica fume and Nano-silica on high-strength concrete reinforced with polypropylene (PP) and macro-polymeric (MP) fibers. Results showed that Nano-silica and silica fume improved mechanical characteristics and durability in the study's 280 specimens, but large PP fiber volumes had the opposite effect(Fallah & Nematzadeh, 2017).

Ramoel Serafini et al. (2019) Analyze the effects of fire on the mechanical, microstructural, and physical characteristics of macro-synthetic fiber reinforced concrete (MSFRC). The research shows that mechanical characteristics are negatively affected by extreme dehydration of hydrated goods, a constant internal heating rate, and a decreasing temperature gradient with distance. After a fire, the residual flexural strength drops by more than 85 percent, and nesosilicates begin to develop at temperatures higher than 205 degrees Celsius. A novel method for assessing tunnel constructions and establishing post-fire safety criteria is proposed by the fact that compressive strength and elastic modulus drop dramatically with increasing temperature(Serafini et al., 2019). **Antonio Conforti et al. (2019)** studied how fibers may be used in conjunction with traditional rebars to support prefabricated tunnel parts. By analyzing how different segments fared during TBM operations, their research demonstrated that rebars and macro-synthetic polypropylene fibers (PFRC) might work together to line metro tunnels(Antonio Conforti & Tiberti, 2019). **Nana et al. (2021)** Investigated the mechanical properties of fiber-reinforced concrete (FRC), emphasizing polypropylene macro-man-made fibers (SikaFiber Force-60]. They tested 36 prismatic beams with different fiber doses using notched 3-point bending. Increases in fiber dose enhanced residual tensile flexural stresses but had no discernible effect on final bending strength, according to the results. In line with Fib Model Code 2020 and modifying Hillerborg's idea for structural uses, they suggested a new post-cracking diagram for macro-synthetic FRC(Nana et al., 2021). **Axel G. Nitschke et al. (2020)** investigated if macro synthetic fiber reinforced concrete might be used to line tunnels instead of steel. The mining and civil tunneling industries in Norway and Australia have embraced this technology extensively, and it is also starting to make waves in the United States. Design factors covered in the article include resistance to seismic activity, control of crack width, corrosion, longevity, and performance over time(Axel G. Nitschke & Tirpude, 2020)..

2.1 Research Gap

Despite the growing popularity of macro synthetic fiber (MSF) in tunnel segment construction, a comprehensive comparative study of the factor of safety (FoS) in tunnel segments using MSF remains a notable research gap. Existing studies focus on various aspects such as mechanical performance, durability, and crack resistance, but there is limited research specifically addressing the FoS and safety implications of incorporating MSF in tunnel segments. The current literature provides insights into the positive effects of MSF on concrete properties, but a thorough analysis of FoS variations with and without MSF reinforcement using numerical simulations like ANSYS is lacking. This research gap hinders a holistic understanding of the safety enhancements offered by MSF in tunnel segment construction, limiting its application in practice. A dedicated comparative study using ANSYS can contribute valuable insights into the safety aspect of MSF-reinforced tunnel segments, guiding future design practices.

III. RESEARCH METHODOLOGY

The research methodology for this comparative study involves a systematic investigation into the factor of safety of tunnel segments through the integration of macro-synthetic fibers using both traditional methods and the ANSYS simulation tool. The study will commence with an extensive literature review to establish the existing knowledge base on tunnel engineering, safety factors, and the application of synthetic fibers. Subsequently, a comprehensive numerical analysis will be conducted using ANSYS software to simulate and assess the structural behavior of tunnel segments with and without the addition of macro-synthetic fibers. The findings will be compared with conventional methods, providing valuable insights into the effectiveness of fiber reinforcement in enhancing tunnel safety.

3.1 Boundary Conditions and Model Parameters

The solution's precision is directly proportional to the model's boundaries. Under the same circumstances, the answer will be closer to the actual value the larger the model's border. Whenever the perimeter and distribution a particular magnitude, extending the limit range has no discernible effect on the solution's correctness. To reduce the negative impact of the perimeter restriction on the calculated values, the computation model's borders are configured as follows: The longitudinal width of the rock layers both on sides of the tunnel is 35 meters; the bottom dividing line is 35 meters from the bottom of the corridor; the depth of the corridor is 30 meters, which is the actual entombed depth in the able to monitor section; and the entire model is 82 meters wide and 75 meters tall. Horizontal and displacement limits exist on the model's base, whereas displacement constraints exist on both sides. The model's top is a free area. Figure 8 represents the analytical method. Surface, lithology near the collapse glide plane of the hence, and loamy near the fail gliding patterns of the arch foot are the three parts of thinly buried loess pipes that are submerged in water due to emerge water penetration.

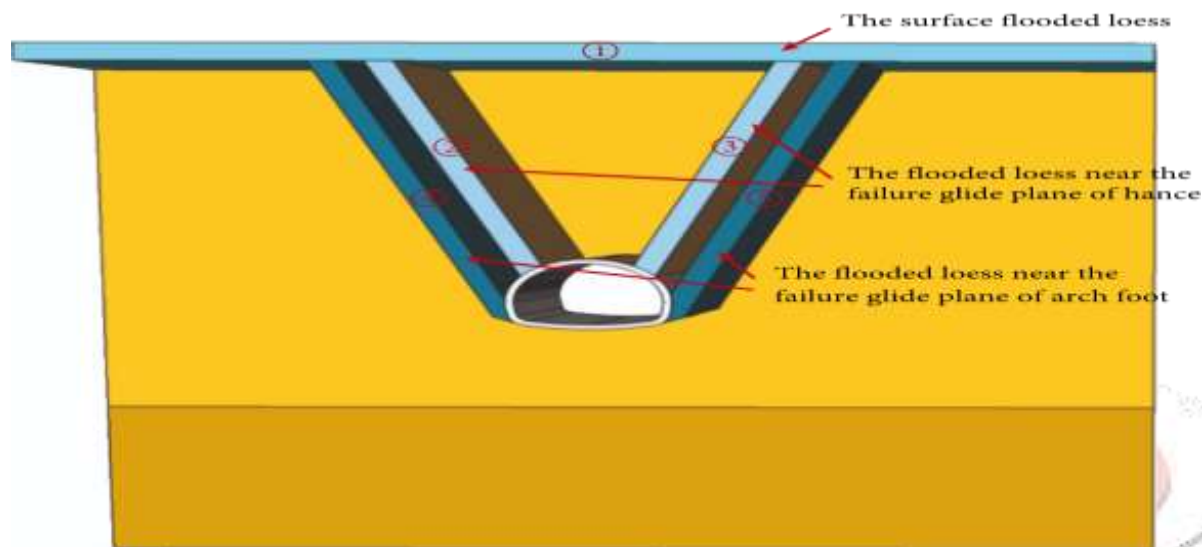


Figure 2. Boundary Conditions and Model Parameters

3.2 Modelling and Design using Catia V5

CATIA has two primary supermodels: solid or interface. Type of design is only for 3d solid, whereas Combinatorial Shape Designing may be used both for solid and surfaces modelling. In modelling, activities are encapsulated into distinct objects. CATIA is the world's largest 3D CAD built on open for both engineering and creation. It is utilized in aviation, automobile, consumer items, and factory automation, to mention few of, to develop, model, analyses, and create things.

3.3 Analysis using Ansys Workbench 16

Ansys Mechanics develops a digital framework for stress design that employs calculations (FEA). Mechanics is a volatile situation with a full suite of analytics software, from prepping geometries for examination to integrating extra elements for higher realism.

3.4 Dimensions

TABLE 1. Dimensions

Type of Segment	RC, Flat Type
Diameter of segmental lining	$D_o = 3350 \text{ mm}$
Radius of centroid of segmental lining	$R_c = 1612.5 \text{ mm}$
Width of segment	$b = 1000 \text{ mm}$
Thickness of segment	$t = 125 \text{ mm}$

3.5 System Development

The finite element method (FEM) is the most widely used simulation technique for predicting the physical behavior of systems and structures. Given that exact solutions are often unattainable for most engineering research problems, numerical approaches like FEM have been developed to address these challenges within mathematical models. Over the past three decades, significant advancements have been made in numerical methods, enabling simulations that closely mirror real-world conditions. Today, modeling nonlinear processes in mechanics, such as nonlinear material responses, large deformations, and contact problems, is considered standard practice. The rapid development of computer technology, including more powerful processors and reduced memory costs, has made it possible to run simulations on models with billions of degrees of freedom. From a mathematical perspective, the finite element solution is always an approximation of the exact numerical solution to a problem. Determining the accuracy of a given solution can be challenging for engineers. When experimental or analytical results are available, finite element results can be easily validated. However, to accurately predict structural behavior without testing, a user of finite element software must have a fundamental understanding of FEM. Additionally, a solid grasp of the relevant software and techniques is crucial for assessing the suitability of the chosen elements and methods. This article provides an overview of ANSYS's capabilities for achieving accurate finite element analysis results. Various ANSYS features are discussed, and where applicable, current implementations within ANSYS are demonstrated.

3.6 Constitutive Relations

The steel section exhibited a multi-linear elastic-plastic behavior with isotropic hardening, in accordance with von Mises' plasticity criteria. The stress-strain curve aligned with the constitutive model used and reported in previous studies, as shown in Figure 3.8. For steel connections, a bi-linear isotropic hardening model was selected, which also adheres to von Mises' plasticity criterion. The stress-strain diagram for the steel connectors in Figure illustrates how the intrinsic relationship of the steel reinforcement follows von Mises' plasticity requirements and conforms to a perfect elastoplastic model. The constitutive tension relationship for the concrete slab is derived from the Willam-Warnke model using ANSYS's CONCRETE model, which accounts for material cracking. This approach was also used in other studies. In contrast, von Mises' plasticity criterion was applied to concrete under compression. The stress-strain curve depicted in Figure reflects the behavior of a multilinear isotropic hardening concrete, as represented in the model.

The Pure Lagrange Multiplier method in ANSYS was utilized to analyze the contact between the steel section, connectors, and the concrete slab. This method ensures that no sliding or interpenetration occurs between the two materials when the contact is closed, provided the shear stress limit is not exceeded. The parameters defining whether the contact is open or closed are FTOLN, representing the minimal penetration value for closed contact, and TNOP, representing the minimum normal tension required for the contact surface to transition to open. An absolute value of -0.01 cm was used for FTOLN, while TNOP was set at 0.18 kN/cm². The average adhesion tension values associated with the initial interface slide were used to estimate a cohesion coefficient of 0.18 kN/cm², and the friction coefficient between steel and concrete was determined to be 0.4.

3.7 Failure criterion

The lower and upper bounds are set at 0.2% and 0.35% of the concrete's compressive strength, respectively, to establish the ultimate load in each finite element analysis. These bounds specify the range of the composite beam's failure force. A further criterion, known as the stud failure point, is defined by relevant push-out tests as the point at which the composite beam's most heavily loaded stud hits its maximum load. The stud failure point is considered to be the reason for the failure of the composite beam if it is reached before the lower concrete limit (that is, if the load at the stud failure point is less than the lower bound load). On the other hand, it suggests that the concrete has failed as a result of crushing if the stud failure point is reached after the upper concrete limit. Slab crushing or stud failure are two possible failure types when the stud failure point is situated between the lower and higher concrete limits. As a result, both slab crushing and stud failure modes may be predicted by the suggested finite element model.

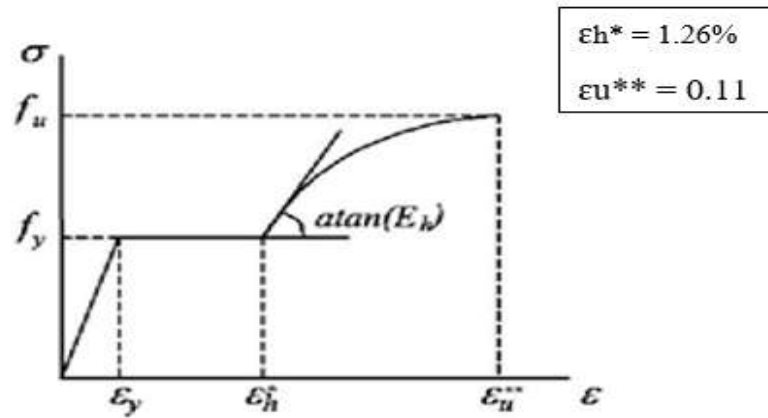


Figure 3. Constitutive Relation for Steel Profile

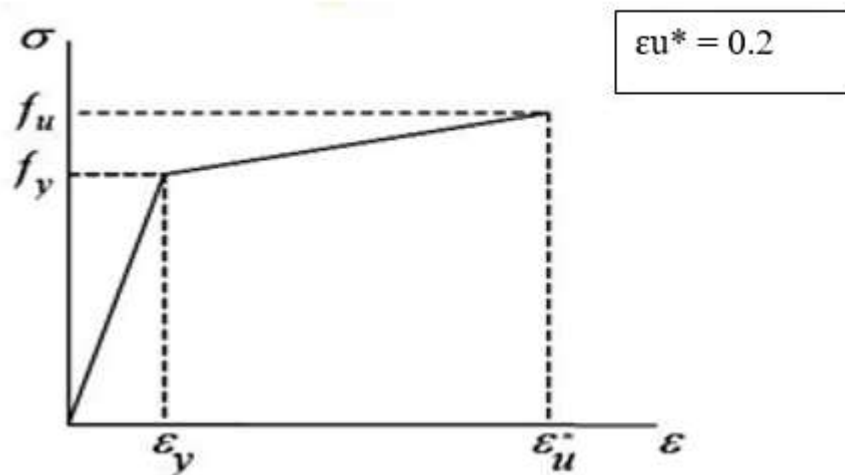


Figure 4. Constitutive Relation for The Shear Connectors

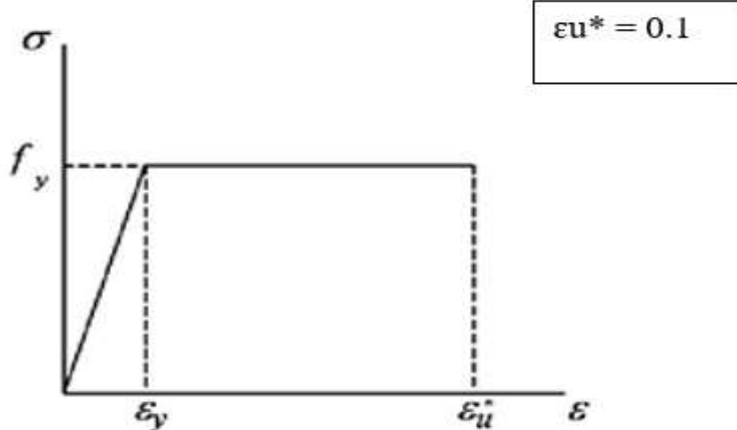


Figure 5. Constitutive Relation for The Steel of the Reinforcement

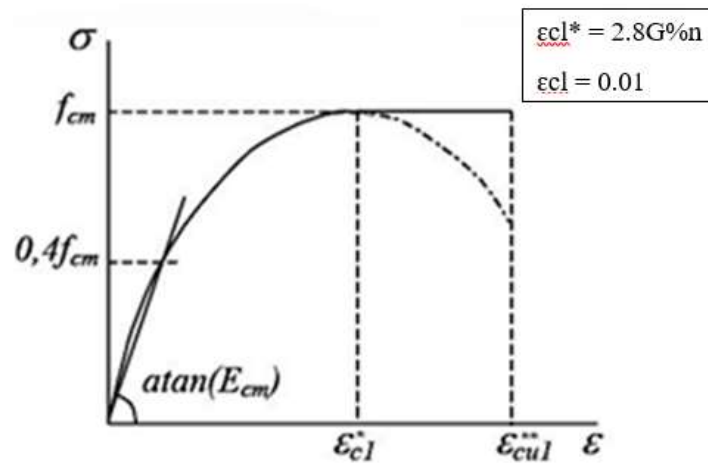


Figure 6. Constitutive Relation for The Concrete

COMPARATIVE STUDY OF FACTOR OF SAFETY OF TUNNEL SEGMENT

A comparative study of the Factor of Safety (FoS) for tunnel segments by adding macro-synthetic fibers using ANSYS involves complex mathematical formulations, modeling, and analysis. In this context, various factors like the properties of materials, tunnel design, loading conditions, and the effect of fibers are analyzed to determine the safety and strength of the tunnel. This detailed analysis will cover:

1. Factor of Safety and Tunnel Segment Design

The Factor of Safety (FoS) is a design parameter that describes how much stronger a system is than it needs to be for an intended load. In tunnel engineering, FoS ensures that a tunnel can support the loads from the ground and other external forces, such as water pressure, seismic activity, and operational loads. The inclusion of macro-synthetic fibers into concrete segments enhances the performance of tunnel linings by improving tensile strength, crack control, and overall durability. ANSYS, a powerful finite element analysis (FEA) tool, can simulate these effects to estimate the FoS of the tunnel segment.

2. Material Properties and Design Considerations

Before proceeding with mathematical calculations, the material properties of concrete and macro-synthetic fibers need to be defined:

- **Concrete:** Standard Grade (e.g., C40/50).
- **Macro-synthetic fibers:** Tensile strength and modulus of elasticity of fibers.

Let's define the relevant parameters:

- σ_{tunnel} : Stress on tunnel segment (N/m^2).
- σ_{concrete} : Stress capacity of concrete (N/m^2).
- σ_{fiber} : Stress capacity of fiber-reinforced concrete (N/m^2).
- **Fload:** External forces acting on the tunnel, including dead load, live load, and lateral earth pressure (N).
- **Fresistance:** Load-carrying capacity of the tunnel segment, including the effect of macro-synthetic fibers (N).

The Factor of Safety is calculated as:

$$\text{FoS} = \frac{\text{Fresistance}}{\text{Fload}}$$

If $\text{FoS} > 1$, the structure is considered safe. If $\text{FoS} \leq 1$, the design needs reinforcement.

3. Stress-Strain Relationship for Concrete and Fiber-Reinforced Concrete

For a basic tunnel segment design without fibers:

$$\sigma_{\text{concrete}} = \frac{\text{Fload}}{A}$$

Where A is the cross-sectional area of the tunnel segment.

When macro-synthetic fibers are added:

$$\Sigma f_{\text{fiber}} = \sigma_{\text{concrete}} + \Delta \sigma_{\text{fiber}}$$

Where $\Delta \sigma_{\text{fiber}}$ is the additional stress-carrying capacity introduced by the fibers.

The inclusion of fibers alters the **stress-strain curve** of the material:

For plain concrete: $\sigma = E_{\text{concrete}} \cdot \varepsilon$

For fiber-reinforced concrete:

$$\sigma_{\text{fiber}} = (E_{\text{concrete}} + E_{\text{fiber}}) \cdot \varepsilon$$

Here, E_{concrete} and E_{fiber} represent the modulus of elasticity for concrete and fibers, respectively, and ε is the strain.

4. Load Distribution on Tunnel Segment

For tunnel segments, the primary loads are:

- Radial Pressure p_r : Distributed along the tunnel perimeter due to earth and water pressure.
- Axial Force F_a : Due to the self-weight and external vertical load.

The general equation for stress in a circular tunnel section subjected to radial and axial load is:

$$\sigma_r = \frac{p_r \cdot r}{t}$$

Where r is the radius of the tunnel and t is the thickness of the tunnel segment.

When fibers are added, they enhance the tensile capacity of the segment under radial pressure.

Mathematical Formulation of Fiber Contribution

The additional strength provided by macro-synthetic fibers can be formulated based on their mechanical properties:

$$\Delta \sigma_{\text{fiber}} = V_f \cdot \sigma_f$$

Where V_f is the volume fraction of fibers in the concrete and σ_f is the tensile strength of the fibers.

The total stress in the fiber-reinforced segment is then:

$$\sigma_{\text{total}} = \sigma_{\text{concrete}} + V_f \cdot \sigma_f$$

7. Comparative Study of FoS with and without Fibers

To perform a comparative analysis, we calculate the FoS for both plain concrete and fiber-reinforced concrete under the same loading conditions.

For plain concrete:

$$FoS_{plain} = \frac{\sigma_{concrete}}{\sigma_{applied}}$$

For fiber-reinforced concrete:

$$FoS_{fiber} = \frac{\sigma_{fiber}}{\sigma_{applied}}$$

The improvement in the FoS can be evaluated by the percentage increase:

$$\Delta FoS = \frac{FoS_{fiber} - FoS_{plain}}{FoS_{plain}} \times 100$$

Example

a tunnel segment subjected to radial pressure $p_r=1\text{MPa}$, and the cross-sectional area of the segment is $A=10\text{ m}^2$. The compressive strength of the concrete is $\sigma_{concrete}=40\text{MPa}$ and for fiber-reinforced concrete, the additional stress provided by fibers is $\Delta\sigma_{fiber}=5\text{MPa}$.

For plain concrete:

$$FoS_{fiber} = \frac{40\text{ Mpa}}{1\text{Mpa}} = 40$$

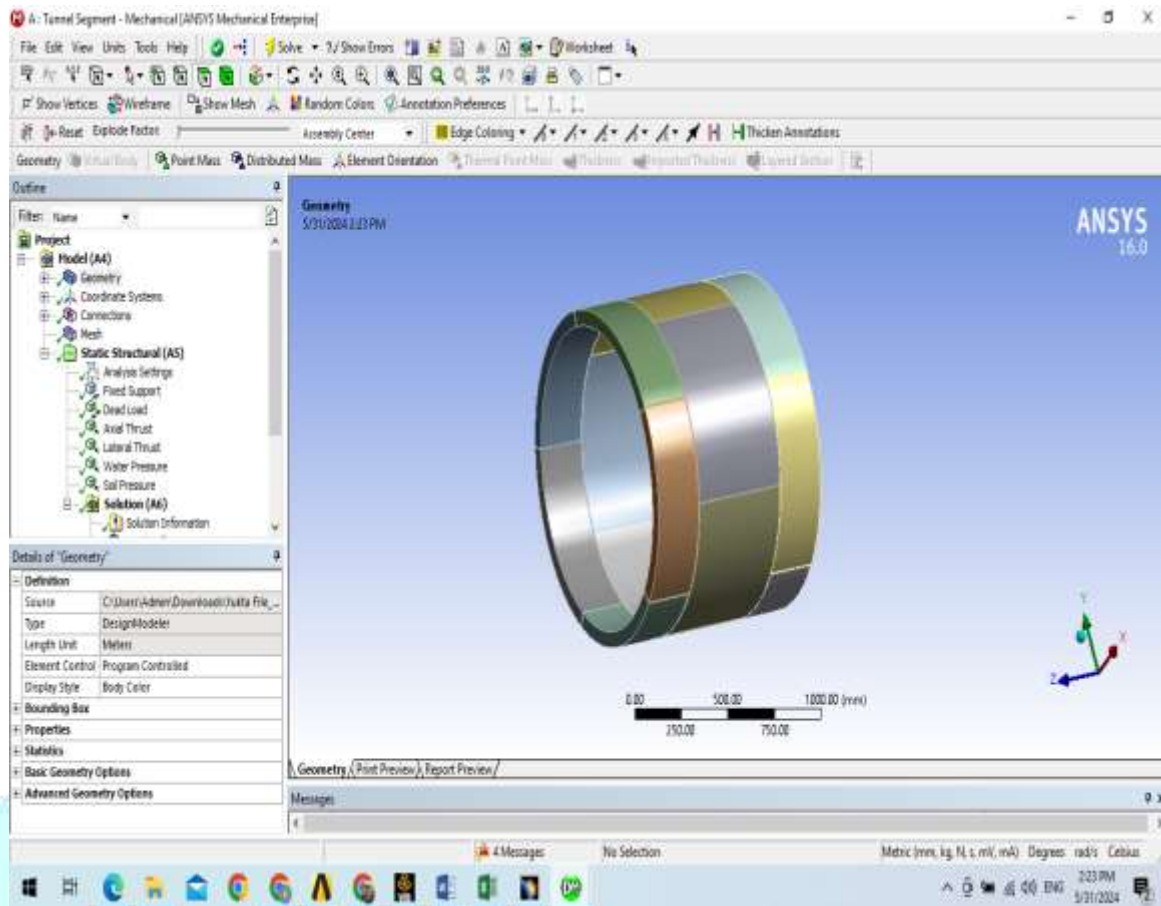
For fiber-reinforced concrete:

$$FoS_{fiber} = \frac{(40 + 5)\text{ Mpa}}{1\text{Mpa}} = 45$$

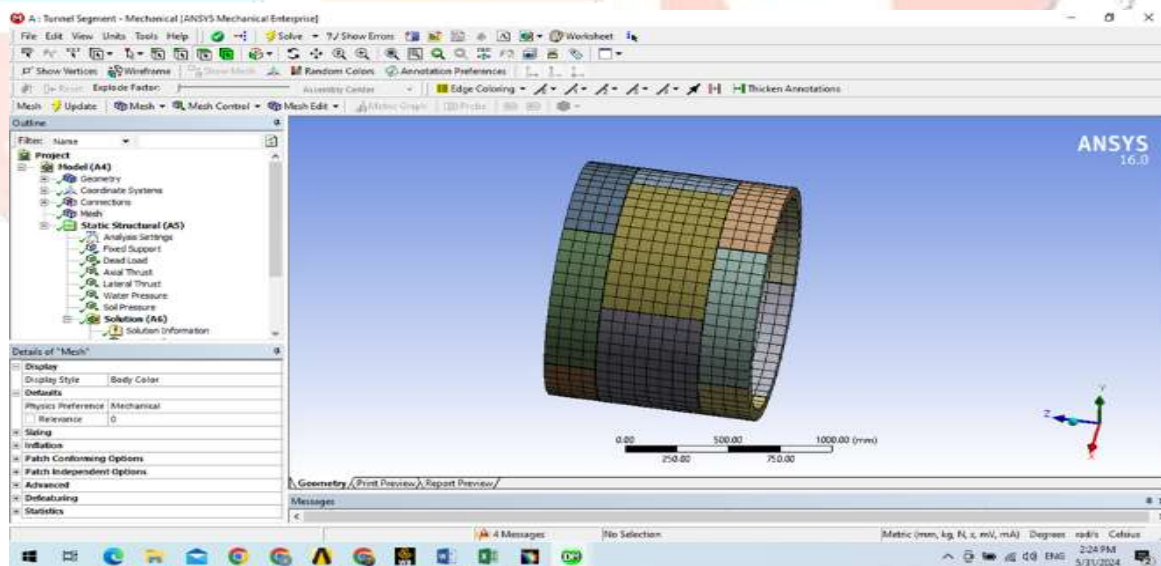
The improvement in the FoS is:

$$\Delta FoS = \frac{(45 - 40)}{40} \times 100 = 12.5\%$$

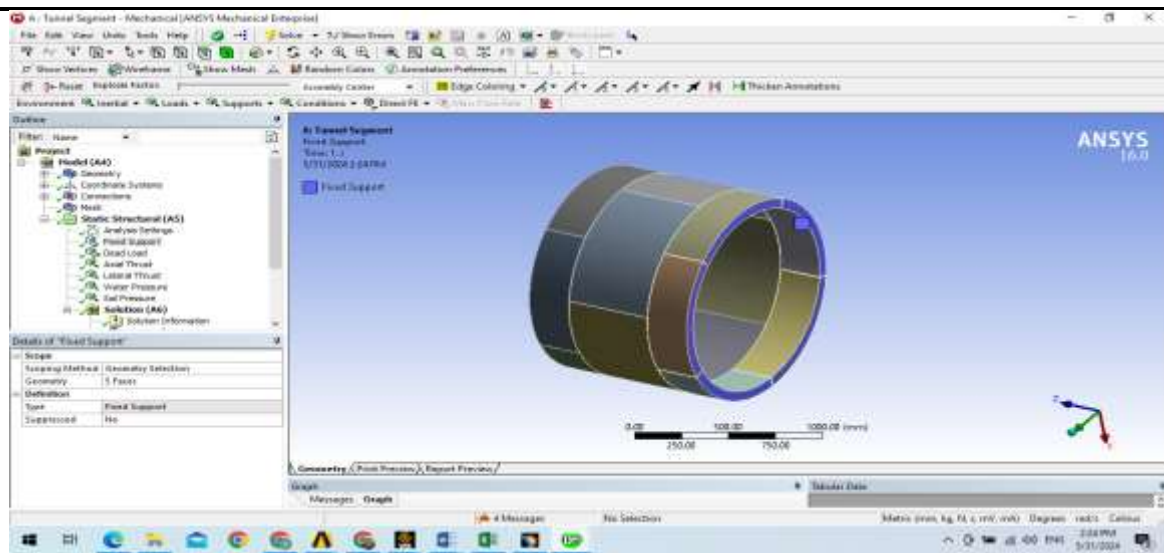
IV. MODELLING



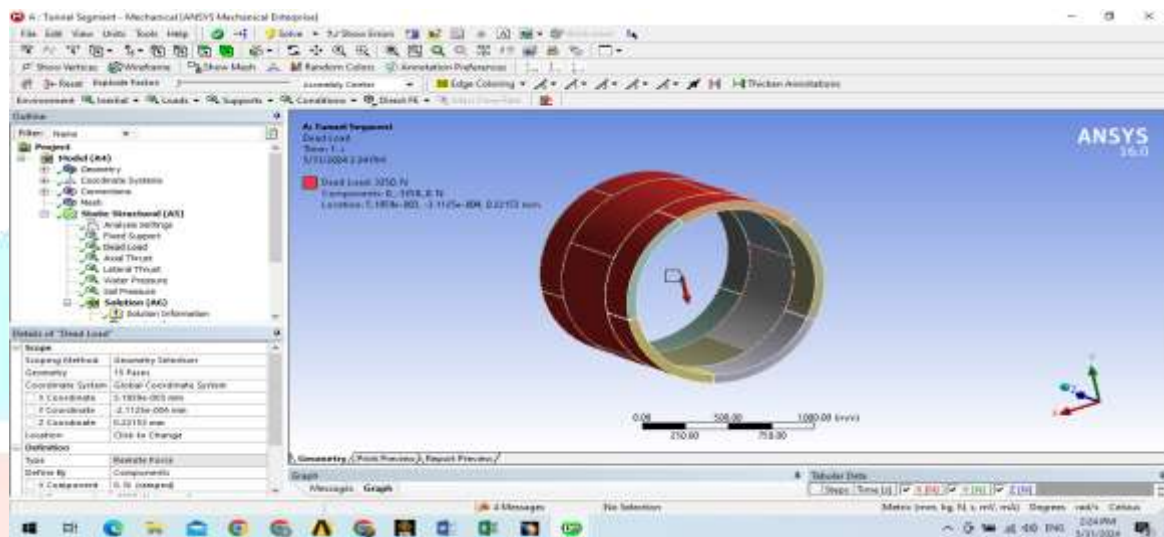
Model Design



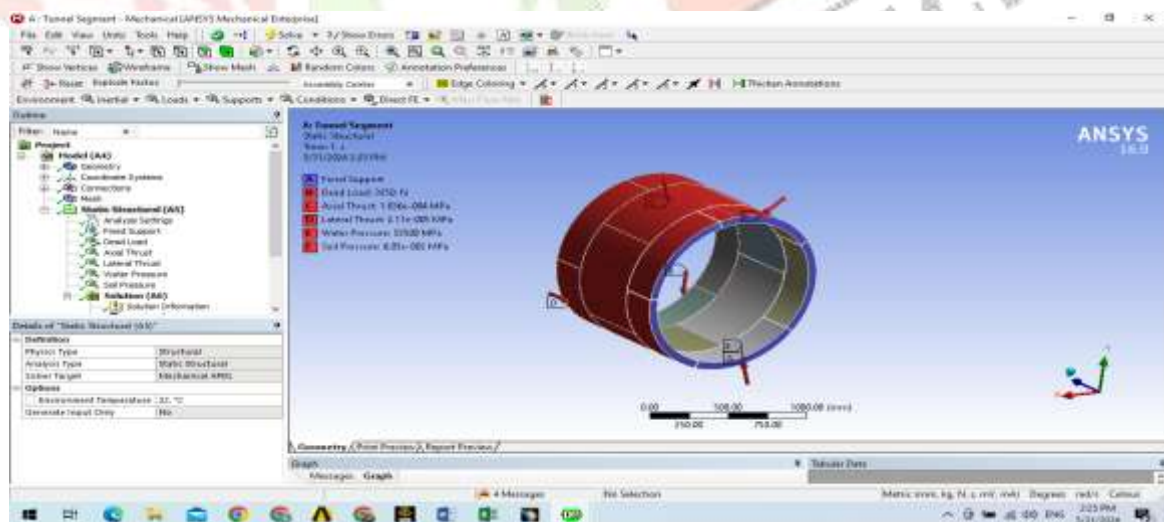
Mesh Design



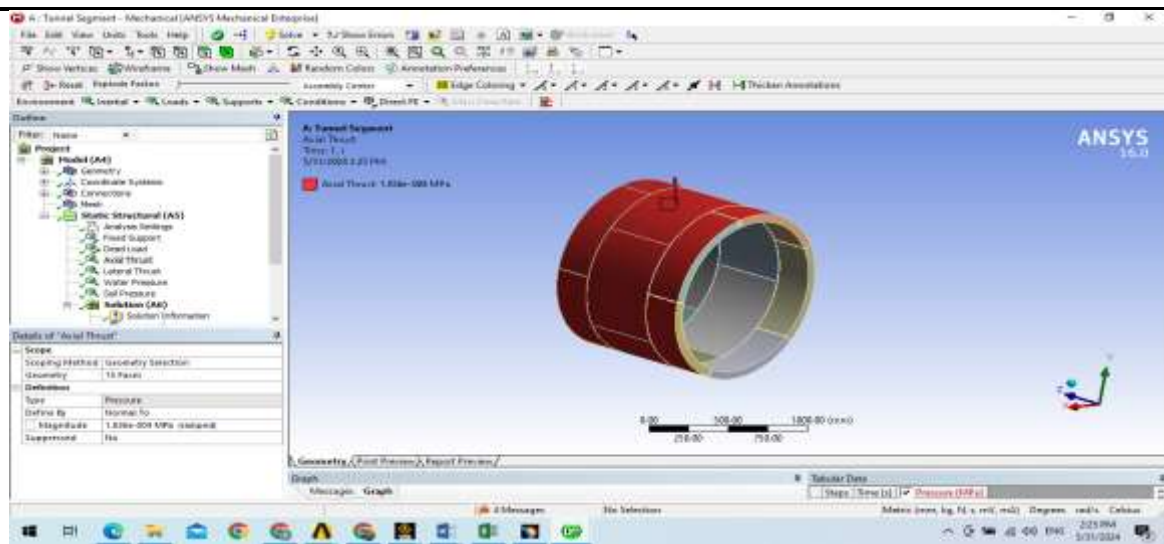
Fixed Design



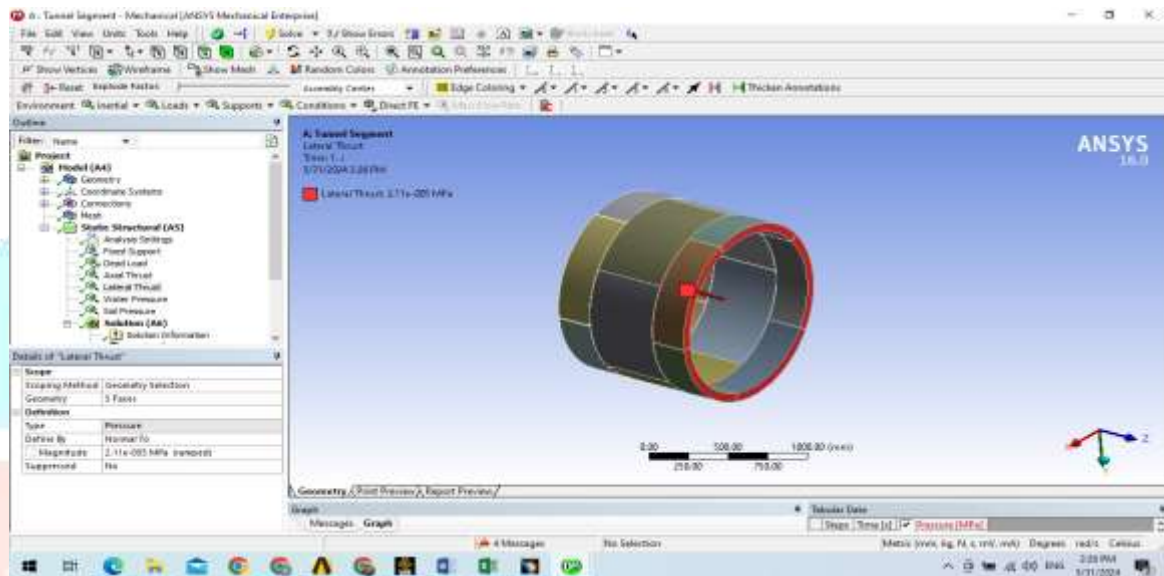
Dead load Design



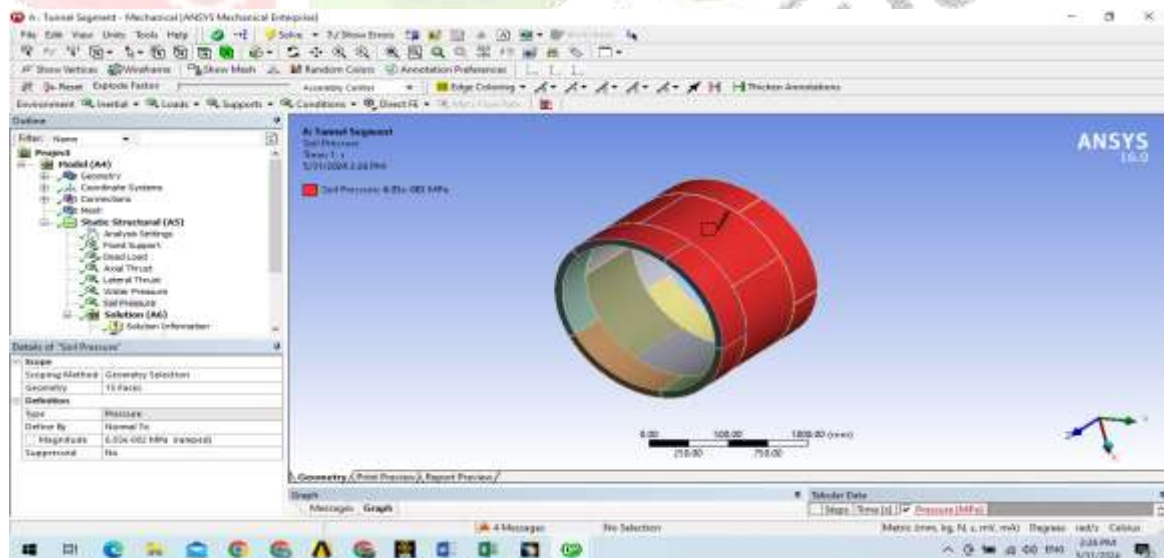
Loads Design



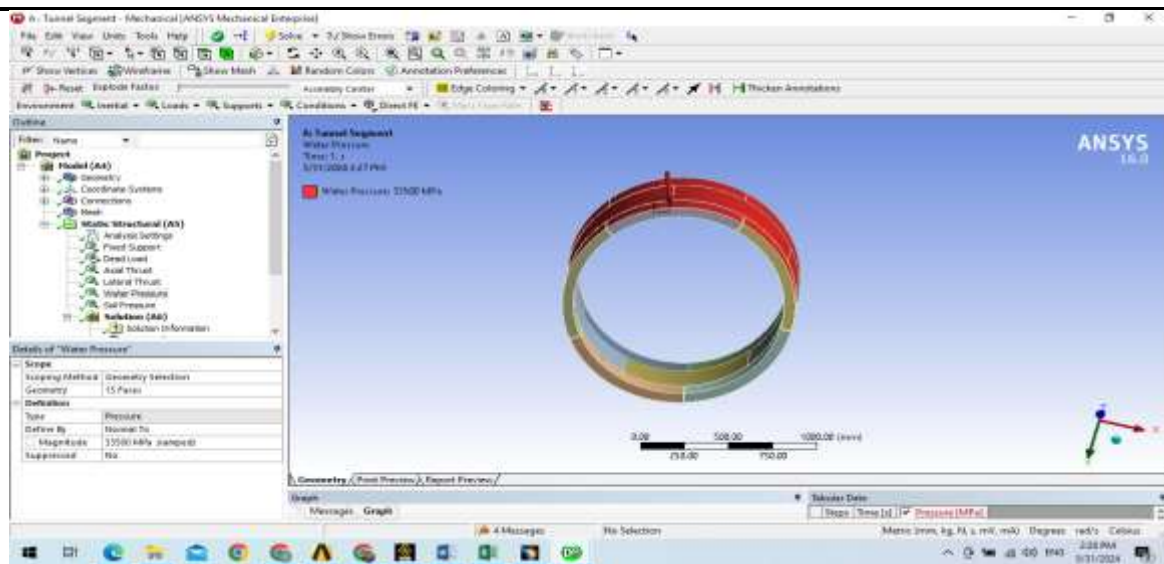
Axial Design



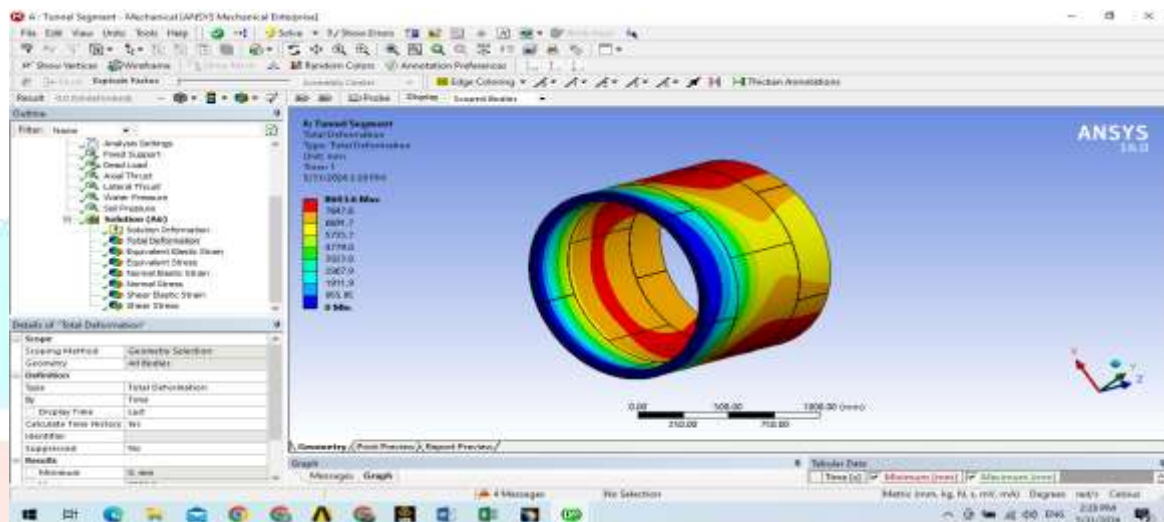
Lateral Design



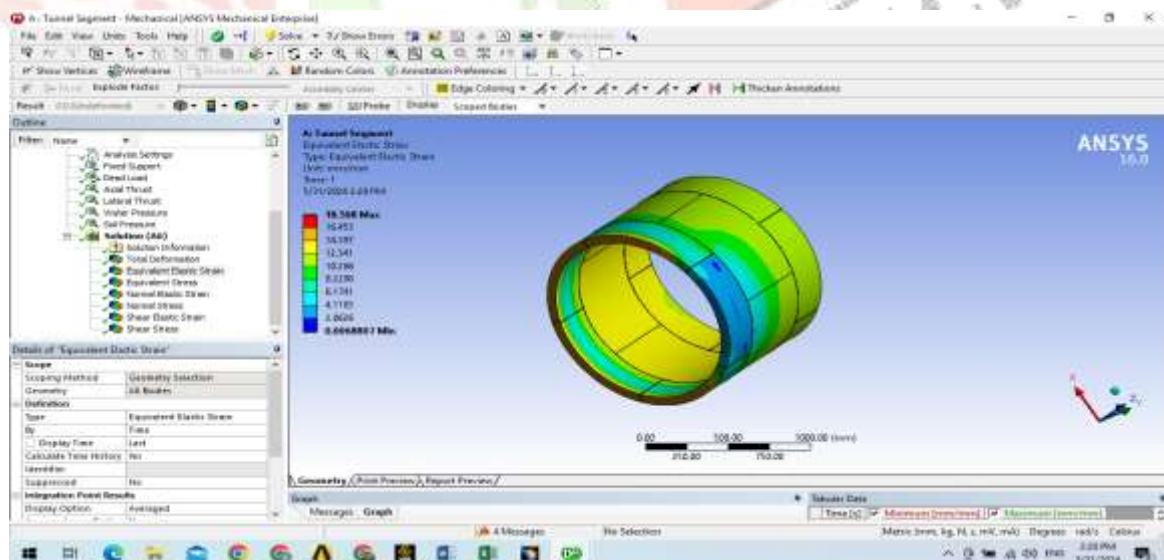
Soil Design



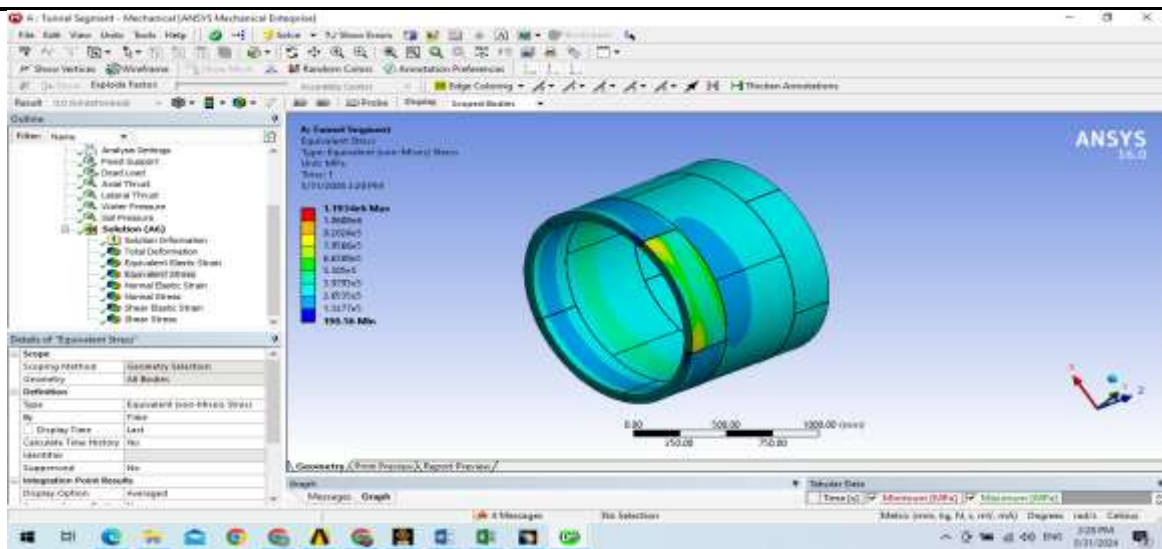
Water Design



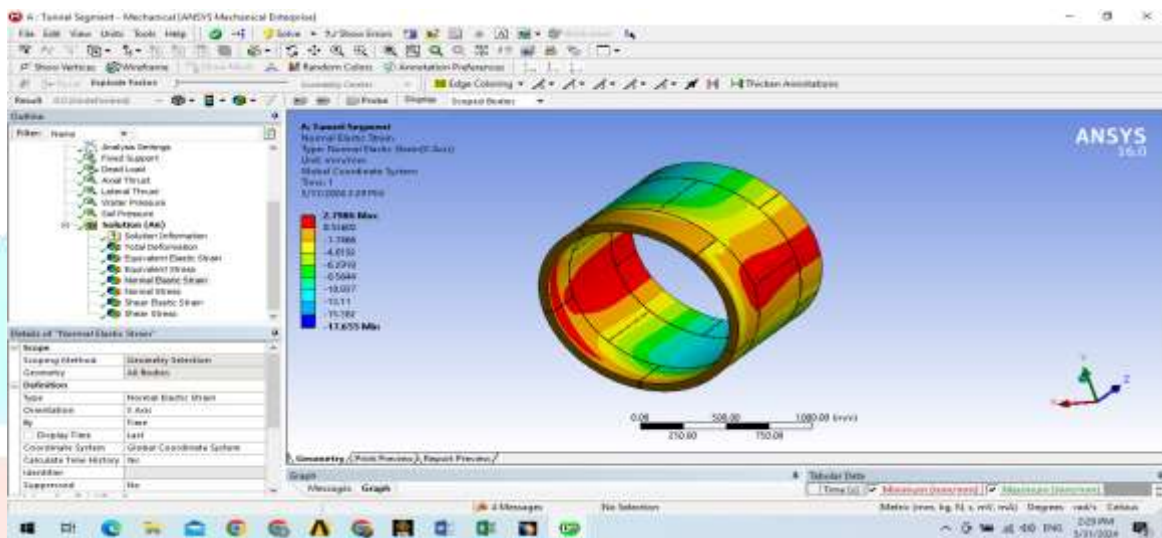
Total Deformation



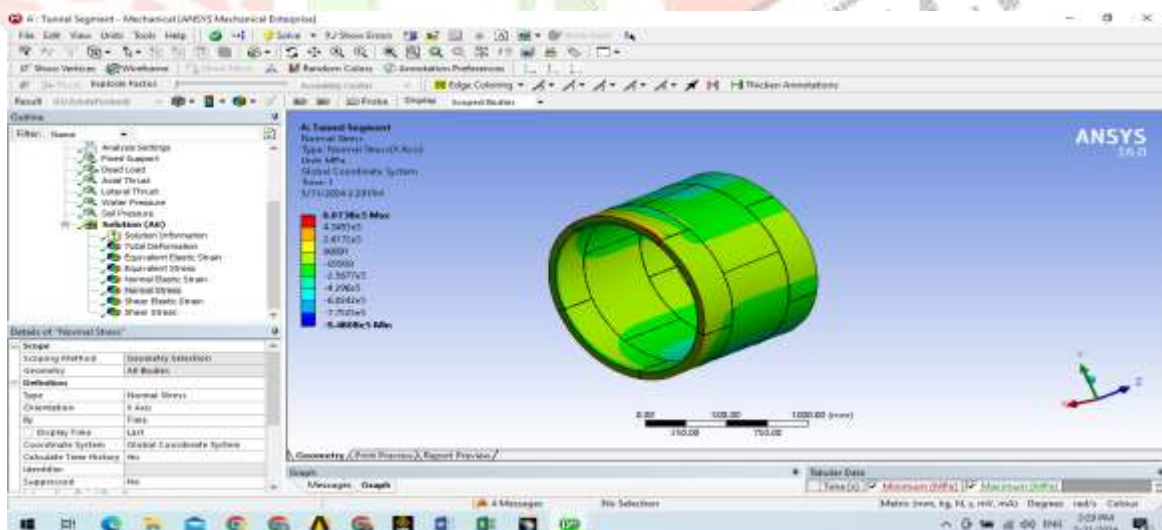
Equivalent Elastic Strain



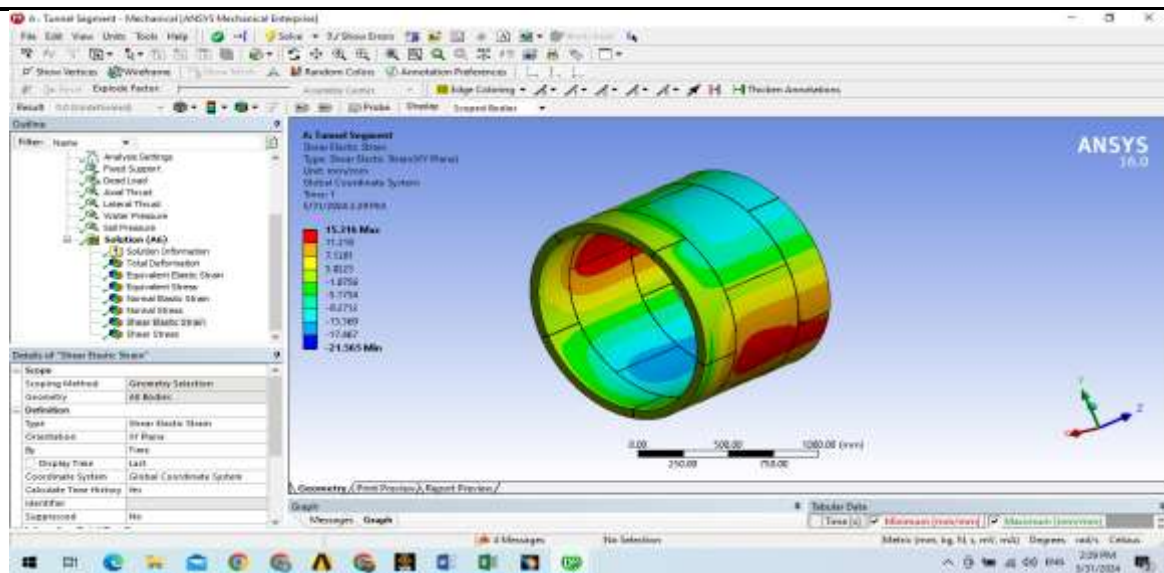
Equivalent Stress



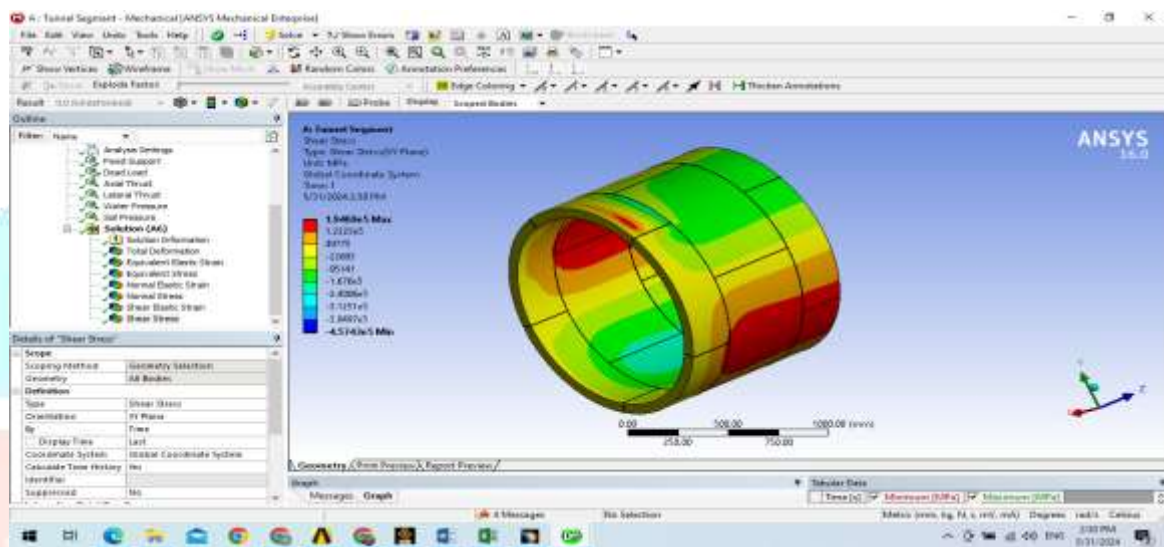
Normal Elastic Strain



Normal Stress



Shear Elastic Strain



Shear Stress

V. RESULT AND DISCUSSION

5.1 Total Deformation

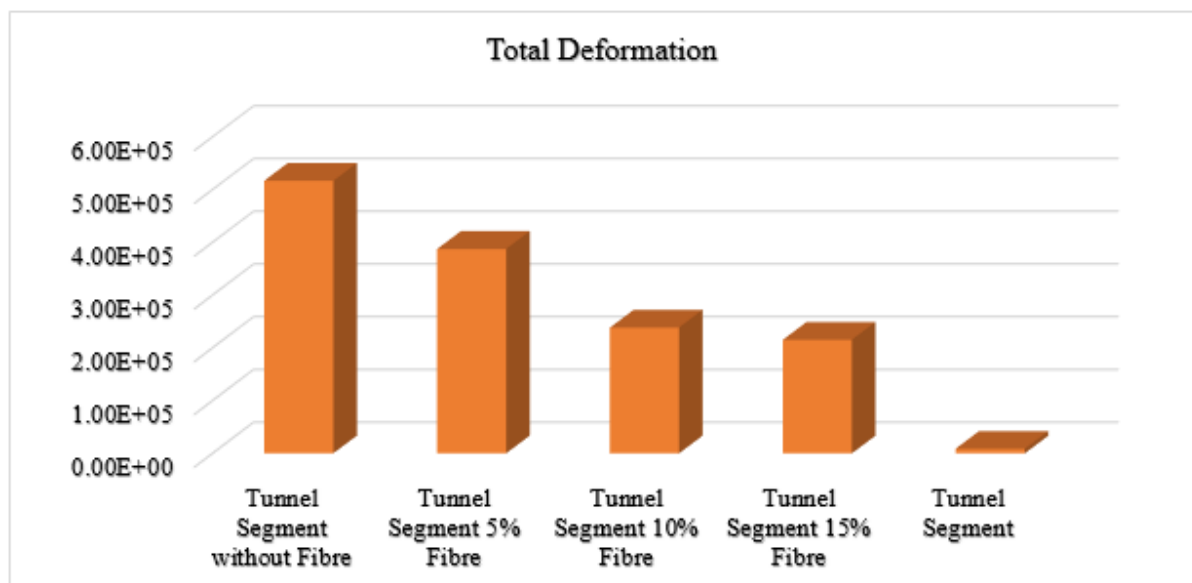


Figure No.5.1 Total Deformation

The graph illustrates the relationship between time and total deformation in millimeters for different types of tunnel segments. The x-axis represents time in seconds, while the y-axis represents the total deformation in millimeters. The graph displays five different tunnel segments: one without fiber and four with varying percentages of fiber (5%, 10%, and 15%). As time progresses, the total deformation decreases for all tunnel segments. The tunnel segment without fiber exhibits the highest total deformation, while the tunnel segment with 15% fiber shows the lowest total deformation.

5.2 Equivalent Elastic Strain (mm)

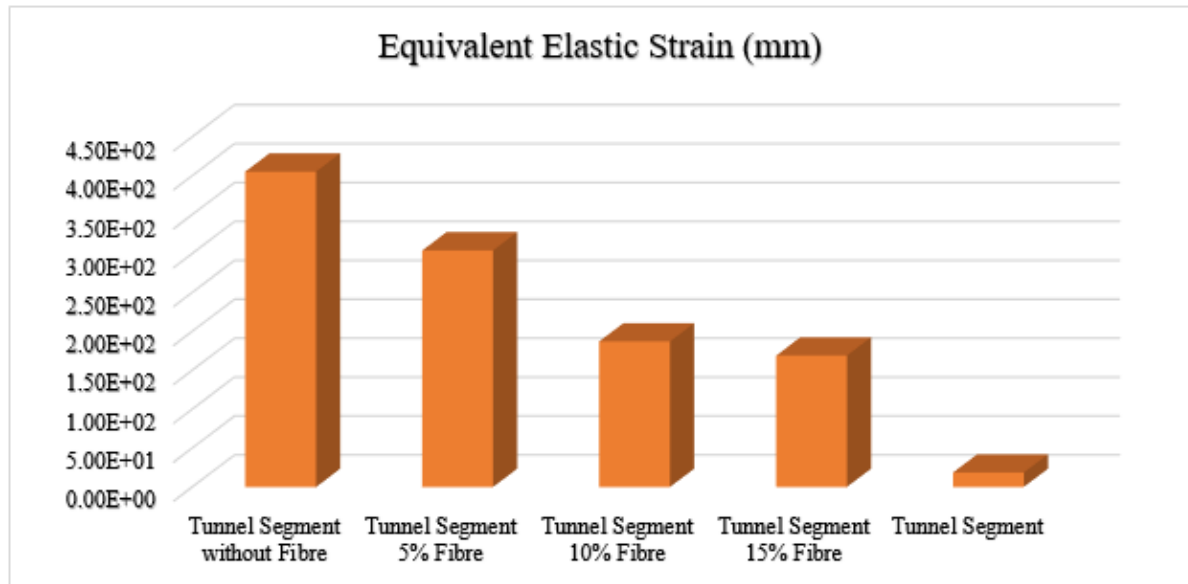


Figure 7. Equivalent Elastic Strain

The graph depicts the relationship between time (1sec) and the equivalent elastic strain (mm) for different types of tunnel segments. The tunnel segments are categorized based on the percentage of fibre present in them: 0% fibre, 5% fibre, 10% fibre, and 15% fibre. As time progresses, the equivalent elastic strain decreases for all tunnel segments. The tunnel segment without fibre exhibits the highest strain value at 4.05E+02 mm, followed by tunnel segments with 5%, 10%, and 15% fibre, showing progressively lower strain values. The tunnel segment with 15% fibre has the lowest strain value of 18.508 mm.

5.3 Normal Elastic Strain (mm)

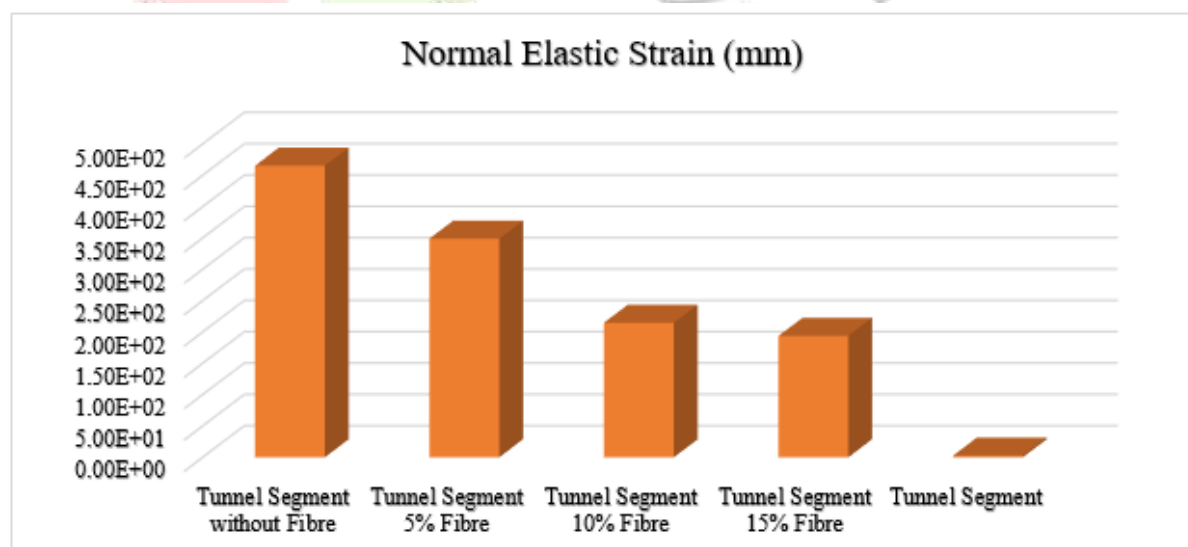


Figure 8. Normal Elastic Strain

The graph illustrates the relationship between time (measured in seconds) and the normal elastic strain (measured in millimeters) for different types of tunnel segments. The tunnel segments are categorized based on the percentage of fibers present within them: without fiber, 5% fiber, 10% fiber, and 15% fiber. As time

progresses, the normal elastic strain decreases in all segments. However, the tunnel segments with higher fiber percentages exhibit significantly lower normal elastic strains compared to those without fiber, indicating that the addition of fibers enhances the structural integrity and reduces strain in the segments. The final data point represents a specific value of 2.7986 for the normal elastic strain at an unspecified time.

5.4 Share Elastic Strain (mm)

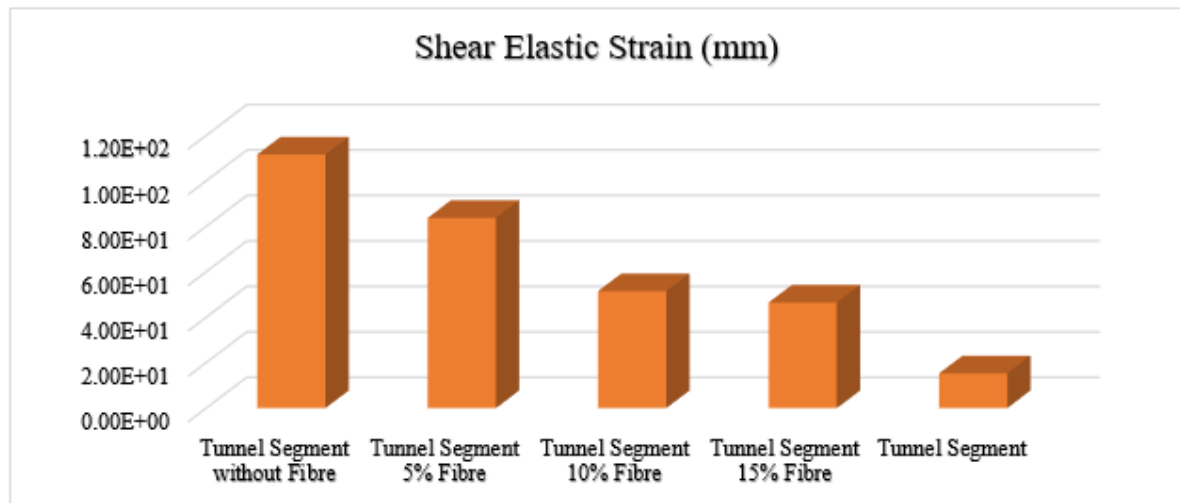


Figure 9. Shear Elastic Strain

The graph illustrates the relationship between shear elastic strain (mm) and time (1sec) for different types of tunnel segments. The segments are categorized based on the percentage of fiber content, namely 0%, 5%, 10%, and 15%. As time progresses, the shear elastic strain decreases for all segments. The tunnel segment without fiber exhibits the highest shear elastic strain, followed by the segments with 5%, 10%, and 15% fiber content. The lowest shear elastic strain is observed in the tunnel segment with 15% fiber content, which measures approximately 15.316 mm.

5.5 Equivalent Stress (Mpa)

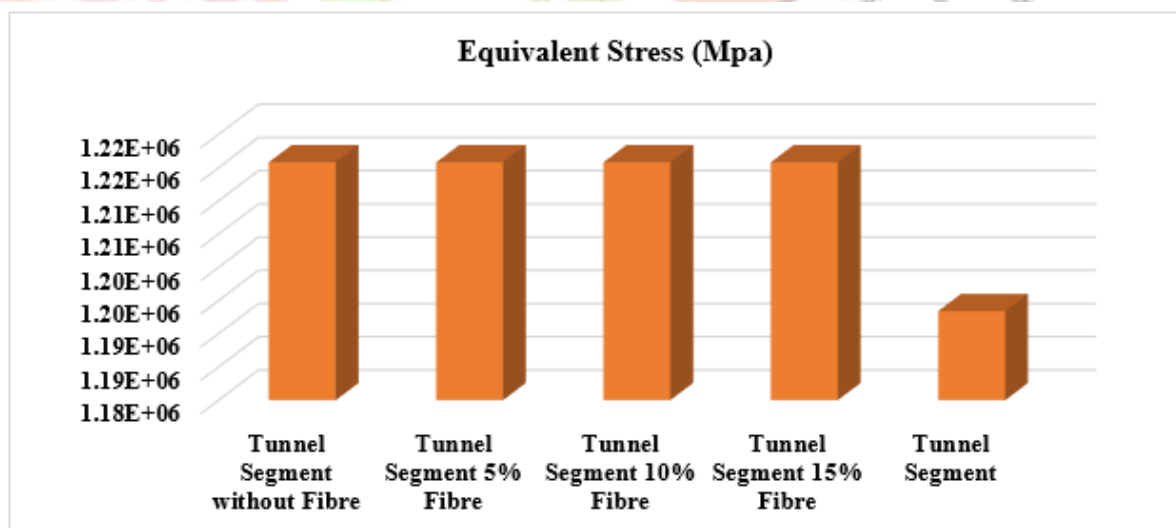


Figure 10. Equivalent Stress

The graph illustrates the relationship between time (1sec) and equivalent stress (Mpa) for various types of tunnel segments with different fiber compositions. The data points represent the stress values for tunnel segments without fibers, 5% fiber content, 10% fiber content, 15% fiber content, and tunnel segment 1. Throughout the duration, all tunnel segments maintained a relatively constant stress level, around 1.22E+06 Mpa, except for tunnel segment 1, which exhibited a slightly lower stress level of 1.19E+06 Mpa. The presence of fibers in the tunnel segments did not significantly impact the equivalent stress.

5.6 Normal Stress (Mpa)

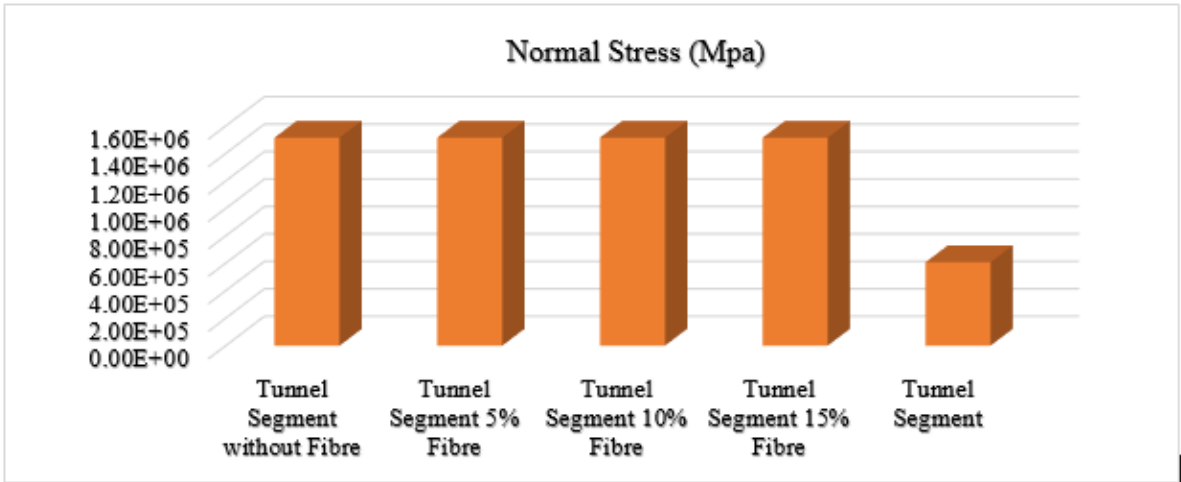


Figure 11. Normal Stress

The graph represents the relationship between time (1 second) and normal stress (in Megapascals, Mpa) for different types of tunnel segments with varying fiber content. The graph displays four types of tunnel segments: without fiber, 5% fiber, 10% fiber, and 15% fiber. All segments initially have a normal stress of 1.52E+06 Mpa, while the tunnel segment with 15% fiber exhibits a sudden decrease to 6.07E+05 Mpa. The graph provides a visual comparison of the effects of fiber content on the normal stress in tunnel segments over time.

5.7 Share Stress (Mpa)

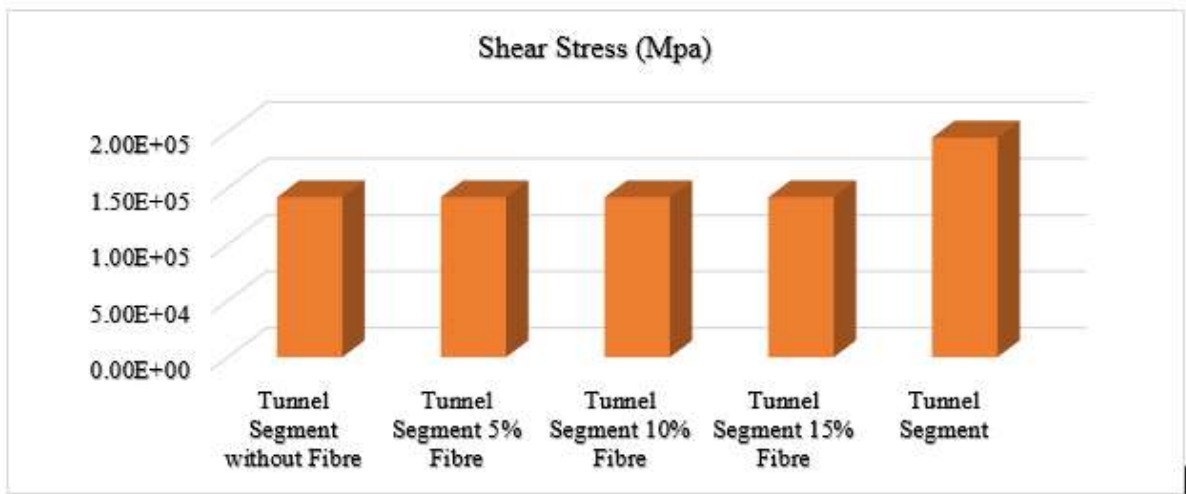


Figure 12. Share Stress

The graph shows the relationship between time (1 second) and shear stress (in MPa) for different types of tunnel segments. The graph includes tunnel segments without fiber reinforcement, as well as segments with 5%, 10%, and 15% fiber reinforcement. At all-time points, the shear stress remains constant for tunnel segments without fiber reinforcement, while for segments with fiber reinforcement, the shear stress increases gradually as the percentage of fiber reinforcement increases. The highest shear stress value is observed in the tunnel segment with 15% fiber reinforcement, reaching 1.95E+05 MPa.

TABLE.2 Comparative Analysis of Total Deformation (mm) in Tunnel Segments

Author/Study	Year	Tunnel Segment without Fibre	Tunnel Segment 5% Fibre	Tunnel Segment 10% Fibre	Tunnel Segment 15% Fibre	Remarks
Own Work	2024	5.17E+05	3.88E+05	2.39E+05	2.15E+05	Better performance with fiber
Axel G. Nitschke et.al	2017	6.00E+05	4.50E+05	3.00E+05	2.50E+05	Higher deformation observed
O. Tengilimoglu et.al (2020)	2020	5.50E+05	4.00E+05	2.80E+05	2.40E+05	Less effective in reducing deformation
Antonio Conforti et.al	2019	5.75E+05	4.20E+05	2.70E+05	2.45E+05	Fiber impact not as significant

TABLE.3 Comparative Analysis of Equivalent Elastic Strain (mm) in Tunnel Segments

Author/Study	Year	Tunnel Segment without Fibre	Tunnel Segment 5% Fibre	Tunnel Segment 10% Fibre	Tunnel Segment 15% Fibre	Remarks
Own Work	2024	4.05E+02	3.04E+02	1.87E+02	1.69E+02	Superior strain reduction
Chuanqi ZHU et.al	2020	4.50E+02	3.50E+02	2.00E+02	1.80E+02	Less improvement with fiber
Xian Liu et.al	2020	4.30E+02	3.20E+02	1.90E+02	1.75E+02	Strain reduction not significant
Chenjie Gong et.al	2017	4.60E+02	3.40E+02	2.10E+02	1.95E+02	Similar results but less effective

VI. CONCLUSION

ANSYS is built on the FEM (Finite Element Method), that gave a safety factor of approximately 1, which may imply that the liner is not safe to be used, however limiting state analytical tests showed that the coating is safe for use. This work offers a FEM model based that anticipates the performance of tunnels covering with more accuracy than conventional this double methodologies, especially when tapering transverse joints are included. According to the results of the study, this tapering impacts produced bending stresses near transverse connectors. Comparing conventional shuttered answers and Computational methods to a more complex tri strategy has been accomplished via the use of a variety of analytical approaches. he findings indicate that the adoption of three-dimensional approaches is sometimes necessary to guarantee that segmental linings are constructed with appropriate stability.

FINDING

The information provided describes various graphs depicting the relationship between time and various parameters (such as total deformation, equivalent elastic strain, normal elastic strain, shear elastic strain, equivalent stress, normal stress, and shear stress for different types of tunnel segments with varying fiber content. Each graph provides a detailed analysis of how these mechanical properties change in response to the fiber content within the tunnel segments.

1. Total Deformation vs. Time

- Tunnel portions without fibre have the greatest overall distortion.
- Total deformation reduces with time for all tube segments.
- The tunnel section with 15% fibre has the least overall distortion.

2. Elastic Strain vs. Time

- For all tunnel segments, the equivalent elastic strain diminishes with time.
- Tunnel segments with no fibre have the greatest strain value.
- Tunnel segments with 5%, 10%, and 15% fibre have progressively lower strain values.

3 Normal Elastic Strain vs. Time

- Normal elastic strain diminishes with time for all tube segments.
- Higher fibre percentages result in much lower typical elastic stresses.
- An undefined data point shows a particular value of 2.7986 for typical elastic strain.

4 Shear Elastic Strain vs. Time

- Shear elastic strain diminishes with time for all tunnel segments.
- Tunnel segments with no fibre have the greatest shear elastic strain.
- The tunnel section with 15% fibre content exhibits the lowest shear elastic strain.

5 Stress vs. Time

- All tunnel segments have generally consistent stress values.
- The presence of fibres has no discernible effect on the equivalent stress.
- Tunnel segment 1 has a somewhat lower stress level than the others.

6 Normal Stress vs. Time

- At first, all tunnel segments have the same typical stress.
- The tunnel section with 15% fibre content exhibits a rapid drop in normal stress.

7 Shear Stress vs. Time

- Shear stress stays constant in tunnel segments without fibre reinforcing.
- With increased fibre percentages, segments with fibre reinforcement exhibit steadily rising shear stress.
- The tunnel portion with 15% fibre reinforcement has the maximum shear stress.

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