Article

Structural Analysis of Tunnel Using FEA

(IJGASR) International Journal For Global Academic & Scientific Research
ISSN Number: 2583-3081
Volume 2, Issue No. 2, 30–37

journals.icapsr.com/index.php/ijgasr
DOI: 10.55938/ijgasr.v2i2.47

IJGASR

Vikash Agrahari[1], Awadhesh Chandramauli[2] and Vinod Balmiki[3]

Abstract

Tunnels are typically built for transportation, such as roads, railways, or canals, but they can also be used for other purposes, such as mining, sewerage, or water supply. Tunnels allow us to travel safely and efficiently through difficult terrain, and they provide us with access to essential resources such as water and energy. The objective of current research is to evaluate the structural characteristics of tunnel structure under geo-mechanical loading conditions. The structural analysis of tunnel is conducted using techniques of FEA. The CAD modelling and FEA simulation of tunnel is conducted using ANSYS simulation package. The shear stress, normal stress and deformation data are generated. From the generated data, the critical regions are identified and the lateral zone of tunnel is one of them. This region is likely to induce damage in the form of crack.

Keywords

Tunnel, FEA

Received: 20 May 2023; **Revised:** 20 June 2023;
Accepted: 29 June 2023; **Published:** 30 June 2023

Introduction

The construction of a tunnel is a challenging and intricate undertaking. The implementation of this solution may entail a significant cost and necessitate the involvement of a proficient team of engineers and personnel. Tunnels play a crucial role in modern infrastructure and transportation systems. Infrastructure facilitates access to essential resources such as water and electricity, while also enabling

[1]Research Scholar, Civil Department, Uttaranchal University, Dehradun.

[2]Assistant Professor, Civil Department, Uttaranchal University, Dehradun.

[3]Assistant Professor, Civil Department, Uttaranchal University, Dehradun.

Correspondence Author:
Vikash Agrahari, Research Scholar Civil Department Uttaranchal University, Dehradun.
E-mail: vikas.amethi@gmail.com

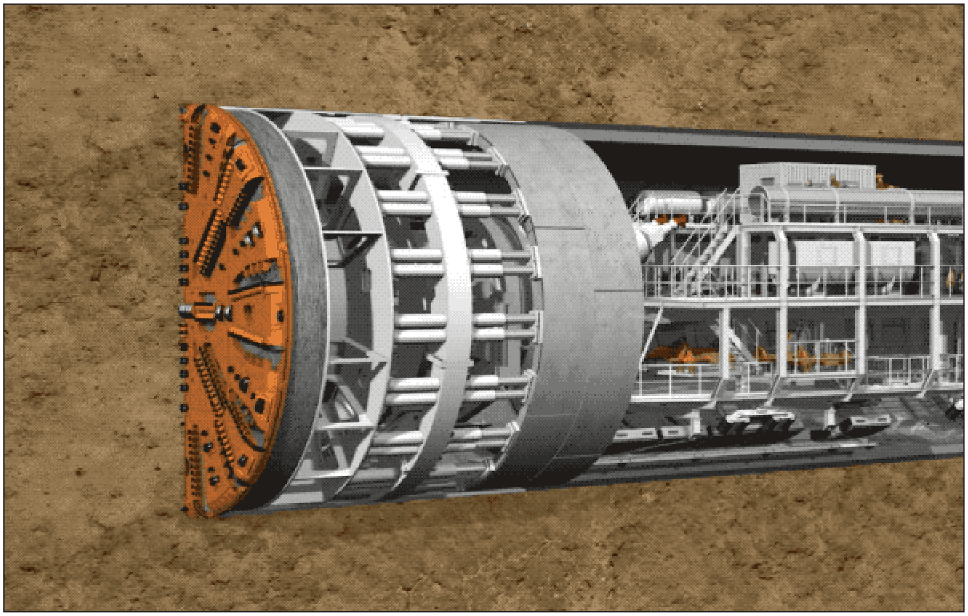

Figure 1. Tunnel Boring Machine [1]

secure and efficient transportation across difficult landscapes. There exist several techniques for constructing tunnels.

- Blasting: The blasting techniques involves use of explosives and other techniques to induce opening/cracks.
- Drilling and blasting: This technique involves both use of drilling and blasting together and better than other technique. However, the technique is expensive.
- Tunneling machines: The tunnel boring machines (TBM's) are now popular among engineers which is more efficient and less disruptive as compared to other techniques.

Literature Review

Foria et. al. [2] (2022) The present investigation focuses on the steady-state conditions of dynamic tunnels through the utilisation of the convergence-confinement technique. A modelling approach was employed to ascertain the duration of stability of the tunnel in the event of a reduction in concrete stiffness leading to the weakening of the main lining. The gradual deterioration of the primary lining results in a reduction of its load-bearing capacity, thereby disrupting the tunnel's state of equilibrium.

Niyirora et. al. [3] (2022) the analytical approach has been widely adopted to investigate the interaction mechanism between surrounding rock and linings for tunnels in rheo- logical rock. The author obtained closed-form solutions of a deep-buried circular tunnel considering the sequential installation of linings [4]

Zhang et. al. [5] (2021) proposed a linear degradation model for the primary lining in order to evaluate the mechanical characteristics of the secondary lining throughout its lifespan. A set of numerical simulation models was developed to investigate the mechanical behavior of the secondary lining, taking into consideration the deterioration of the sprayed concrete lining. Degradation was deemed to have occurred when there was a gradual decrease in the Young's modulus of the sprayed concrete lining.

Barros et. al. [6] (2020) This research contributes to the advancement of our understanding regarding the evaluation of tunnel safety in the long run. The limitations of the prescribed analytical framework necessitate further discussion, as it has been excessively simplified in specific domains. In this study, the rheological behavior of soft rock is characterized using the Burgers model, which accounts for the temporal dynamics of the encompassing rock.

Deme et. al. [7] (2020) The present study introduces an innovative methodology for the quantitative assessment of tunnel stability in rock masses with joints. The proposed strategy is founded upon a variation of the traditional finite element approach. The revised approach considers the interrelationships among joint orientation, joint spacing, joint strength, and tunnel stability. The comparison between field measurements and numerical analysis is being made. The results indicate the efficacy of this distinct methodology in forecasting the stability of tunnels in rock masses that are characterized by joints.

Qiu et. al. [8] (2017) The present study introduces an innovative method for forecasting tunnel distortion. The approach integrates principles from the finite element technique, albeit with notable modifications. The revised approach incorporates considerations pertaining to the influence of ground conditions, construction techniques, and tunnel geometry on tunnel displacement. Field measurements are compared with numerical analysis. The findings indicate that the novel methodology effectively predicts tunnel deformation.

Bassan et. al. [9] (2016) This study aims to examine the impact of groundwater on the structural stability of tunnels. The utilization of a numerical model is employed by the authors to replicate the process of tunnelling through soil that is imbued with moisture. The model incorporates factors such as soil deformation, seepage pressure, and groundwater circulation. The outcomes of the simulation bring into focus the potential influence of groundwater on the stability of tunnels. The authors argue that the incorporation of groundwater considerations is imperative in the planning and implementation of tunnel construction in moist soil environments.

Objectives

The objective of current research is to evaluate the structural characteristics of tunnel structure under geo-mechanical loading conditions. The structural analysis of tunnel is conducted using techniques of FEA. The CAD modelling and FEA simulation of tunnel is conducted using ANSYS simulation package.

Methodology

The structural analysis of tunnel is conducted using techniques of FEM which involves different stages. In the 1st stage CAD model of tunnel and computational domain is developed as shown in figure 2.

The tunnel design is imported in ANSYS design modeller where it is checked for geometric errors, imperfections and surface imperfections. The imported design of tunnel and computational domain is shown in figure 2. The model of tunnel is discretized using fine sizing as shown in figure 3.

After discretization, the tunnel model is applied with loads and boundary conditions. The base of tunnel domain structure is applied with fixed support and with gravitational load. The material definition is defined for tunnel lining with M30 concrete and domain is defined with rock mass.

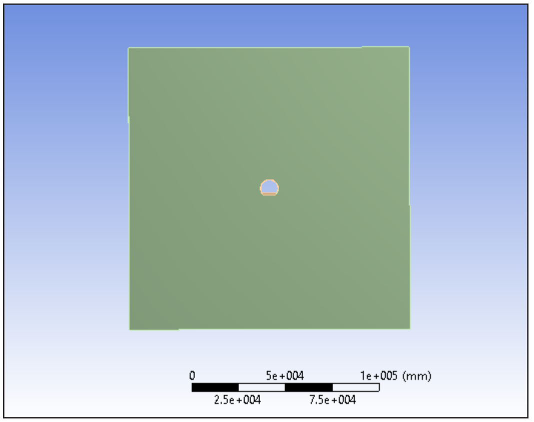

Figure 2. CAD design of tunnel and domain

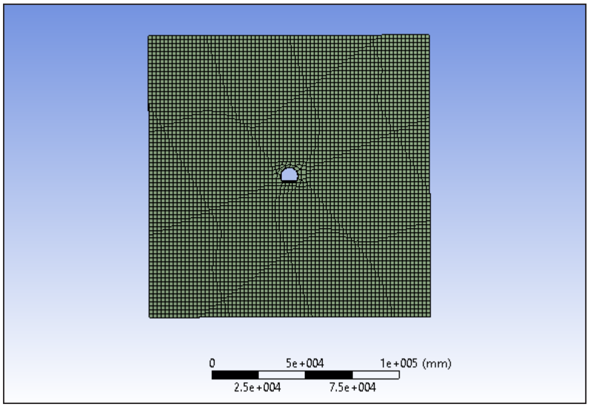

Figure 3. Meshed model of tunnel and domain

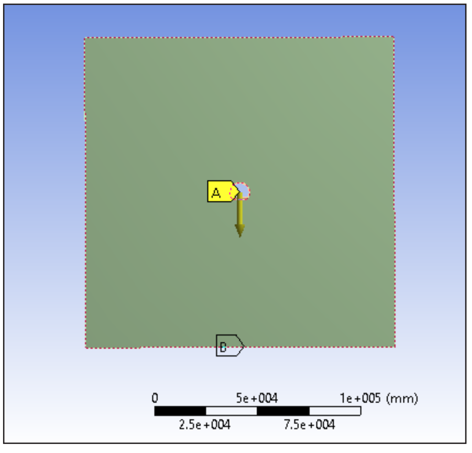

Figure 4. Loads and Boundary condition on tunnel

Results and Discussion

The FEA simulation is conducted on tunnel with computational domain to determine total deformation, normal stress and shear stress.

The total deformation plot is generated for computational domain comprising of earth and tunnel lining. The deformation plot shows higher magnitude at the top most region of tunnel structure. The deformation at this region is nearly 335mm which reduces towards the tunnel lining structure.

The shear stress distribution plot is obtained for entire tunnel domain as shown in figure 7. The plot shows positive shear stress at top most and side faces of tunnel lining and bottom right zone shows negative shear stress of 9.638MPa.

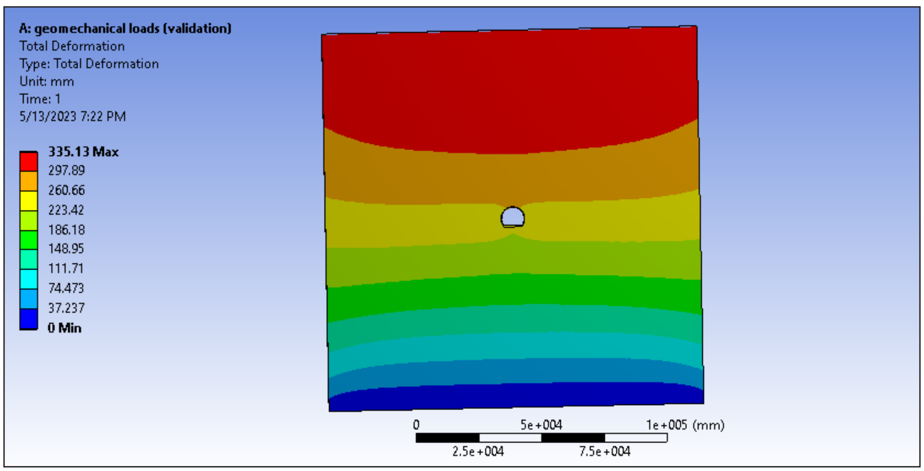

Figure 5. Total deformation plot on tunnel domain

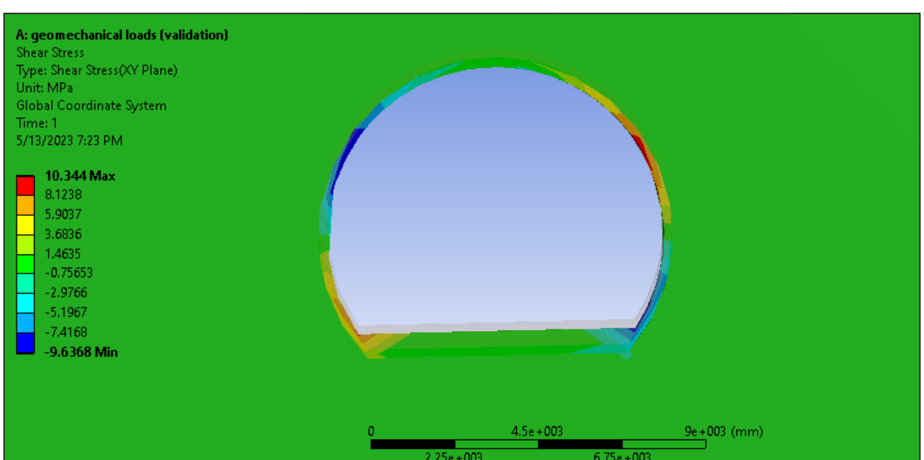

Figure 6. Shear stress plot on tunnel domain

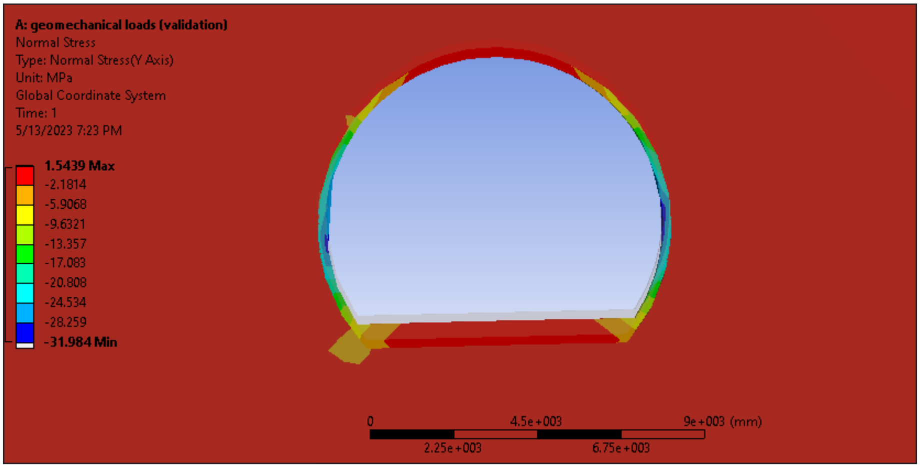

Figure 7. Normal stress plot on tunnel domain

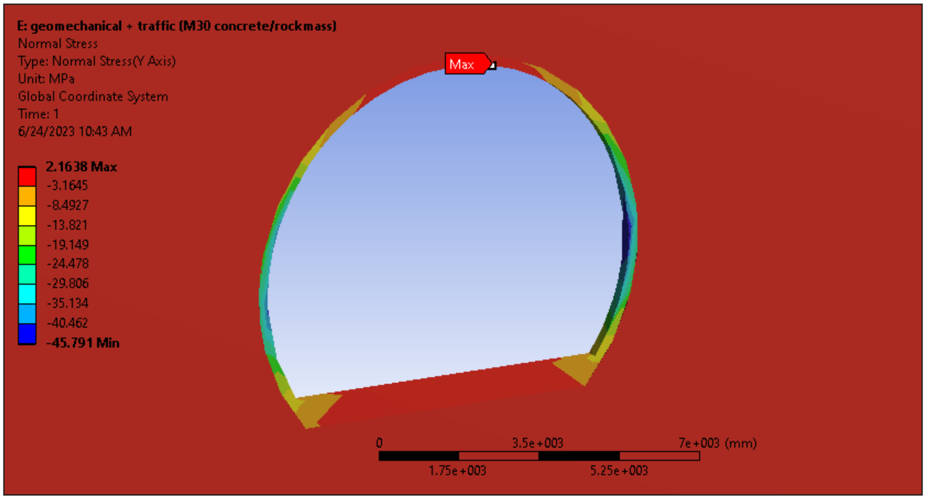

Figure 8. Normal stress (vertical) plot on tunnel domain for both geotechnical and traffic load

The normal stress distribution plot is generated for tunnel domain as shown in figure 8 above. The topmost region of tunnel lining has tensile normal stress with magnitude of 1.53MPa and side faces of tunnel lining has compressive normal stress with magnitude of 28.2MPa.

The normal stress distribution plot (vertical direction) is generated for tunnel subjected to both geotechnical and traffic loads. The induced normal stress is in both tensile and compressive. The side surface of tunnel experiences compressive normal stress with magnitude of 40.46MPa whereas the top surface experiences tensile normal stress wherein the magnitude is more than 2MPa.

The normal stress distribution plot (horizontal direction) is generated for tunnel subjected to both geotechnical and traffic loads. The induced normal stress is in both tensile and compressive. The bottom road surface of tunnel experiences tensile normal stress along horizontal direction wherein the magnitude

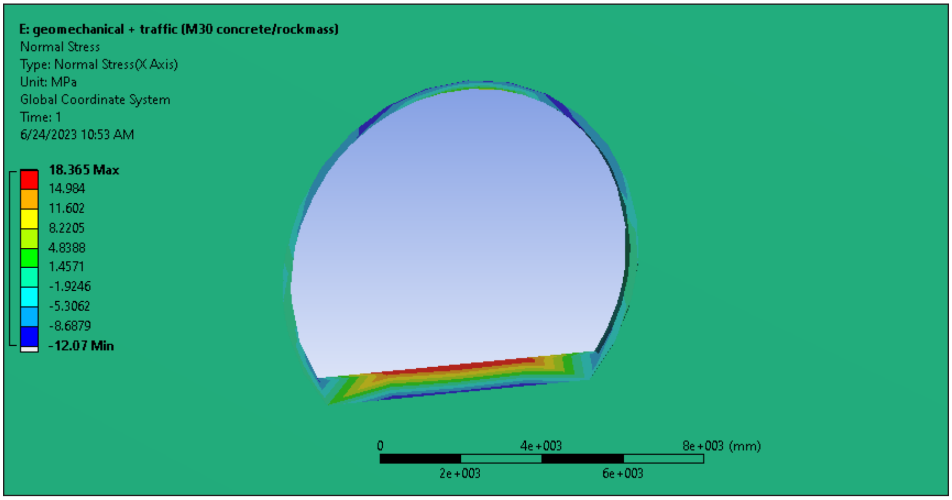

Figure 9. Normal stress (horizontal) plot on tunnel domain for both geotechnical and traffic load

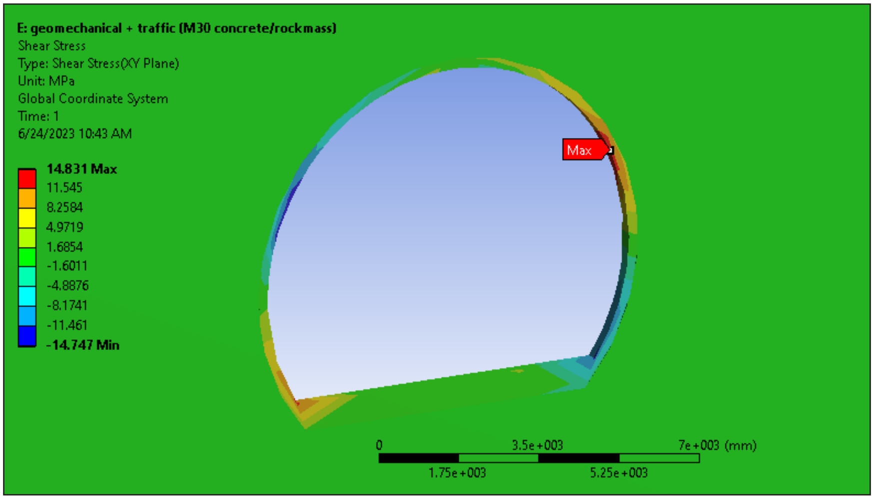

Figure 10. Shear stress plot on tunnel domain for both geotechnical and traffic load

of stress is more than 18MPa. The induced normal stress on side walls is nearly 12MPa along horizontal direction.

The shear stress distribution plot is obtained for tunnel domain subjected to both geotechnical and traffic load as shown in figure 8 above. The induced shear stress is higher at the side walls wherein the magnitude is nearly 14 MPa.

Conclusion

The FEA is a viable tool in evaluating the structural characteristics of tunnel subjected to geo-mechanical loading conditions. The use of computer simulation tools enabled to determine the critical regions of tunnel lining which are prone to damage. The shear stress, normal stress and deformation data are generated. From the generated data, the critical regions are identified and the lateral zone of tunnel is one of them. This region is likely to induce damage in the form of crack.

The use of advanced structural monitoring systems and DAS (distributed acoustic sensing) systems along with wireless sensor networks can aid in construction of tunnel within stipulated time. These techniques can also enable to identify various types of failures i.e. cracks, deformations etc.

The tunnel can be inspected using intelligent inspection robots. These robots comprise of cameras which can capture images of high resolution and can identify any possible failures/cracks/fracture.

The tunnels can be constructed using more energy efficient and sustainable materials. The use of green construction materials in tunnel would reduce the impact on environment and enhance sustainability.

ORCID iD

Vinod Balmiki https://orcid.org/0000-0002-4795-3357

References

1. Website: www.geotech.hr
2. Foria F., Miceli G., Calicchio M., Catigbac G.M., Loprencipe G. Digital transformation in the visual inspection of heritage railways tunnels: technology, artificial intelligence and methodology in: *Geotechnical Engineering for the Preservation of Monuments and Historic Sites III*, CRC Press, 2022, pp. 337–348.
3. Niyirora R., Wei J., Masengesho E., Munyaneza J., Niyonyungu F., Nyirandayisabye R., Intelligent damage diagnosis in bridges using vibration-based monitoring approaches and machine learning: a systematic review, *Results in Engineering* (2022), 100761.
4. Broˇz J., Tichý T., Angelakis V., Bˇelinov´ a Z., Usage of V2X applications in road tunnels, *Appl. Sci. 12* (9) (2022) 4624, https://doi.org/10.3390/app12094624.
5. Zhang X., Wu X., Broere W., *Impact of subsoil spatial variability on deformations of immersed tunnel, in: 10th International Symposium on Geotechnical Aspects of Underground Construction in Soft Ground, IS-CAMBRIDGE 2022*, CRC Press/ Balkema-Taylor & Francis Group, 2021.
6. Farahani B.V., Barros F., Sousa P.J., Tavares P.J., Moreira P.M., A railway tunnel structural monitoring methodology proposal for predictive maintenance, *Struct. Control Health Monit*. *27* (2020) e2587.
7. Deme D., A review on effect of pavement surface failure on road traffic accident, *American international journal of sciences and engineering research 3* (1) (2020) 14–19.
8. Lai J., Qiu J., Fan H., Chen J., Hu Z., Zhang Q., Wang J., Structural safety assessment of existing multiarch tunnel: a case study, *Adv. Mater. Sci. Eng*. (*2017*) 1–11, 2017.
9. Bassan S., Overview of traffic safety aspects and design in road tunnels, *IATSS Res*. *40* (1) (2016) 35–46.
10. Vashitz G., Shinar D., Blum Y., In-vehicle information systems to improve traffic safety in road tunnels, Transport. *Res. F Traffic Psychol. Behav*. *11* (1) (2008) 61–74.