A Major Project – II
On

EFFECT OF SHAPE OF TUNNEL ON ITS STABILITY

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN

GEOTECHNICAL ENGINEERING

Submitted by:
ABHISHEK PATEL
(Roll No. 2k19/GTE/02)

Under the supervision of
PROF. AMIT KUMAR SHRIVASTAVA

DEPARTMENT OF CIVIL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi- 110042

August, 2021

CANDIDATE'S DECLARATION

I, Abhishek Patel, Roll No. 2K19/GTE/02, a student of M. Tech (Geotechnical Engineering), hereby declare that the report titled "Effect of Shape of Tunnel on its Stability" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi, in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or another similar title or recognition.

Place: Delhi ABHISHEK PATEL
Date: 10 August 2021

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the report titled **"Effect of Shape of Tunnel on its Stability"** which is submitted by ABHISHEK PATEL, 2K19/GTE/02, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: New Delhi **Prof. AMIT KUMAR SHRIVASTAVA**

Date: 10 August, 2021 **SUPERVISOR**

ACKNOWLEDGMENT

I would like to express my gratitude for introducing this research, and for its illuminating direction, constructive review and valuable suggestions during the project work to Prof. AMIT KUMAR SHRIVASTAVA, Professor, the Department of Civil Engineering, Delhi Technological University, New Delhi.

I am also thankful to all professors and support staff of the Department of Civil Engineering, Delhi Technological University, New Delhi, for their advice and guidance they have given me.

ABHISHEK PATEL
2K19/ GTE / 02
Department of Civil Engineering

Delhi Technological University, New Delhi

ABSTRACT

Due to rapid urbanization, the role of underground construction is increasing day by day. Underground tunnels are used for several purposes such as storage space, transportation, sewage, water and, oil delivery, and so on. Due to the constant pressure of high-rise residential buildings and, traffic movement, tunnels can be damaged. Hence, the study of stability assessment is very imperative. Many researchers have been proven that the stability of a tunnel depends on various factors like cover depth, type of loading, material properties, etc. This paper investigates the stability appraisal of different shapes of the tunnels in rock mass under static load. Finite element software, ANSYS has been used for numerical modeling and investigation of the static response of different shapes of 3-D shallow tunnels, which are Circular, Horse-shoe, Box Shape, and Semi-ellipse considering the same cross-sectional area under static loading conditions. In the paper, a load has been applied as pressure through a steel patch on top of the tunnel. A 3-D finite element model has been taken for the numerical study with a constant C/D ratio. This paper aims to compute longitudinal deformation on the lining and crown of each tunnel. The failure of the tunnel along the tunnel axis has been investigated. The conclusion of the study represents that the most stable shape is circular from a deformation point of view among all the tunnels when subjected to static loading conditions.

Keywords: *Ansys, Static loading, Stability, Tunnel*

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

1.1 General

Due to the scarcity of land, the demand for underground construction has increased in our society. Hence, tunneling structures are a huge need of our developing society for the transport of locomotive, lubricate, water, seepage, people, and so on. In the Himalayan region, a tunnel connects the two places so that the time taken to travel between those places is reduced.

During the design and construction of the tunnel, engineer faces many challenges. Some of these challenges are-

- All underground projects are fraught with uncertainty.
- Geology dominates the project's cost and feasibility.
- Geologic investigations are more demanding in every way than standard foundation engineering projects.

So, before the construction and design of the tunnel, it is essential to know about the geology of a rock. Rock is classified based on origin as-

- Igneous Rocks which are formed as a result of the solidification of molten mass above or beneath the earth's surface.
- Sedimentary rocks which are formed due to the gradual deposition of the material like sand, gravel, etc.
- Metamorphic rocks which are formed due to change of original rock structure under temperature and heat.

The descriptions of rock masses are significantly more complicated than soils. The primary distinction between rock and soil behavior is anisotropy or other discontinuities that have a dominant effect on the rock mass. The kinematic behavior of the rock masses is dominated by joints and the interactions between the several joint sets. So, the existence of joints alters the rock mass engineering characteristics dramatically. In this investigation intact rock is taken which has greater strength than soil.

The tunnel construction method depends upon many factors such as depth of the tunnel, ground condition, length and diameter of tunnel drive and groundwater condition, etc. Various innovative excavation method of tunnel construction is used which are given below:

- **Cut and Cover method-** In the cut & cover method, excavation takes place from top to bottom starting from the basement of the tunnel to the desired elevation. Afterward, back-filling of the foundation pit to restore the ground is carried out. This method is primarily chosen, when there is no restriction on the ground traffic movement, and environment as construction can be achieved as and when desired. It is to be avoided when there is a primary traffic route as it will block the same for a long time.
- **New Austrian Tunneling Method (NATM)-** This method is the application of the theory of rock mechanics based on maintaining, and employing surrounding rock's self-supporting capacity. The surrounding rock acts as the primary support system. The construction process involves 6 steps, i.e. the positioning of the line; boiling, loading and blasting; dust removed with a ventilation; anchor and support for the steel arch followed by reinforcement of the mat; a short construction to form the first bracing. The main advantage of NATM is the elimination of supporting material as it makes use of the surrounding structure extensively. Another important trait of this method is its low cost. Tunnel building in weak surrounding rocks, shallow tunnels, and poor geology conditions, can all benefit from this strategy.
- **Tunnel Boring Method**- A shield and a trailing support mechanism are included in a TBM**.** Excavation of soil at the front face of the tunnel is done using a shield and excavated waste is removed through machinery as either slurry or left as it depends on TBM types. To build tunnel lining, an erector is utilized to pick up precast concrete segments and position them in the correct area. The shield method is executed in five steps which are listed as exhuming foundation pit or constructing vertical shaft at both starting and tunnel end, soil excavation; TBM advancement and correction to deviation; assembling the lining material; pressing the lining material.

If a tunnel is to be built for a highway, various methods are used around the world, including the Mining method, the Shield method, and the Immersed tube method (He, Wang 2013). The drilling and blasting excavation method are used in mining.

There are several excavation methods available, including full face excavation, and bench cut methods. The surrounding rock mass was made more stable as a result of these methods. The Norway Tunnel Method (NTM) (Barton et al. (1974); Barton et al.,1992 is another advancement in tunnel construction technology that is complementary to the NATM. The rock classification system is the main difference between NTM and NATM. Q- System of rock classification is used in NTM. Immersed tube tunnels are commuting carrier tunnels that dig a groove beneath the water of the sea, river, or channel through which the tunnel will be built. Sections are floated onto the site, and the related structure is required to integrate each segment into entire traffic and finally build roads (Wang, 1997).

Three types of loads are exposed to tunnels that must be considered during the design of the lining material and the permitted settlement according to guidelines.

- The static load is caused by Rock or Soil overburden mass.
- The dynamic load caused by heavy vehicle, metro rail, or mechanical movements.
- The impact load generated due to Blast & earthquakes.

The tunnel lining material experiences bending moments, shear forces, and normal forces as a result of these stresses, which might be compressive or tensile. The geometry, deformation, and stress at the tunnel's periphery determine the nature of these forces in the end. In some circumstances, excessive deformation can cause accidents or even super-structure settlement, and structures can eventually collapse. Hence, in this research, investigation of deformation has been carried out at a different location of the tunnel for different cross-section shapes of tunnel considering Circular, Horseshoe, Box- shape, Semi-ellipse.

Another aspect is to assess the tunnel's stability depends upon relative position of the tunnel and the construction procedure adopted. There are numerous ways to construct the tunnels such as the cut cover method, sequential excavation method, boring technique using TBM, etc, which has been already described briefly. The tunnel’s cross-section may be circular, Box shape, Horseshoe, semi ellipse, arched, multi-curve. Hence, appropriate tunnel analysis is very imperative. Tunnel analysis includes different approaches such as analytical approaches, observation approaches, physical modeling, numerical modeling & empirical approaches. Numerical modeling has been adopted for the stability analysis of tunnels. Some of the methods used in numerical modeling include the finite element method, the boundary element method, the discrete element method, beam element method. This research uses the finite element method for modeling of a tunnel in 3D to monitor the deformation in different cross-section of tunnels which has been excavated in rock mass at shallow depth. Finite element based software ANSYS Inc. is used for analysis of tunnel behavior under static load. A parametric study was conducted by taking various cross-section shapes of shallow tunnels and % change in load value. The load has been applied as UCS of rock mass at top of the tunnel through a steel patch. Finally, a comparison analysis is carried out to identify which type of tunnel section is most suitable for rock mass under static loading.

1.2 Objectives of the research

1. To study the effect of varying overburden pressure on different shape of lined and unlined tunnel.
2. To study the deformation behavior of different shape of unlined and lined tunnel.
3. To know the what is the best shape for lined and unlined tunnel.
4. To investigate the critical zone in different shape of lined and unlined tunnel.
5. To study the deformation behavior of lining of different shape of tunnel.

CHAPTER 2 LITERATURE REVIEW

Pandit, et al., 2021 conducted stability analysis with uncertain rock mass properties for tunnel support system. Random field, Deterministic, and random variable approaches analyze a horse-shoe shape tunnel driven in surrounding weak rock mass. The montecarlo simulation is carried out a random finite difference analysis. The scale of fluctuation ratio for random field were varied to investigate their impact on tunnel performance and failure mechanism. It was observed that the tunnel support system's performance is underestimated by the random variable approach.

Dhammne, et al., 2021. did physical modelling on D-shaped shallow tunnels in order to better understand a tunnel behavior under high impact loading rates. For tunnel modeling, geometrical and Plaster of Paris is considered as rock mass with three different cover depth, and numerical model is validated with the help of experimental result. It was observed that excessive deformation occurs in the lowest cover depth of tunnel, and influence zone or area through which cracks propagate is less.

Zaid, et al., 2021 have performed a numerical study of Himalayan rock tunnel under static, and blast loading conditions. They considered shape of tunnel i.e., circular, arch, rectangular, and horseshoe for 3D modeling using ABAQUCS software, and in three distinct types of rocks, the response of each tunnel has been observed..It was detected that under blast loading condition, Arch shape tunnel is the most secure amongfour tunnel. However, Circular shape of arch tunnel provide maximum resistance under static load.

Yu, et al., 2021. perposed a novel semi-supervised framework to predict rockmass type a head tunnel face.A feature extractor and a feature classifier are used in semi-supervised frame work, and based on the profound neural network and geological characteristic labelled to carryout the rock mass prediction is obtained a feature classifier. It is found that in comparison with current supervised soft method, perposed semi supervised method predicts rockmass types a head of tunnel face more accurately.

Forsat, et al., 2021 have perposed a 3D model to predict the ground movements in single and twin metro tunnel and also simulated the impact of EPB-TBM effective parameter on surface setlement during excavation.The preliminary findings indicated that the ground settlement behaviour was appropriate. The shield's tail had the most colonies, which were greater in the single tunnel than the twin tunnel.

Pabodha, et al., 2021 have investigated the surface settlement on twin tunnel in clay, and earth pressure and blanced shields scheme was used to predict the surfacesettlement on twin tunnel. The impact of the parameter of four sheild operation on surface settlement of twin tunnel have also investigated and it was found that profile of total settlement over twin tunnels have an inverted biomodal shape.

Srivastav, et al., 2020 have performed numerical analysis to study the impact of earth quakes on circular tunnels in various rock-mass. Using the phase 2 software, the effects of earthquakes on the circular tunnels were examined using a pseudo-static approach. The axial force of the liner and its net increase as a result of seismic loading, referred to as a seismic axial force, increase as the rock mass quality decreases according to the study, while seismic load remains constant.

Zaid, et al., 2020 performed finite element modeling to investigate the behavior of unlined and lined circular tunnels under litho- static pressure. The weathering effect on the deformation and stresses was simulated for various rock mass. For simulation work, FEM tool ABAQUCS is used. As the weathering indices of the surrounding rock mass increased, substantial deformation was detected even with extremely modest magnitudes of applied stress.

Chai, et al., 2021 have done plain strain finite element analysis of deep tunnel in an under consolidated clayey deposit, and first, analysis was carried out usingFEA in under-consolidated deposits clay and a satisfactory agreement between simulated retaining wall and lateral displacement of measured was achieved. Second, the deposit was subsequently subjected to another FEA, this time with the premise that it was in a typically consolidated form. They have found that, when compared to the numerically consolidated case, maximum displacement of contiguous pile formed retaining wall is 25% increased, and 32% increased in bending moment in the wall and twice as much surface settlement as there is behind the wall.

Poovvizihi, et al., 2019 examined the current risk &the safety management system on metro tunnel in order to identify the risks that may occur during the process of construction period. In view of the natural uncertainties of the ground conditions, they proposed that a new model for the risk & safety management in the Metro project is necessary, so that it is not designed according to the surface conditions.

Nematollahi, et al., 2019 have investigated a pile tunnel interaction using three-dimensional numerical model. A finite difference technique was used to model all of the mechanized excavation phase of an EPB-TBM as well as the segmental lining. They used Mohar-Coulomb and Cap-Yield constitutive model for analysis of ground settlement and force in tunnel and piles. It is found that mohar-coulomb model does not effectively predict settlement and forces in the tunnels and piles than Cap-Yield model.

Jose et.al, 2018 depicted the effect of blast on the different cross-sectional shapes of the tunnel using Ansys and have concluded that the box shape tunnel is more resistant to demolition than the circular tunnel and less resistant than the semi-ellipse tunnel.

Dhamne et al.2018 conducted a numerical study of Blast and Impact loading on the Cross-Sectional Shape of the shallow tunnels. Circular and D-shape sections are considered for analysis purposes and they have concluded that both the shape having maximum deformation when subjected to blast loading and concrete lining of Circular Shape experiences minimum deformation as compared to D-shape tunnel.

Mishra et al. 2017 scrutinized the effect of dynamic, and static loads on the circular tunnel. They experimented with the effect of cover depth, overburden pressure, and rock mass strength on the tunnel, and have concluded that fracture zone’s radius decreases as the material's brittleness increases and the fracture tunnel crushed when subjected to dynamic loading with a high velocity of impact. A tunnel with a shallow depth will have more deformation and a shorter crack length.

Liu et.al., 2009 investigated subway structures subjected to blast loading in 2D& 3D tunnel models to examine the response of an underground structure subjected to subfield explosions in the soil medium. The general characteristics of the resulting explosion were discussed and the precision of the 2D &3D model was evaluated. The 2D model was able to predict the soil medium's blast wave with acceptable accuracy. They also found that a 2-dimensional model can be used to accurately predict the load of blast and front wall response in structures of the subsurface.

Khadka et.al., 2016 investigate stress and deformation behavior in 2D & 3D tunnels in weak rock and very weak rock mass subjected to overburden pressure. They concluded that the effect of tunnel face advancement is well described by the 3D analysis as compared to the 2D. Stress paths by 2D analysis are linear and are not able to predict the state of stress at a different location during tunnel advancement.

Zhu, et al., June 2015 conducted a numerical and experimental study of uncracked and cracked tunnels and found the principal stress effect in the tunnel when subjected to stresses and concluded that instability occurs in the unlined tunnel due to change in orientation of the principal stress.

Xiang & Yang, 2017 investigated the spatial response in the submerged tunnel due to dynamic impact loading. They concluded that cable hydraulic strength and tilt angle have an imperative effect on maximum displacement.

Ng et al 2018 investigated the effect of an existing tunnel of the horse-shoe cross-section on crossing tunnels of circular sections. They concluded that, in comparison to the crossing tunnel, the present tunnel has significant distortion due to the construction of the crossing tunnel beneath the existing tunnel.

Khan, et al., 2015 conducted the numerical analysis of the different shapes of the 2D tunnel in fractured and unfractured rock mass tunnels and concluded that horse-shoe tunnel is the most appropriate section from a vertical stress point of view and semi-circular is the most appropriate tunnel from a deformation point of view in unfractured rock but in fractured rock semi-circular is the most appropriate section from both point of view.

Naqvi et al 2017 investigated the effect of joint orientation in a rock mass tunnel under static and dynamic load. They concluded that 90 dip joints produced maximum surface settlement which can be damaged the ground structure and also found that the range of 30-45 dip angle produced the safer result.

Sharma, et al. 2018 investigated the influence of cover depth on tunnel lining when subjected to impact loading. They concluded that tunnels experience excessive deformation at the lowest depth and lining material is more likely to break at the lowest depth.

Kumar, et al., 2019 investigated the behavior of deformation in the tunnel under different loading and they concluded that stability of tunnel affected due to overburden pressure, type of soil, discontinuities or joint present rock, construction procedure, the relative position of tunnels, and also found that stress distribution depends also upon radial stress, tangential stresses, and shear stress.

Sagong, et al., 2011 conducted experimental and numerical study of a rock opening undergoing biaxial compression considered the joint set of a dip angle of 30, 45, and 60 for horizontal analysis and initiation, and propagation of tensile cracks around the circular hole were simulated. They concluded that area of damage around the hole increases with the joint angle decrease. A high joint angle rock model causes abrupt propagation, and initiation of tensile crack.

Vishnumaya, et al., 2019 conducted the study of stability analysis of a tunnel in soft ground and also investigated the effect of change in diameter of the tunnel. They concluded that the least deformation and stresses are obtained at the large diameter of the tunnel.

Marshall et. al., 2012 studied the influence of tunnel depth, tunnel size, and volume loss on the morphology of surface settlement in dry sand with relative density as 90%. They concluded that, mobilized shear strain decreased and the width of settlement trough increased when cover depth to diameter ratio of the tunnel increased.

Mohammad, 2017 investigated the effect of internal and seismic loads on the stability of circular tunnels at different depths using a response spectrum. He simulated the static and dynamic behavior of circular tunnels and compared the results in stresses, forces, displacement, and bending moment which is acting in tunnel lining. He concluded that due to static load, displacement in tunnel periphery is changed and deformation in the tunnel to the down is more than to the upside. Hence, the balance is disrupted, and potential of instability increases for underground structures, dynamic stress is less than that on the surface structure.

Shirinabadi et al 2016 investigated the behavior of the twin tunnel of Shiraz metro under static and dynamic load. They concluded that after excavation of the tunnel Under dynamic load, the unbalanced force is greater than under static load. The tunnel roof has a greater variation in displacement and velocity than the rest of the tunnel, when static loads are applied to tunnel. After applying the dynamic loads, variations in tunnel bottom have a higher displacement and velocity than the rest of the tunnel.

Singh, et al., 2018 did a stability analysis of the twin tunnel. They investigate the role of spacing amid twin tunnel and diameter of tunnel on its stability using the Finite Element Method. They have been taken a total of ninety simulations in their investigation. In the simulation, they took twin tunnel diameter from 2m to 10 m and spacing between twin tunnels 0.2 to 2 times of diameter. They concluded that a minimum distance between tunnel diameter should be 0.8 times diameter of tunnel, and they also found that large diameter tunnel affects near field, as well as far-field but tunnel of small diameter, affects only near field.

CHAPTER 3 METHODOLOGY

3.1 General

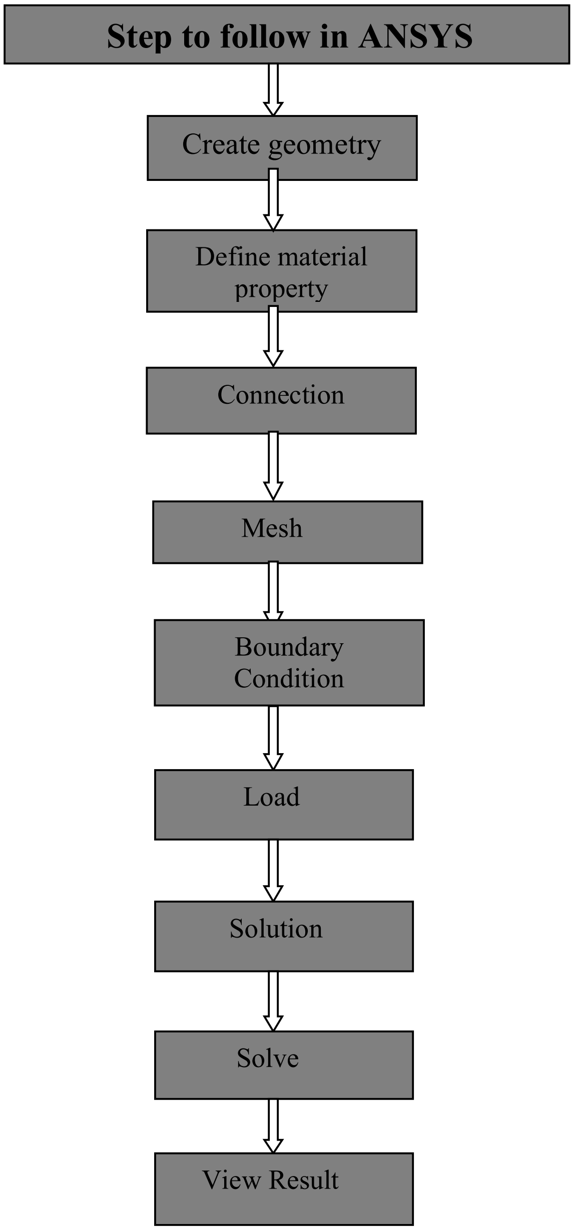
In the present research, numerical modeling of three-dimensional rock tunnel considering Circular, Horse-shoe, Box-shape, and Semi-ellipse tunnel has been performed in ANSYS Inc. numerical tool which is FEM based tool for modeling and visualization of the analysis. The numerical analysis is separated into two-part, each with its own set of results and conclusion as well as a detailed project work.

1. In the first part of the project, the first numerical analysis is conducted to validate the result from circular tunnel model of the literature (Zaid, et al., 2020).
2. After completion of the first part of the project, numerical analysis is conducted to find best shape of the tunnel from different cross-section shapes of the shallow tunnel which resist the effect of static load where geometry and meshing related data are shown below.

To properly comprehend the three-dimensional effect of the 3D FE model of weak rock and the tunnel assembly has been shaped using the static structure analysis option in ANSYS software. The rock mass is assumed homogeneous, isotropic, continuous, and semi-infinite. 3-D finite element models of rock mass having the size of 0.30 m × 0.30 m× 0.35 m with unlined and lined tunnels having a constant cover depth of 0.05 m are used (Zaid, et al., 2020). The load is applied in the form of the unconfined compressive strength of rock. The Mohr-Coulomb plasticity model is used for surrounding rock mass analysis. The plasticity theory assumes that the rock may be modeled as an elastic-plastic solid. To describe the yielding and strength of rock under a general loading condition, a great range of approaches have been presented. Few methods or approaches are widely used in geotechnical analysis. These models are based on yield criteria proposed by Tresca (1864), Mohr-Coulomb (1773), Ducker and Prager (1952), Tresca (1864), Lade and Duncan (1975), Hoek and Brown (1980). Mohr-Coulomb model is applied for elastic-plastic analysis in this investigation because it is simple and easy and the property was available for this model, which was taken from literature of Zaid et al 2020.

3.2 Analysis Procedure

All simulation models were created using the same fundamental procedure. The chronological sequence of the following event is shown below:



3.3 Geometry

The response of rock mass in different cross-sectional shapes of the tunnel, when subjected to litho-static pressure, was studied using finite element software ANSYS. A model of the tunnel was created using a 3-D design modular. The model was 0.30 m × 0.30 m ×0.35 m with a tunnel diameter of 0.05 m. The thickness of the lining with concrete property has been considered as 0.0017 m. A cylindrical patch of 0.05 m diameter, and 0.05 m height was created at the center of a tunnel. The geometry of the Geo material model with circular cross-section has been adopted from Zaid et al 2020. There are four different cross-section shapes of the tunnel is considered for numerical investigation. These cross-sectional shapes are Circular, Horse-shoe, Box shape, Semi-ellipse. All shape of the tunnel is represented by fig. 1.

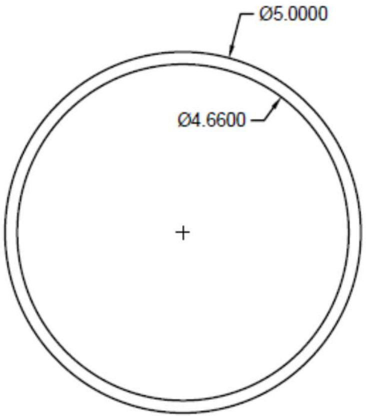


Fig (a) Circular shape

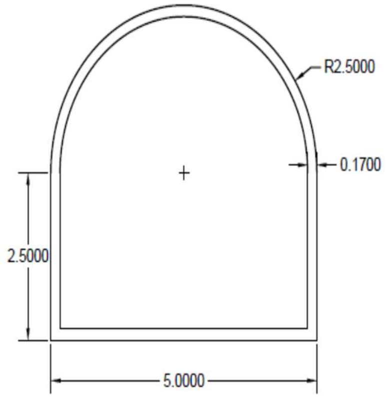


Fig (b) Horse-shoe shape

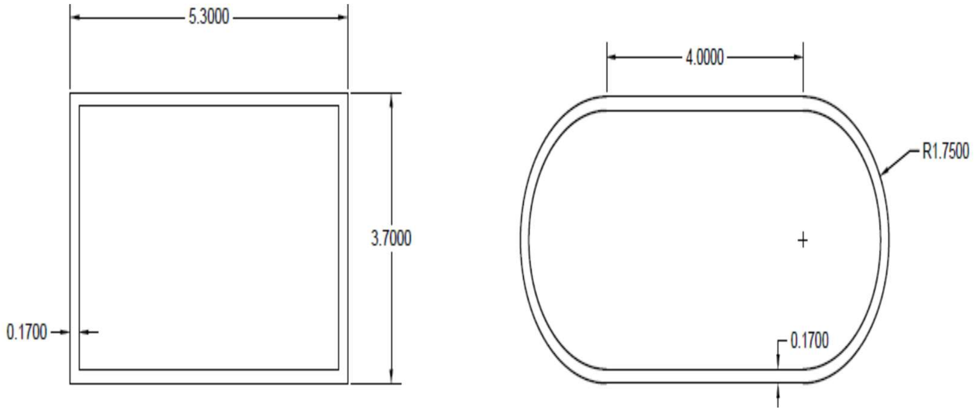


Fig (c) Box shape Fig (d) Semi-ellipse

Figure1. View of model geometry of all sections (dim in cm).

3.4 Input Parameter

3.4.1 Property of steel Patch

A steel patch is used through which a load is exerted as a form of pressure on the middle of tunnel. When a load is applied to the patch, it moves downwards due to which distortion is created on the tunnel. This steel patch is a cylindrical shape. Hence, the property for the cylindrical patch is given in Table. 1. This is adapted from the research paper (Zaid, et al., 2020).

TABLE 1 PATCH SPECIFICATION

S No	Parameter	Value	Unit
1	Mass Density	7800	Kg / m^3
2	Poisson ratio	0.30	-
3	Modulus of elasticity	210e03	MPa
4	Tensile strength	250	MPa

3.4.2 Property of Material

For the elastic-plastic behavior of rock, the Mohar-Coulomb model is used in this numerical investigation. Bray (1967) proposed a theoretical model which states that stress developed exceeds the yield strength in the case of soft and weak rock. Hence the formation of both elastic and plastic zone developed and the yield zone is developed in the plastic zone. So, for the investigation of the surface-laid tunnel in surrounding weak rock, elastic-plastic analysis was done. In the analysis, the elastic property is assigned to lining and hammer. Some properties like the angle of internal friction, cohesion, dilatation angle is implemented in plastic analysis. Dilatation angle is assumed to be zero in this analysis. Young modulus, density, and Poisson ratio are considered for elastic analysis. Concrete as a material property for lining is considered. Material property for Geo-material (sm1) has been taken from Zaid et al. 2020, which is listed in Table 2 (Zaid, et al., 2020).

Table 2 Index Property of Rock mass

Material type	Mass Density (kg/m^3)	Young Modulus (MPa)	Poisson Ratio	Friction Angle	Cohesion (MPa)	UCS (MPa)
Geo-material (sm1)	1410	3150	0.16	42	1.81	4.48

3.5 Details of Meshing

Meshing is the most important part of modeling. Meshing size has been adopted for Circular, Horse-shoe, Rectangular, Semi-ellipse model as 8mm. This is taken after the mesh convergence study. The meshing of all components of the model and each shape of the tunnel is shown in figure 6. The steel Patch and tunnel lining have been meshed by 6mm and 4mm respectively and, other details of meshing are shown in table-3

Table 3 Meshing Details in 3D analysis

Tunnel section & Component	**No of elements**	**Element shape & type**
Circular	60016	Linear hexahedron(Hex)
Horse-shoe	63536	Linear hexahedron(Hex)
Rectangular	62524	Linear hexahedron(Hex)
Semi-ellipse	31010	Linear hexahedron(Hex)
Steel Patch	4000	Tetrahedrons

Tetrahedrons type meshing is also given to concrete lining. The geometry of tetrahedron mesh is like a triangular pyramid, which is composed of six straight edges, four triangular faces, and four vertex corners. Hexahedron is also known as a hex or a brick. The geometry of hexahedron type mesh is like a topological cube, which is composed of eight vertices, twelve edges, and six quadrilateral faces.

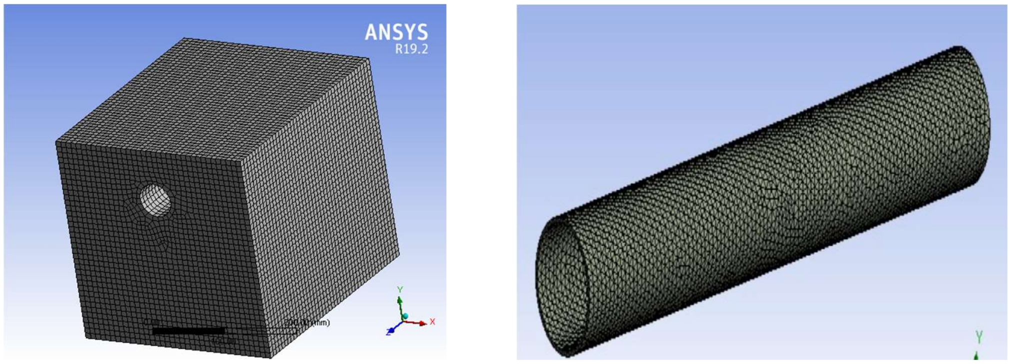


Fig (a) Circular tunnel with lining

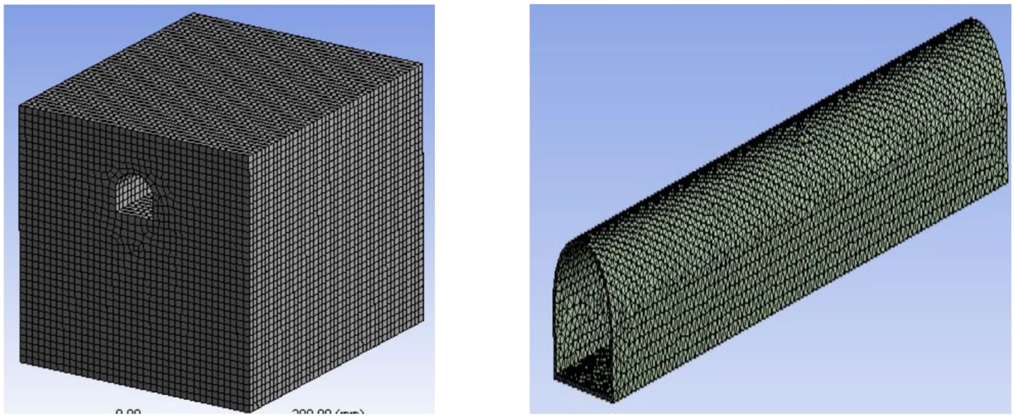


Fig (b) Horse shoe tunnel with lining

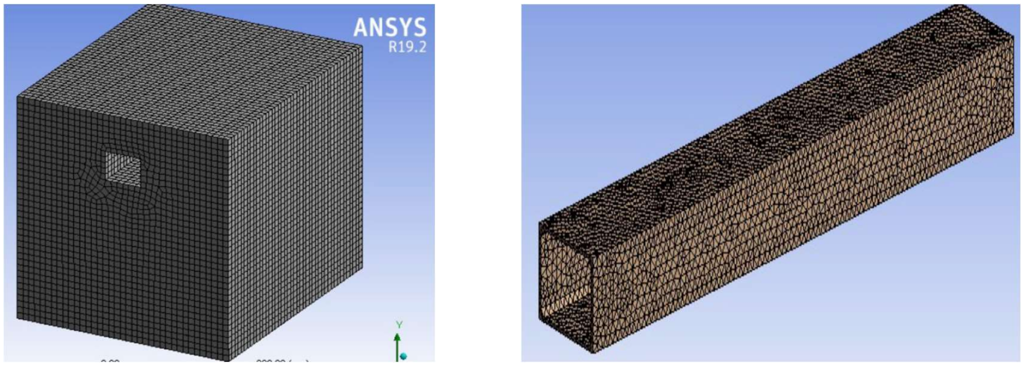


Fig (c) Box shape tunnel with lining

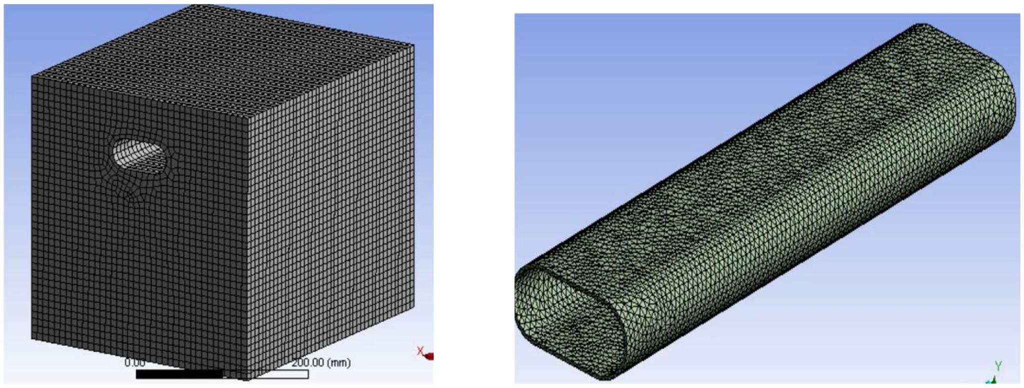


Fig (d) Semi-ellipse tunnel with lining

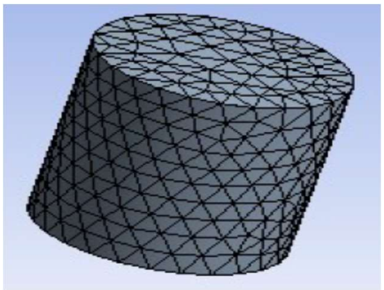


Fig (e) Meshing of Cylindrical Patch

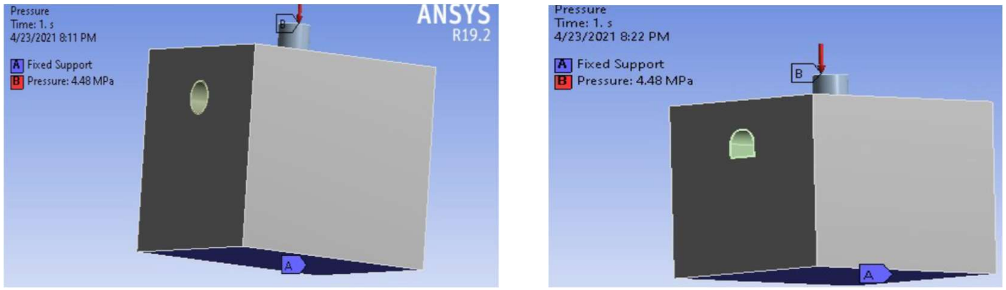
Figure2. Meshing view of an individual component of tunnel assembly

A mesh convergence study has been performed for tunnel assembly of 0.05 m cover depth under static loading. Based on the mesh convergence study, it is discovered that a finer mesh size has less of an impact on tunnel deformation. A Mesh convergence study has been performed on circular tunnel assembly to correlate it with another shape of a tunnel.

3.6 Load setup and Boundary condition

Load is applied to the top of the steel patch in the form of the rock mass's unconfined compressive strength (UCS). The steel patch is placed in the middle of tunnels and loads act through this patch on the tunnels. For analysis same UCS value is considered for all types of tunnel models.

The tunnel model is considered as fixed at bottom but free on sides so that displacement at the base in all directions is equal to zero. The view of load setup, and boundary condition assembly of all tunnels model are presented below in Figure. 3



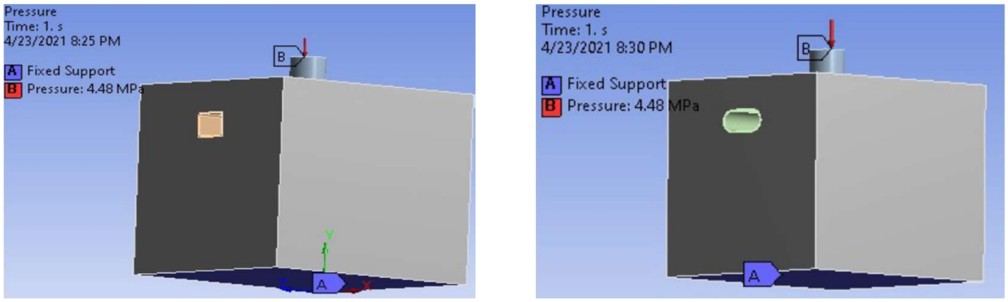


Figure 3 View of boundary condition and load setup of each tunnel assembly

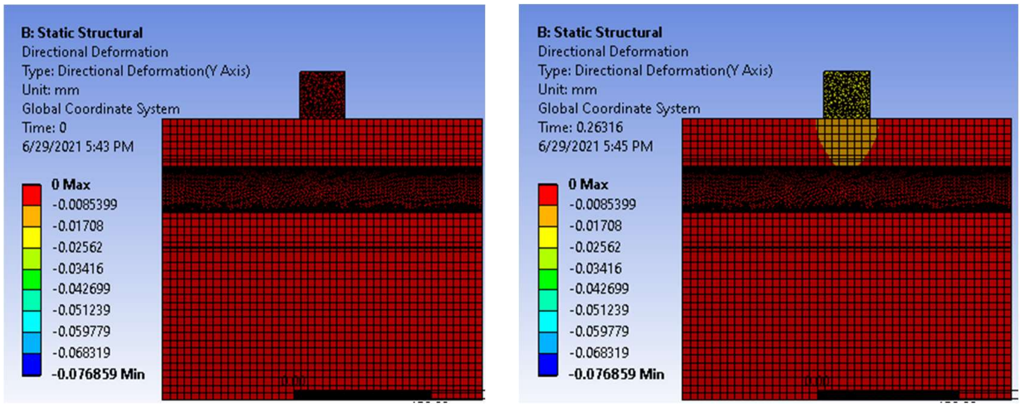
In this study, a cylindrical patch was used in analysis with 0.05m height and 0.05m diameter for loading purposes. When the load is acted on the top of the steel patch then the patch moves downward which distorts at the top of the tunnel. To study the deformation behavior of rock mass, different zones along tunnel length are shown in Table 4 (Zaid, et al., 2020).

Table 4 Different Zones along tunnel length with their distances

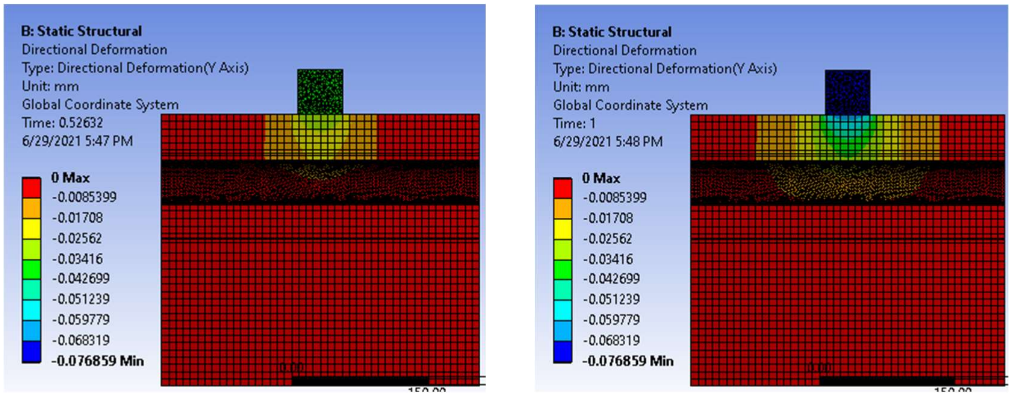
Zones	L1	L2	L3	L4	L3’	L2’	L1’
Distance	0	11.670	14.583	17.50	20.417	23.33	35

3.6.1 Contour view of deformation with time

For numerical simulation, the entire phenomenon was investigated, and the results were acquired using 200 frames. When the load is applied to the steel Patch, depression forms at the top of the tunnel. So, a portion of time with deformation has been captured and categorized into four different stages. Contour plots of deformation for all shapes of the tunnel at various stages have been depicted.



i. Stage 1 ii. Stage 2



iii Stage 3 iv Stage 4

Figure 4 Contour Plot of Deformation at Four Stages along the Tunnel axis.

CHAPTER 4 RESULTS AND DISCUSSION

In the present investigation, an effort is made to comprehend tunnel damage behavior under static loading conditions to simulate deformation profile.

So, in this chapter, the behavior of top surface tunnel lining for different cross-sectional shapes surrounded by weak rock are compared numerically and analyses the results obtained from this study.

The deformation of the crown just below the steel patch is highest. Hence, deformation of the top surface of the lined and unlined tunnel of different cross-sectional shapes considered Circular, Horseshoe, Box shape, semi ellipse under static loading surrounded by weak rock has been prepared using the design modular option in Ansys.

The result of this thesis is validated by the research paper of Zaid. et al 2020. Hence, the deformation value of unlined circular tunnel including each value of UCS is considered for validation purposes.

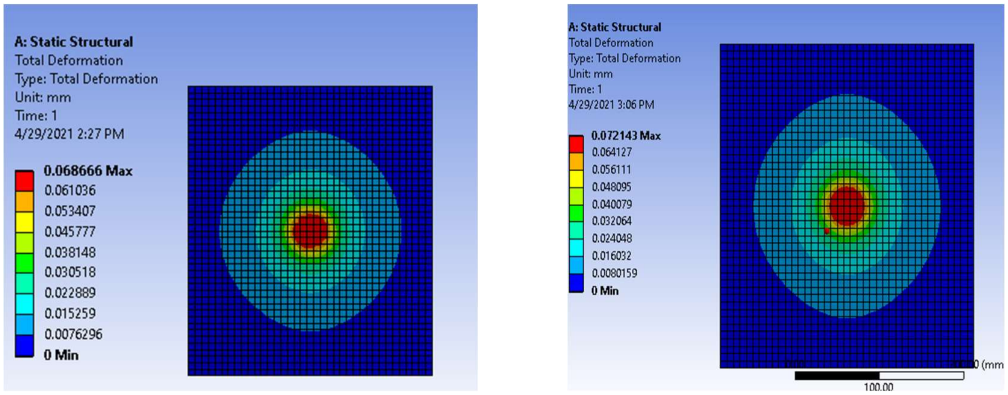
Table 5 Comparison of result for validation

% reduction in UCS	**Deformation at crown (mm)**	
	Present Result	Zaid et. al 2020 Result
0	0.0686	0.0646
10	0.0618	0.0581
20	0.0549	0.0516
30	0.0481	0.0453
40	0.0412	0.0388
50	0.0343	0.0323
60	0.0275	0.0258
70	0.0206	0.0193
80	0.0137	0.0129
90	0.00688	0.00646

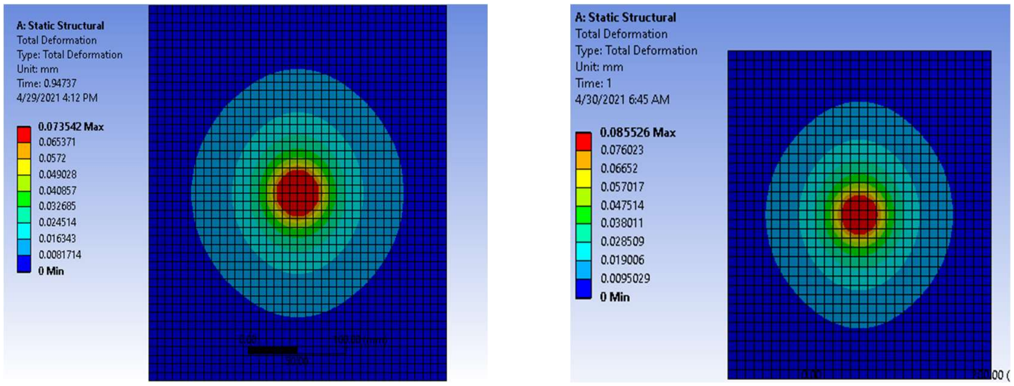
From table 5 it has been seen that in every case of loading for the circular unlined tunnel, results obtained from numerical analysis using ANSYS software have high value than the result obtained in the research paper of Zaid et al 2020. For unlined circular tunnel obtained deformation from ANSYS is 6% more with respect to a result of literature of Zaid et. al. 2020. However, for a circular tunnel under static loading conditions result shows minimum error, which is under the permissible limit. So parametrically study may be done numerically considering the different shapes of tunnel and % reduction in loading.

Vertical Response

Maximum vertical deformation of the crown of the tunnel after static analysis is in fig. 5&6. Table 6 depicts the comparison of extreme vertical deformation for all shapes of tunnel considering Circular, Horse-shoe, Box shape, Semi-ellipse.

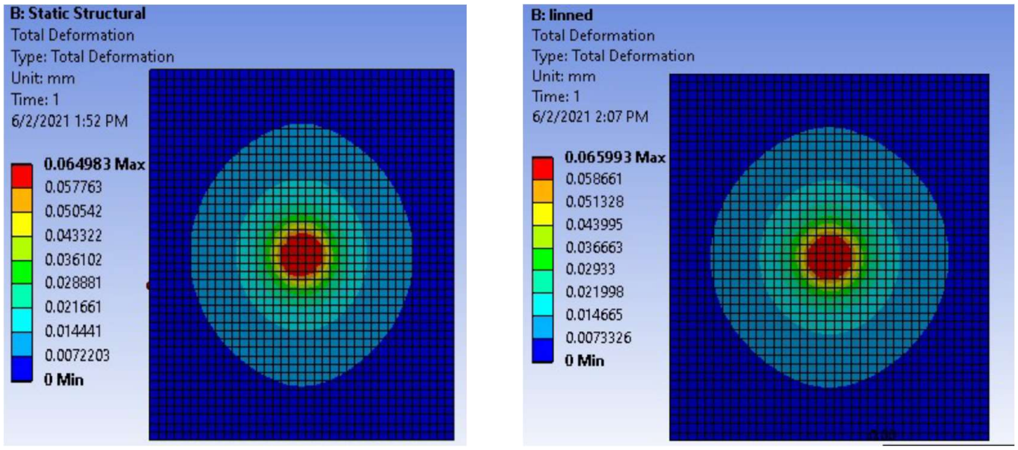


(a) Circular tunnel (b) Horse-shoe tunnel

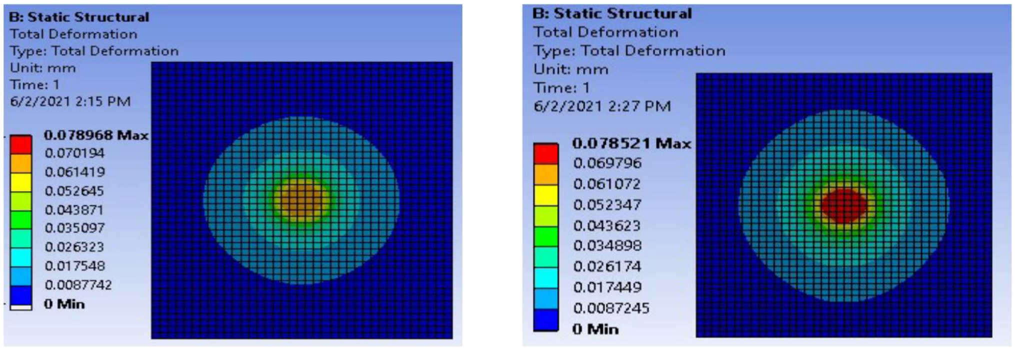


(c) Box shape tunnel (d) Semi-ellipse tunnel

Figure 5. Maximum deformation contour on the top of the unlined tunnel.

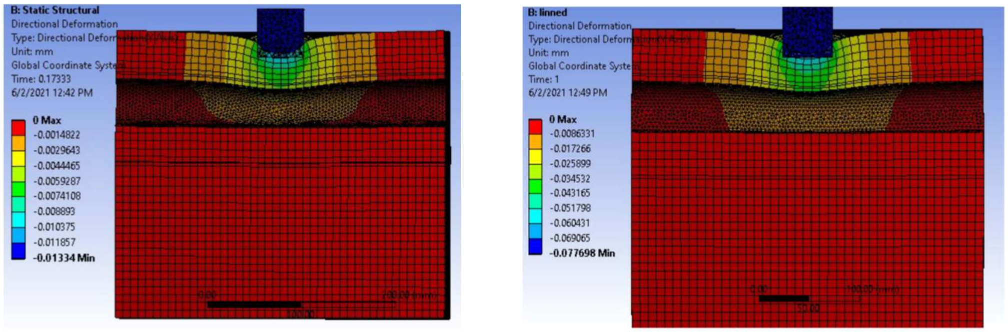


(a) Circular (b) Horse-shoe

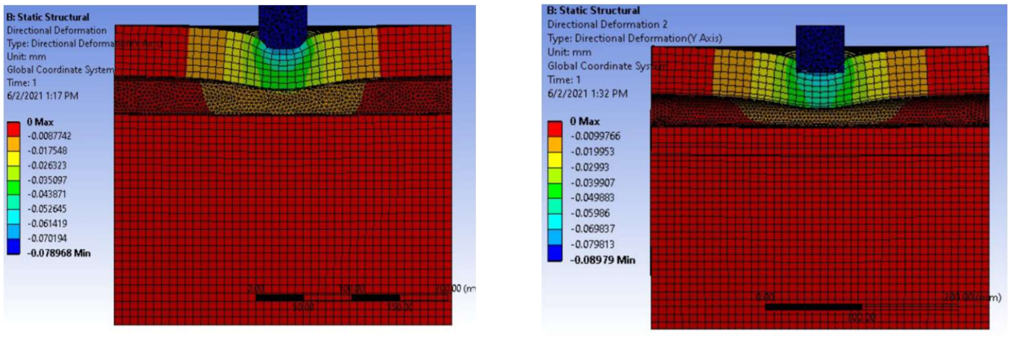


(c) Box- Shape (d) Semi-ellipse

Figure 6. Maximum deformation contour on the top of the lined tunnel.

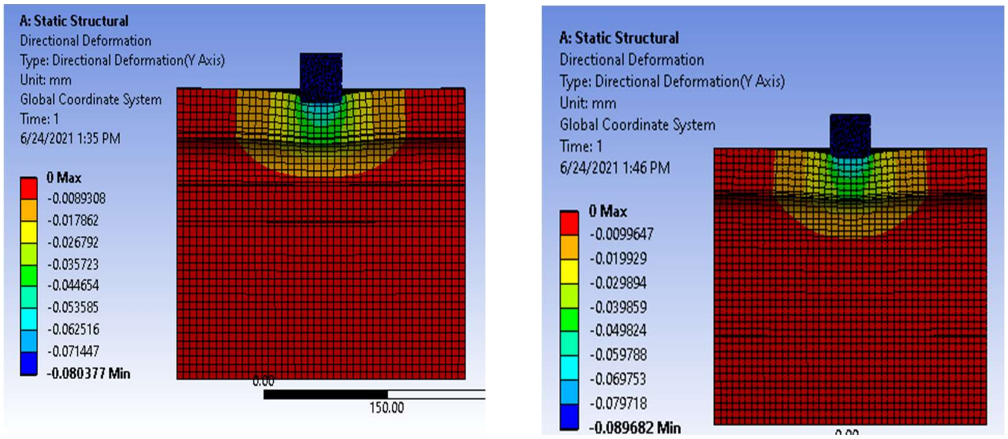


(a) Circular (b) Horse-Shoe

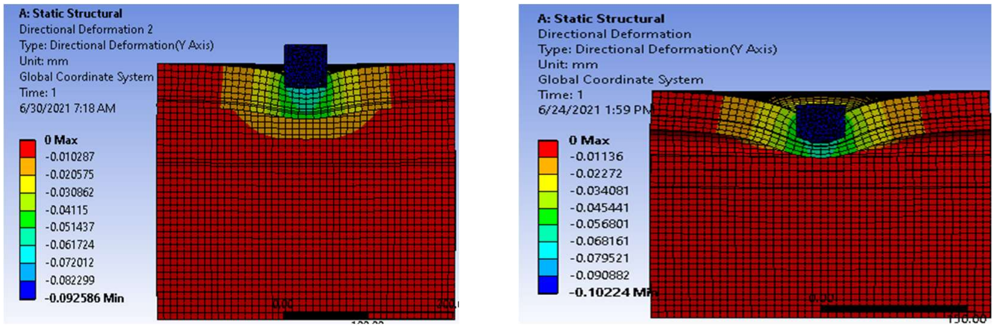


(c) Box- shape (d) Semi-ellipse

Figure 7. Deformation Profile of lined Tunnel along tunnel length



(a) Circular (c) Horse-shoe



(C) Box-Shape (d) Semi-ellipse

Figure 8. Deformation Profile of Unlined Tunnel along tunnel length

Table 6 Maximum Vertical Deformation in Tunnel

% reduction in UCS	**Deformation at the crown (mm)**							
	Unlined Tunnel				*Lined Tunnel*			
	Circular	Horse-shoe	Box-Shape	Semi-ellipse	Circular	Horse-shoe	Box-Shape	Semi-ellipse
0	0.0686	0.0721	0.0776	0.0849	0.0649	0.0659	0.0675	0.0785
10	0.0618	0.0649	0.0698	0.0765	0.0585	0.0594	0.0607	0.0706
20	0.0549	0.0550	0.0621	0.0680	0.0501	0.0528	0.0541	0.0628
30	0.0481	0.0505	0.0544	0.0595	0.0455	0.0462	0.0471	0.0550
40	0.0412	0.0433	0.0466	0.0510	0.0390	0.0396	0.0400	0.0451
50	0.0343	0.0361	0.0388	0.0425	0.0325	0.0350	0.033	0.0393
60	0.0275	0.0289	0.0311	0.0341	0.0260	0.0264	0.0272	0.0315
70	0.0206	0.0217	0.0233	0.0255	0.0195	0.0198	0.0200	0.0236
80	0.0137	0.0144	0.077	0.0170	0.0130	0.0132	0.0135	0.0157
90	0.00688	0.00720	0.00777	0.0856	0.00651	0.00661	0.00676	0.00787

From the table of the deformation for reducing % of UCS in case of the unlined and lined tunnel, it has been seen that, at certain % decrease in UCS for Circular, Box-shape, Horse-shoe, Semi-ellipse, rate of change in deformation become equal. It is found that UCS and deformation are linearly proportional to each other for both lined and unlined case.

Figure 9 and Figure 10 show the deformation along tunnel length just above the tunnel lining for 0% reduction in UCS.

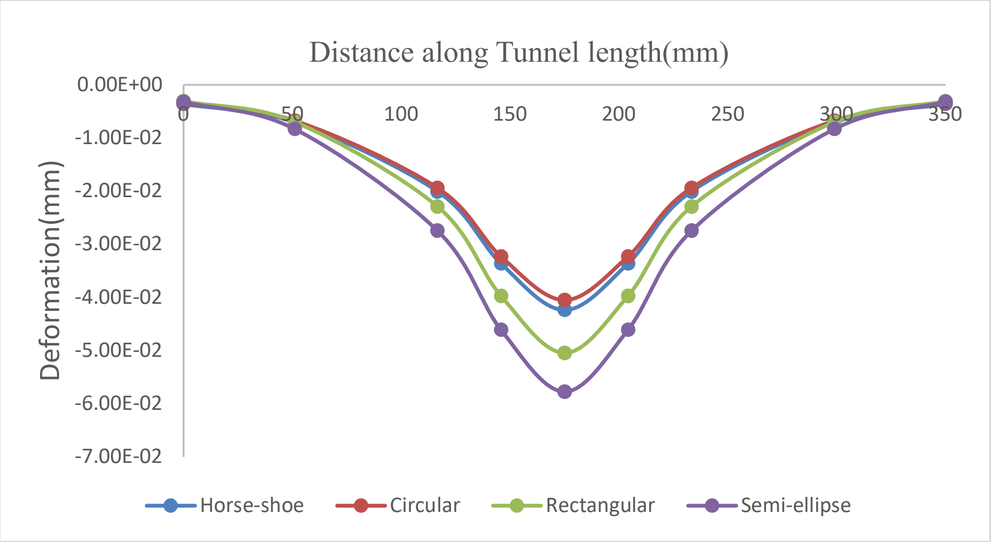


Figure 9 Vertical deformations along the length of unlined tunnel

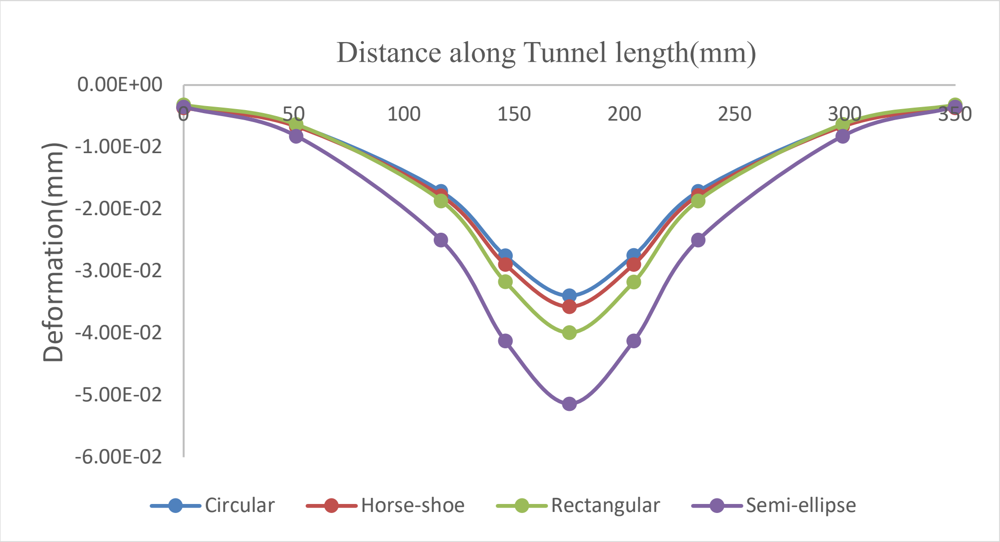
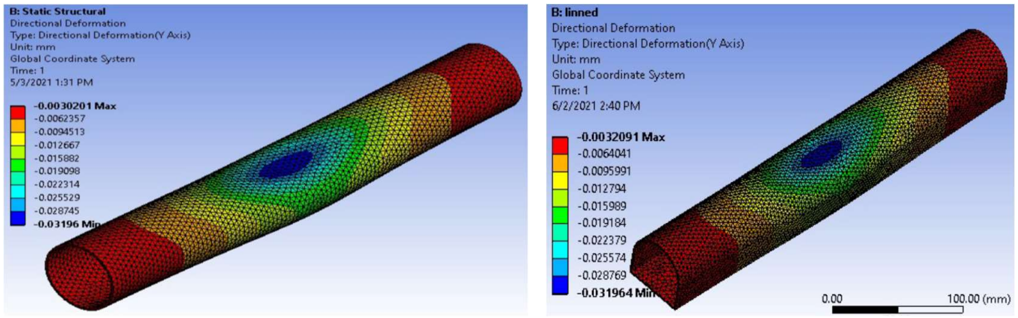
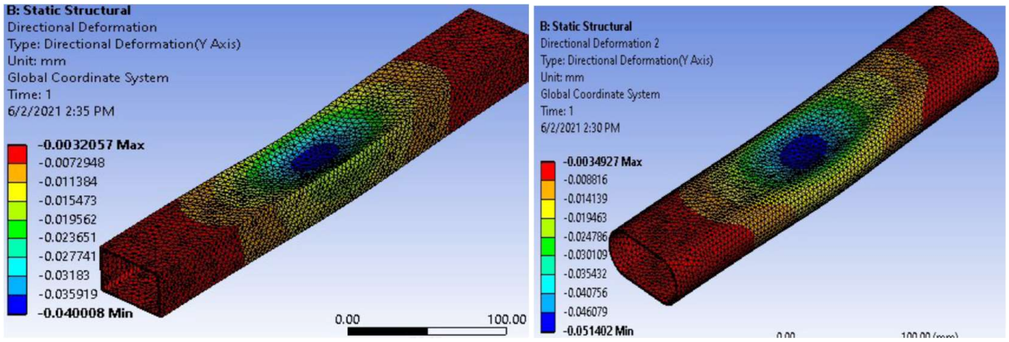


Figure 10 Vertical deformations along the length of the lined tunnel



(a) Circular (b) Horse-shoe



(c) Box shape (d) Semi-ellipse

Figure 11 Deformation behavior of tunnel lining.

From figure 11, it has been observed that for 0% reduction in UCS, negative sign indicate that tunnel lining is under compression. That means concrete lining behaves as a compressive member when subjected to static loading conditions.

Figure 12 and Figure 13 show the vertical deformation in the traverse direction of tunnel length for both unlined and lined case respectively, just above the tunnel lining for 0% reduction in UCS.

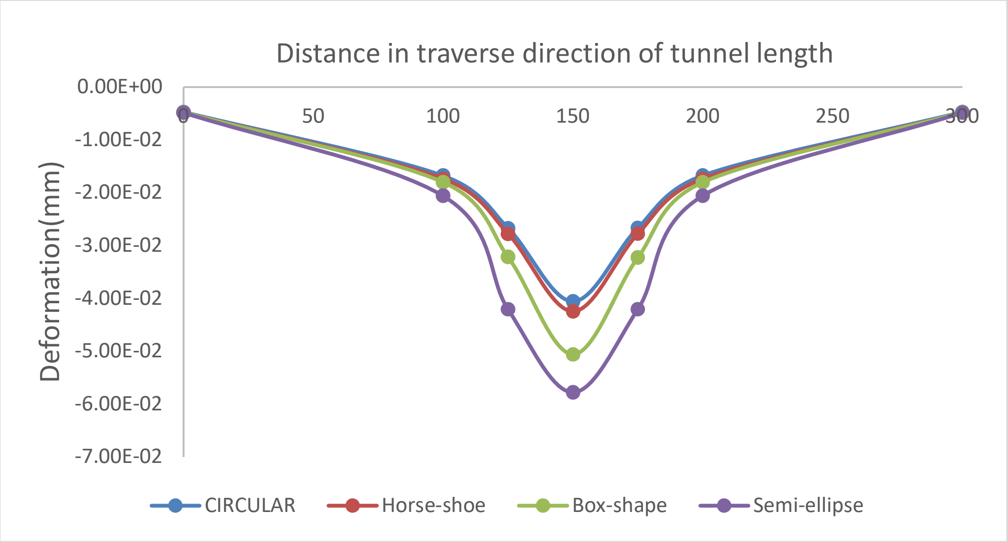


Figure 12 Vertical deformations in traverse of the length of unlined tunnel

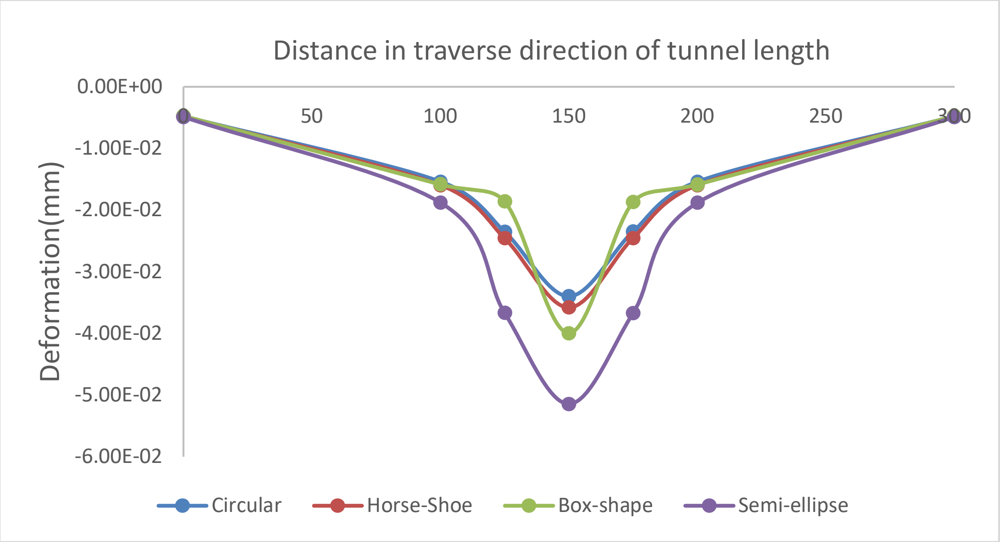
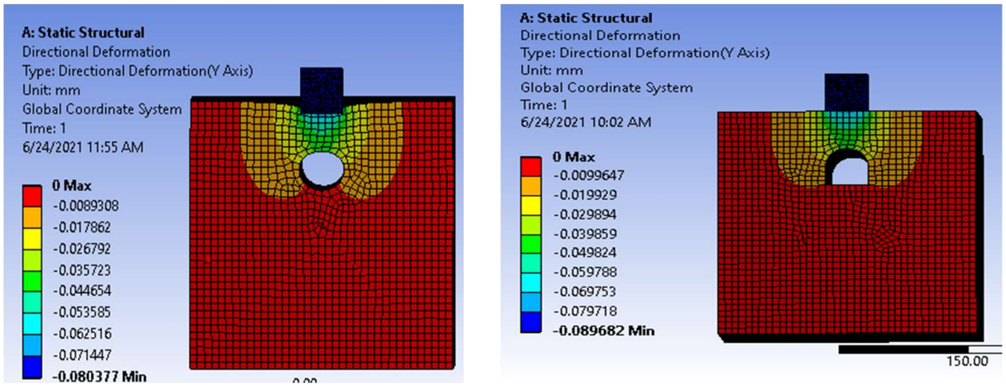
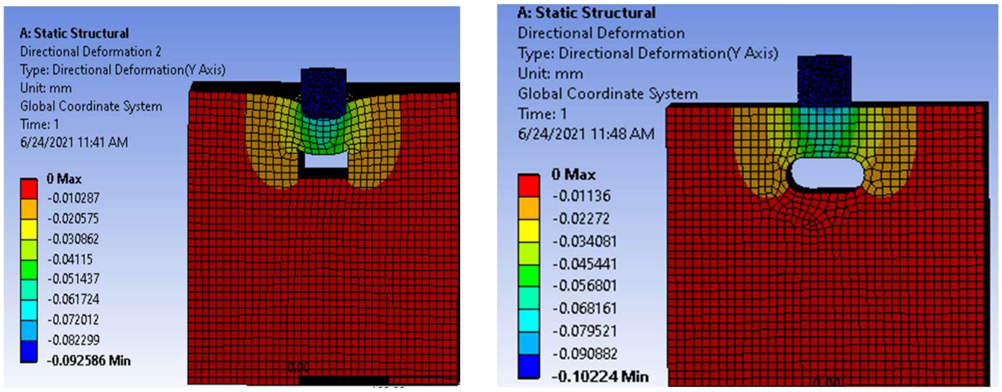


Figure 13 Vertical deformations in traverse of the length of lined tunnel



(a) Circular

(b) Horse-shoe



(c) Box-Shape

(d) Semi-ellipse

Figure 14 Deformation contour in traverse direction of tunnel length.

From above Figure, it can be seen that deformation contour formed from top to bottom due to movement of steel patch. At bottom, Tunnels do not go under deformation and deformation contour length is lower. That means lesser area experiences higher damage.

CHAPTER 5 CONCLUSION

Based on the above work, following conclusion have been made here-

1. In case of unlined tunnel, the maximum vertical deformation at the top of crown is 23.7%, 17.5%, and 9.4% higher in Semi-ellipse tunnel than Circular, Horse-shoe, Box-shape, respectively. Hence, the Semi-ellipse tunnel is the most unstable and circular is most stable shape among all the tunnel shape when subjected to maximum overburden pressure or static load.

2. In case of lined tunnel, the maximum vertical deformation at the top of crown is 20.9%, 19.11%, and 16.29% higher in Semi-ellipse tunnel than Circular, Horse-shoe, Box-shape, respectively. Hence, the Semi-ellipse tunnel is the most unstable and circular is most stable shape among all the tunnel shape when subjected to maximum overburden pressure or static load.

3. So, based on point of application of maximum overburden or static load, Circular shape is the best, and Semi-ellipse is the worst shape among all the tunnel shapes for both lined and unlined case.

4. After studying the deformation result, maximum vertical deformation at the top of the crown just below the load alignment is 70 % and 93.8% higher than deformation in the periphery just above the tunnel lining for unlined and lined circular tunnel respectively. Hence, the most critical zone is the top of the crown of the tunnel for each case, when subjected to overburden or litho-static pressure.

5. The vertical deformation profile of the lining can easily predict the nature of the failure of the lining. It was found that fractures of tunnel lining under overburden or static pressure are mainly due to compression.

REFERENCES

Chai, J.Weng,Q.,Yafei,Lu.,Bung,X. , 2021. Deep Excavation in Underground-consolidated clayey deposit. *Underground Space, 25 September, 06(04), pp. 455-468.*

Dhammne, R., Mishra, S., Kumar, A. & Rao, K., 2021. Deformation behavior of D-Shaped shallow tunnels under dynamic loading conditions. *Structures, October, Vol.33, pp. 3973-3983.*

Dhamne, R., Mishra, S. & Rao, S. K., 2018. Numerical Study of the Cross Sectional Shape of Shallow Tunnels Subjected to Impact and Blast loading. *Geophysics and Instrumentation, ISEC. Hyderabad.*

Forsat, M., Taghipoor, M. & Palassi, M., 2021. 3D FEM Model on the Parameters' Influence of EPB-TBM on Settlements of Single and Twin Metro Tunnels During Construction. *International Journal of Pavement Research and Technology.Vol.122.,1997-1400.*

Jose, J. & Verma, A., 2018. Numerical Study of the Cross- Sectional Shape of Tunnel Under Blast Effect Using Ansys.. *International Research Journal of Engineering and Technology (IRJET), May, 05(05), pp. 3582-3586.*

Khadka, S. S. & M., A., 2016. Comparative Numericla Study of 2D and 3D Finite Element Modeling of Hydropower Tunnel: Case Study From lesser Himalayan Region of Nepal. *Portugal, s.n.03*

Khan, I. A., Ventatesh, K. & Srivastava, R., 2015. Fractured and Unfractured Analysis of a Rock Tunnel by Finite Element Method., *IGS Chapter. Pune, Maharashtra*

Kumar, P. & Shrivastava, A. K., 2019. Deformation Behaviour of Tunnels under Different loading Conditions: State of Art., *Proceeding of the 4th World Congress on Civil, Structural , and Environmental Engineering. Rome,Italy*

Liu, H., 2009. Dynamic Analysis of Subway Structures Under Blast Loading. *Geotechnical and Geological Engineering, 17 September.27(699).*

Mishra, S., Rao, S. K., Gupta, N. K. & Kumar, A., 2017. Damage to shallow Tunnels under Static and Dynamic loading. *Procedia Engineering, 173(1877-7058), pp. 1322-1329.*

Mohammad, J. A., 2017. Numerical Modelling For Circle Tunnel under Static and Dynamic loads for Different Depth.: *17th International Multidisciplinary Scientific GeoConference , SGEM, Bulgaria 2017.*

Naqvi, M., Zaid, M., Sadique, M. & alam, M., 2017. Dynamic Analysis of Rock

Tunnels considering Joint dip angle: A Finite Element Approach. *Guwahati, 13th International Conference on Vibration Problem(ICOVP).Guwahati,India.29 Nov-2 Dec, 2017.*

Nematollahi, M. & Dias, D., 2019. Three-dimensional numerical simulation of pile-twin tunnels interaction –. *Tunnelling and Underground Space Technology, Volume 86, pp. 75-88.*

Ng, C., Fong, K. & Liu, H., 2018. The Effect of Existing Horseshoe- shaped tunnel sizes on Circular crossing Tunnel Interactions: Three- Dimensional numerical analyses. *Tunnelling and Underground Space Technology, 2(77), pp. 68-79.*

Pabodha, K., Kannangara, M., Ding, Z. & Zhou, W.-H., 2021. Surface settlements induced by twin tunneling in silty sand. *Underground Space, 21 May.6(4).*

Pandit, B. & Sivakumar Babu, G., 2021. Probabilistic stability assessment of tunnel-support system considering spatial variability in weak rock mass. *Computers and Geotechnics, September.137(104242).*

Poovvizihi, G. et al., 2019. Accident Analysis and Safety Measures at Erode City. *International Research Journal of Multidisciplinary Technovation (IRJMT), November, Volume 1, pp. 266-273.*

Sagong, M., Park, D., Yoo, J. & Lee, J. S., 2011. Exprimental and Numerical Analyses of an Opening in a Jointed Rock Mass under Biaxial Compression. *International Journal of Rock Mechanics and Mining Sciences - INT J ROCK MECH MINING SCI, 10, 48(7), pp. 1055-1067.*

Sharma, H., Mishra, S. & Rao, S. K., 2018. Effect of Cover Depth on Deformation in Tunnel lining when subjected to Impact load.Asian Rock Mechanics *Symposium(ARMS 10). At: Suntec City,November 2018.*

Shrinabad, R. & Moosavi, E., 2016. Twin Tunnel Behavior under Static and Dynamic loads of Shiraz Metro. *Journal of Mining Science, Vol.52, pp. 461-472.*

Singh, R., Singh, T. & Bajpai, R., 2018. The Investigation of Twin Tunnel Stability Effect of Spacing and Diameter. *25 May, 91(0974-6889), pp.563-568.*

Srivastav, A. & Satyam, N., 2020. Understanding the impact of the earthquake on circular tunnels in different rock mass: a numerical approach. *Innovative Infrastructure Solution, 03 March.Vol 5.*

Vishnumaya, P. & Vijayam, V., 2019. Stability Analysis of Tunnel Resting over a Soft Ground. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH,* 8(4).

Wang, J., 1997. *An Important Tool to Construct Under Water Tunnels, Segment Immersing Method. s.l.:Word Tonn.*

Xiang, Y. & Yang, Y., 2017. Spatial Dynamic Response of Submerged Floating Tunnel Under Impact Load. *Marine Structures, Volume 53, pp. 20-31.*

Yu, H. G. et al., 2021. Rock mass type prediction for tunnel boring machine using a novel semi-supervised method,. *Mesurement, July, Vol. 179, p. 109545.*

Zaid, M., Mishra, S. & Rao, K., 2020. Finite Element Analysis of Static Loading on Urban Tunnels. *Springer, singapore.*

Zaid, M. & Shah, I. A., 2021. Numerical Analysis of Himalayan Rock Tunnels under Static and Blast Loading. *Geotechnical and Geology Engineering, Springer.23 April, 1573-1529..*

Zhu, Z., Liu, Y. & Bang Liu, J., 2015. The Effect of Principal stress orientation on Tunnel Stability *Tunnelling and Underground Space Technology. Vol 49. pp. 279-286.*