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Analysing the Effect of Tunnel Construction on Existing Structure by Using Analytical and Numerical Method

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Abstract: ***Underground construction in urban areas is a challenging work to carry out and includes a lot of factors to be considered. In varying geological conditions, it becomes very difficult as there are various faults and fracture, so it requires a proper investigation to be done before starting of the project. The aim of this report is to determine the effects of tunneling on existing structures and tunnel surrounding due to tunnelling work, like crack in structure, vibrations caused to the above structure and ground settlement. To identify the movements caused and giving a solution by using the RS2 software and deciding the best suitable method for Construction of tunnel.***

Keywords: Faults, Fracture, Ground settlement, Ground investigation, Vibration

I. INTRODUCTION

As India is growing at a very rapid pace in becomes very important to provide a good infrastructure in country like roads bridges tunnel etc. As India is a very populated country availability of space is very limited, there is lot of traffic congestion so the best option is to go underground. By providing metro it will reduce lot of problems like traffic congestion, pol- lution free, Accident rate in metro is far less than other means of transport, Mass movement of passenger is possible. To study the effect of tunnel on existing and important structure plays a crucial role for successful completion of the project. It also helps in identification of the problems and avoid the major losses in tunnel. Construction of tunnel required a lot of work to be done considering various parameters like geology, dept of tunnel, water table, etc. These parameters effect the tunnel as well as the above structure so they must be considered carefully.

In varying geology conditions, it becomes very difficult as there are various faults and fracture plans which makes tunneling hard so proper investigations should be done before starting of the project. If the depth of the tunnel is more it becomes very hard to investi- gate the tunnel site due to which there are many unseen surprises that may occur during tunneling. And if there is water table in the tunnel line then it becomes extremely difficult for tunneling work as we have to pump out the water before stating the tunneling work.

Stability of excavated tunnel with respect to construction method and depending on conditions of field. Stability of the tunnel should be maintenance all along the construction process. The effect of tunnel on ground settlement and on the nearby buildings should be taken into account. Supporting system efficiency: Temporary and permanent support is to be provided of good quality and capacity for the applied load. So, it becomes important to evaluate the pre load before start of the tunnel work and design tunnel support. Are to be considered for design of tunnel construction.

There are various tunnel construction methods like TBM, Drill and Blast, cut and cover from these Drill and Blast will cause maximum distortion in ground because of the explosion done during drill and blast. Depending upon the geology and nature of the surrounding the methods are decided for construction of tunnel. For heavy traffic or dense area TBM is generally preferred as it causes less ground movement during tunneling but has a very slow speed as compared to drill and blast. Cut and cover is generally used for constructions of underground stations.

By using Analytical method and comparing with numerical method like RS2 software we can determine the various stress in tunnel at different location which helps in designing the tunnel, it will also help to determine the stress at the building foundations which will help in tunneling and also reduce overall cost and time of the project.

Different things are taken into consideration like Stability of the excavated tunnel and which constructions method should be adopted depending on site conditions. Due to the tunneling activity, there are various settlements caused to the buildings on the surface and to the tunnel surrounding Tunnel support system should be provided of proper capacity for the given load coming on the tunnel. So, we should determine the existent loads of the buildings before the tunnel support is designed and constructed.

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II. ANALYTICAL METHOD

Several results are given using different parameters on ground surface settlements like geological strata, depth of tunnel, dimensions of tunnel and excavation methods used for tunneling. For good results both analytical and Numerical methods are used. Analytical methods are mostly based on the assumption of elastic behavior of the soil. There are some equations given for calculating the surface settlement of the ground strata.

A. Limanov's Method

Limanov in the year 1957 gave a formula for calculating the surface settlement on the bases of theory of elastic behavior for the surrounding soil of tunnel. this method was developed on Maxwell theorem for calculating the settlement curve.
The Formula for calculating the settlement by Limanov's is given by

$$Smax = (1 - v^2)\frac{p}{E}\left[\frac{4R_0^2 h_0}{h_0^2 - R_0^2}\right]$$

Where:
v = Poisson's ratio

E = Young's modulus

R0 = Tunnel radius

*h*0 = Tunnel depth

P = Radial load
Were:

$$p = \sigma z \ \frac{1 + Kr}{2}$$

σz = The vertical stress in tunnel centerline
Kr = Lateral earth pressure

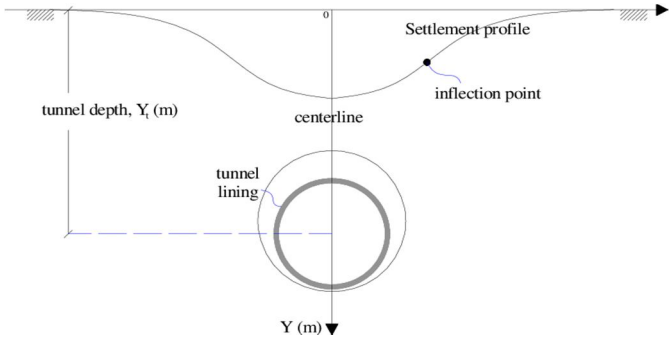


Fig -1: Basic Profile of settlement due to tunnelling

B. The Ecrelebi Method

The Ecrelebi Method gave a formula for calculating maximum amount of surface settlement over the tunnel axis in the year 2005
The Formula for calculating Settlement is given by:

$$Smax = 0.785 \times \gamma \times h_0 \times \frac{4xR^2}{1 \times E}$$

Where:
*h*0 = Tunnel axis depth
R = Tunnel radius
γ = Unit weight given in terms of (ton/m3)
E = Elasticity modulus given in terms of (ton/m2)
I = Inflection point position
Note- I is given by 0.5 X depth of the tunnel

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C. The Oteo Method

The Oteo method is semi-empirical method which gives the estimation of the settlement perpendicular to the axis of the tunnel. Oteo method is based on modification of peck formula we take more values of tunnel parameters into consideration.

The equation is given by

$$s_{max} = \Psi \times \frac{\gamma D2}{E} \times (0.85 - U)$$

Were,

U = Poisson's ratio

γ = The total unit weight of the soil

D = Diameter of the tunnel

Ψ = An empirical parameter (0.4- 0.5)

E = Modulus of elasticity.

D. Sagaseta's Method

Sagaseta's in the year 1987 said that If problems are in boundary conditions in terms of displacements, where displacements are required to get the answer, we can remove stress from the equations and consider strain for soil problems. in this model determination of displacement field in given in isotropic homogeneous soil material. An elastic homogeneous soil type is considered where the material is defined by ground loss. In Sagaseta's method strain field is independent of soil stiffness. Sagaseta's told that in closed structure for soil the deformed due to ground loss can be seen.

The Equation by Sagaseta's is –

$$\delta z = \frac{\gamma D^2 z^2}{4G(x^2 + z^2)}$$

were,

D = Tunnel diameter

γ = Unit weight of soil

G = Shear modulus of soil

X = Horizontal distance from tunnel center

Z = Depth measured from tunnel center

III. CALCULATION OF TBM TUNNEL

A. Parameters Taken for Calculation

Table -1: Parameters Considered

Parameters	Values
Over burden of the tunnel	15m
Diameter of the Tunnel	6.7m
Radius of tunnel	3.35m
Unit weight of soil is taken as	18 KN/M3
Youngs modules	50MPA
Poisson's ratio	0.3
Depth of tunnel is	18.35m
Peak Friction Angle	32 degrees
Peak Cohesion	0 MPA
Peak Tensile Strength	0 MPA

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B. Limanov's Method

(1-0.3) x (0.247/50) x (4x3.35^2x18.35 / 18.35^2 – 3.35^2)
Settlement observed is = 11.37 mm

C. The Ecrelebi Method
0.785x 1.84x 18 35x (4x3.35^2 / 9.175x 5098
Settlement observed is = 25.41mm

D. Oteo Method
0.4x (0.016x6 7^2 / 50 x (0.85 – 0.3)
Settlement observed is = 3.52mm

E. Sagaseta's Method
(18x6.7^2x18.35^2) / 4x33557 (18.35^2 + 18.35^2)
Settlement observed is = 3.00 mm

IV. CALCULATION OF NATM TUNNEL

A. Parameters Taken for Calculation

Table -2: Parameters Considered

Parameters	Values
Over burden of the tunnel	12m
Diameter of the Tunnel	9m
Radius of tunnel	4.5m
Unit weight of soil is taken as	18 KN/M3
Youngs modules	50MPA
Poisson's ratio	0.3
Depth of tunnel is	16.5m
Peak Friction Angle	32 degree
Peak Cohesion	0 MPA
Peak Tensile Strength	0 MPA

B. Limanov's Method
(1-0.3) x (0.222/50) x (4x4.5^2x16.5 / 16.5^2 – 4.5^2)
Settlement observed is = 21.46mm

C. The Ecrelebi Method
0.785x 1.84x 16.5x (4x4 5^2 / 8.25x 5098)
Settlement observed is = 45.89mm

D. Oteo Method
0.4x (0.018x9^2 / 50 x (0.85 – 0.3
Settlement observed is = 6.38mm

E. Sagaseta's Method
(18x9^2x16.5^2) / 4x33557 (16.5^2 + 16.5^2)
Settlement observed is = 5.43 mm

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V. NUMERICAL ANALYSIS AND MODELLING OF TBM TUNNEL

Model has been made by using RS2 software. A model is made in number of stages in the software to check the displacement and the amount of support system requirement required for the construction of tunnel. A 0.05 MN/M2 uniform load is considered on the surface

A. Support System of Tunnel

The System used for support is a Reinforce Concrete member. Properties of the support provided is given in the table below. A reinforced concrete member is installed in the tunnel of M50 grade concrete for support system with I beam.

B. Values Used For Support System

Table -3: Properties of concrete

Names of properties	Values
Concrete Grade	M50
Compressive Strength	50 MPA
Tensile Strength	5.26 MPA
Young's Modulus	36126 MPA
Poisson Ratio	0.1

Table -4: Reinforcement Properties

Names of properties I Beam (W 150x18)	Values
Spacing (m)	0.2
Section Depth (m)	0.153
Area (m^2)	0.00229
Moment of inertia (m^4)	9.2e-06
Young's Modulus (mpa)	200000
Poisson Ratio	0.3
Compressive Strength (mpa)	500
Tensile Strength (mpa)	500

C. How The Model Was Made In Various Stages

Table 5 : Different Stages

Stage	Description
01	Defining Properties
02	Adding Distribution Load
03	Excavation + In-situ
04	Relaxation
05	Support System

D. Modeling in RS2

By using the RS2 Software the modeling was done for the TBM tunnel, and the results were taken by applying the conditions like.

1) 0.05MN/m2 load was applied on the ground surface
2) In-situ stress conditions are taken
3) Top surface was kept free and ends were kept fixed
4) Reinforced concrete lining was provided for the support of the tunnel

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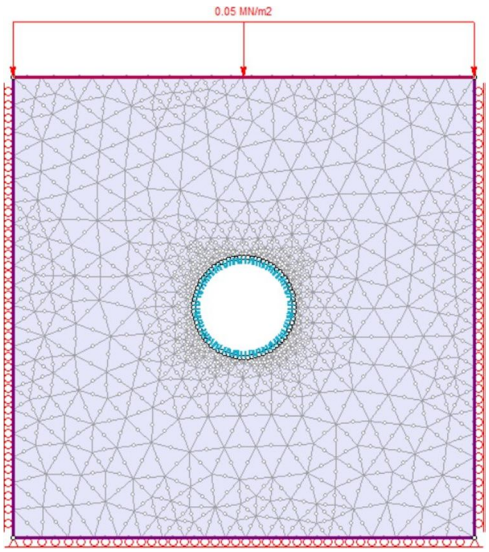


Fig -2: TBM model in RS2

E. Results of the Modeling

1) After computing the model total displacement v/s stage number graph was plotted.

a) The total displacement was increased in stage 3 to stage 4 as we have excavated the tunnel in 3rd stage of the model

b) After providing the support system in 4th stage the total displacement is reduced in 5th stage

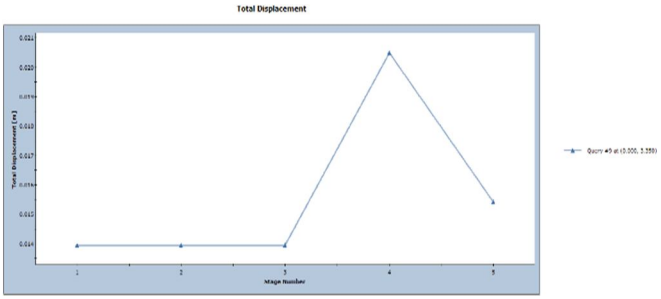


Fig -3: Total Displacement for various stages

2) A vertical displacement v/s the distance graph is plotted to determine the displacement on the ground surface of the tunnel. A maximum displacement of –26.3 mm was seen in figure 4 after the excavation was carried out without providing support conditions and compared with providing support system.

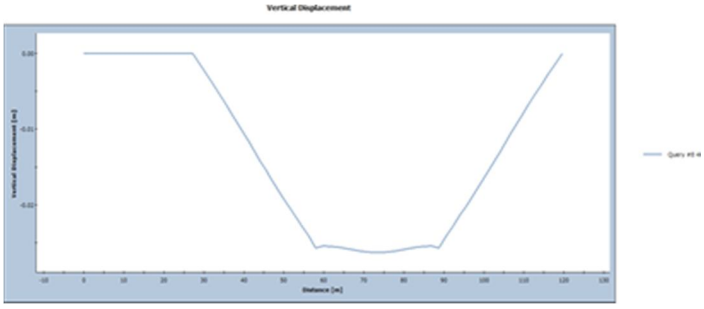


Fig -4: Vertical Displacement on Ground surface after excavating

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3) A vertical displacement v/s the distance graph is plotted after providing the support system and the maximum vertical displacement is reduced to -22.22 mm, so we can say that after providing the support system the vertical displacement was reduced

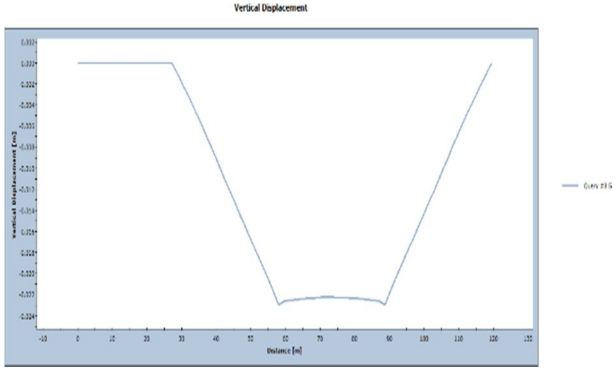


Fig -5: Vertical Displacement on Ground surface after support installation

4) A support capacity curve is plotted to determine the conditions for the support provided
a) I-beam w200x15 and concrete is provided and factor of safety 1, 1.2, 1.4 are considered
b) All the support provided are in safe conditions

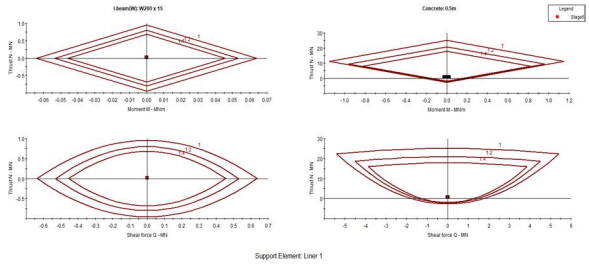


Fig -6: Support Capacity curve

5) A graph of total displacement on tunnel surface is plotted and maximum value of 15 mm was observed on the tunnel surface

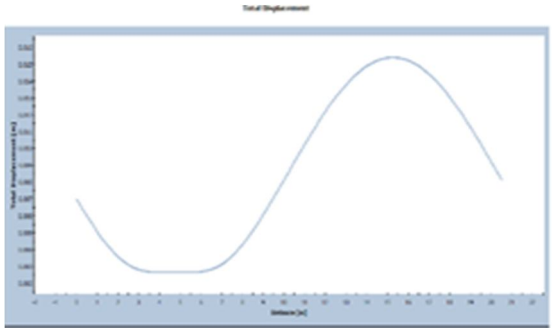


Fig -7: Total Settlement on Tunnel Surface

VI. NUMERICAL ANALYSIS AND MODELLING OF NATM TUNNEL

Model has been constructed by using RS2 software. A model is made in number of stages in the software to check the displacement with the formula calculated value and the amount of support system requirement required for the construction of tunnel. A 0.05 MN/M2 uniform load is considered on the surface of the tunnel.

A. Support System of Tunnel

The System used for support is a Reinforce Concrete member. Properties of the support provided is given in the table below. A reinforced concrete member is installed in the tunnel of M70 grade concrete for support system with I beam

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B. Properties Used For Support System

Table -6: Properties of concrete

Names of properties	Values
Concrete Grade	M70
Compressive Strength	70MPA
Tensile Strength	7.1 MPA
Young's Modulus	45000 MPA
Poisson Ratio	0.1

Table -7: Properties of Reinforcement

Names of properties I Beam (W 200x15)	Values
Spacing (m)	2
Section Depth (m)	0.20
Area (m^2)	0.00191
Moment of inertia (m^4)	1.28e-05
Young's Modulus (mpa)	200000
Poisson Ratio	0.3
Compressive Strength (mpa)	500
Tensile Strength (mpa)	500

C. Modelling in RS2

By using the RS2 Software the modeling was done for the NATM tunnel, and the results were taken by applying the conditions like.

1) 0.05MN/m2 load was applied on the ground surface
2) In-situ stress conditions are taken
3) Top surface was kept free, and ends were kept fixed
4) Reinforced concrete lining was provided for the support of the tunnel

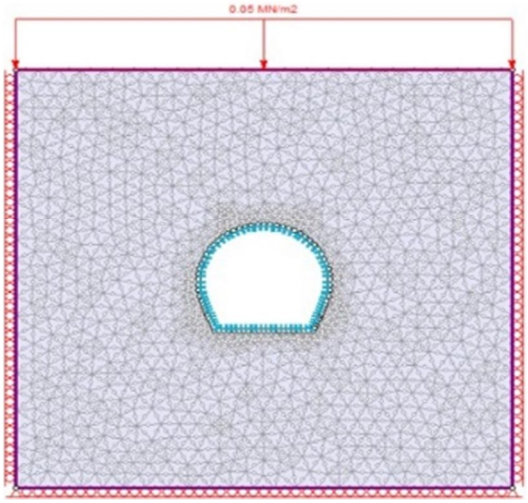


Fig -8: NATM model in RS2

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D. Results of the Modelling

After computing the model total displacement v/s stage number graph was plotted

1) The total displacement was maximum in stage 3 as we have excavated the tunnel in 3rd stage of the model

2) After providing the support system the total displacement is reduced gradually till the last stage of the model

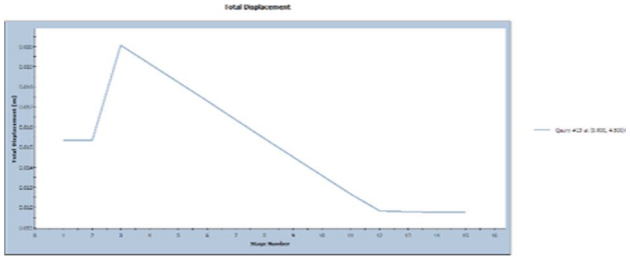


Fig -9: Total Displacement for various stages

6) A vertical displacement v/s the distance graph is plotted to determine the displacement on the ground surface of the tunnel. A maximum displacement of -27 mm was seen in figure 10 after the excavation was carried out without providing support conditions and then compared with providing support system

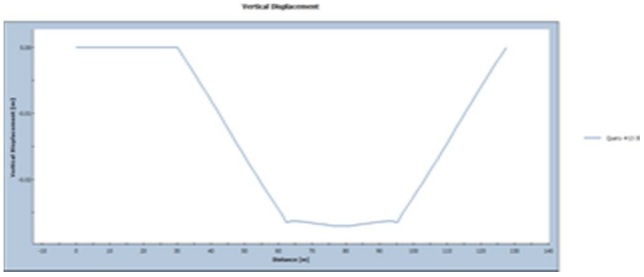


Fig -10: Vertical Displacement on Ground surface after excavating

7) A vertical displacement v/s the distance graph is plotted after providing the support system and the maximum vertical displacement is reduced to -20.2 mm, so we can say that after providing the support system the vertical displacement was reduced

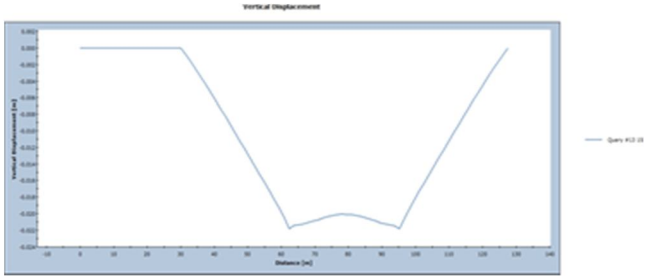


Fig -11: Vertical Displacement on Ground surface after support installation

8) A support capacity curve is plotted to determine the conditions for the support provided.

a) I-beam w200x15 and concrete is provided and factor of safety 1, 1.2, 1.4 are considered.

b) All the support provided are in safe conditions.

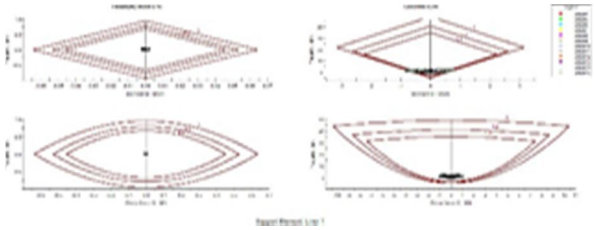


Figure 12: Support Capacity curve

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9) A graph of total displacement on tunnel surface is plotted and maximum value of 11 mm was observed on the tunnel surface

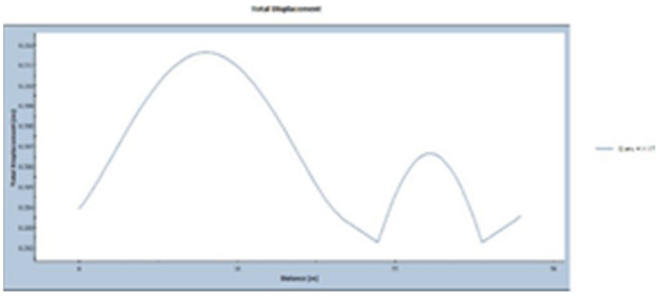


Fig -13 : Total Settlement on Tunnel Surface

VII. COMPARISON

A. *Analytical values with Numerical values For TBM Tunnelling*

Table -8: Displacement values for TBM

Methods	Values displacement
Limanov's Method	11.37 mm
The Ecrelebi Method	25.41mm
Oteo Method	3.52mm
Sagaseta's Mthod	3.00 mm
Numerical modeling max settlement without support with loading	26.3 mm
Numerical modeling max settlement with support with loading	22.22 mm

B. *Analytical values with Numerical values For NATM Tunnelling*

Table -9: Displacement values for NATM

Methods	Values of displacement
Limanov's Method	21.46mm
The Ecrelebi Method	45.89mm
Oteo Method	6.38mm
Sagaseta's Method	5.43mm
Numerical modeling max settlement without support with loading	27.0 mm
Numerical modeling max settlement with support with loading	20.2 mm

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VIII. CONCLUSIONS

In this study, the analysis was performed for predictions of the ground condition to find out the maximum ground settlement using 2D numerical modeling by using Roc science software and analytical analysis by applying field conditions in TBM tunnel construction and in NATM tunnel construction

The TBM tunneling method was computed and modeled in 2D numerical modeling and values of maximum settlement were compared with the analytical method for predicting settlement. The displacement predicted by The Ecrelebi Method and the 2D model were very close to each other

By modeling the TBM tunnel In Roc science software it was observed that max settlement on ground without providing the support conditions was higher as compared to settlement observed by providing the Reinforce concrete support system.

For NATM tunnel method a computing model was done in 2D numerical modeling and the results was compared with the maximum settlement values by analytical method for predicting settlement. The displacement shown by The Limanov's Method and the 2D model were very close to each other.

By modeling the NATM tunnel In Roc science software it was observed that max settlement on ground without providing the support system is more as compared to settlement observed by providing the support system.

Selecting for best possible modeling method for determination of settlement cannot be dependent on any single method either numerical model method or Analytical method for prediction of settlement we have to consider both method for accurate prediction

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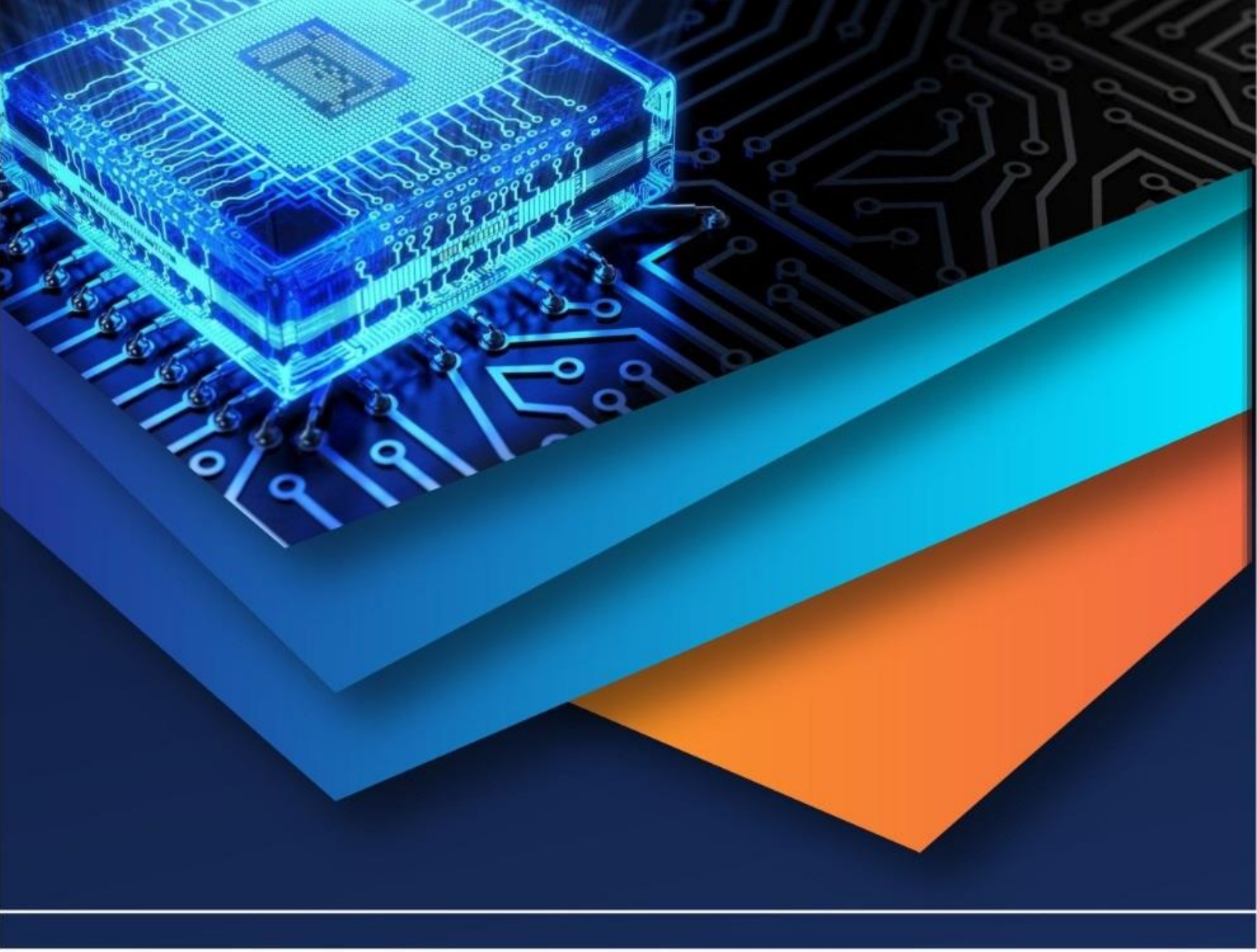
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