International Journal of Engineering

Journal Homepage: www.ije.ir

Numerical Analysis of Stress Distribution During Tunneling in Clay Stone Rock

D. H. Ali, H. O. Abbas*, T. H. Abdullah

Department of Civil Engineering, University of Diyala, Diyala, Iraq

PAPER INFO

Paper history:
Received 09 April 2020
Received in revised form 01 May 2020
Accepted 12 June 2020

Keywords:
Tunnel
Clay Stone
Stress
Numerical

ABSTRACT

In recent years, modern technology has been applied to build tunnels by means of drilling machines (TBM) that were used for civil engineering work in large cities to reduce the harmful effects of spending on the surface of the earth significantly. To build the tunnel, numerical modeling was used on the basis of the finite element method to predict stress behavior during the tunnel construction process. Tunnel simulation model by using the numerical method (FEM) with the Hoek-Brown model, which includes calculating the behavior of predicting stress-that surrounds the tunnel and analysis during the process of building the tunnel and compared with the natural state of the rocks during the different tunnel construction stages. Vertical stresses at the top and bottom of the tunnel are reduced during the advance of tunneling while horizontal stresses are increased. TBM progression is reflected in phases through one to five by performing an axial symmetric FE analysis, math calculation results revealed significant stress changes occurring in rock regions near the boundary of the tunnel. In other words, proximity to rocks is mostly affected by the tunnel. These pressure variations decrease as you move away from the tunnel horizontally and the seams reach extremely small values for distances greater than (2D) meters from the edge of the tunnel, where D is the diameter of tunnel.

***doi**: 10.5829/ije.2020.33.08b.05*

1. INTRODUCTION

An increase in economic and social development made the need to build tunnels significant due to its multiple functions such as transportation and water supply. The construction and design of the tunnel is different from other engineering fields. The tunnel design procedures in a rock mass affect the strength of the rocks, pressure behavior, and other measures [1]. Shot concrete is a crucial component of tunnels and underground structures as protection. To determine the time-dependent nature of a tunnel boring machine (TBM) tunnel liner under high site stress a new fundamental model of sprayed concrete is being implemented. The Shotcrete model is based on a versatile plasticity system designed to more accurately view the non-linear and time-dependent behavior of concrete materials [2]. Horizontal rock strata is a geological state of rock that is often encountered in tunnel construction and has a major impact on tunnel construction, it is important to examine and study the stability of horizontal rock strata in tunnel construction to ensure the safety and efficiency of tunnel construction. By using the "Xishan Highway Tunnel" as the focus of study and using the numerical simulation method [3].

Thus, for the purpose of overcoming problems of insufficient information about ground conditions and in order to predict the condition of the land under loading after drilling, some have used numerical analysis [4, 5].

Modeling rock mass is a very difficult task due to interruptions, heterogeneous, and inflexible nature of the rock mass, using experimental and modern methods [6, 7]. The complex nature and various formations make rock blocks a difficult material for experimental and numerical modeling. The RS2 numerical modeling technique was used by analytical methods to validate the support proposed. The data obtained from field and laboratory test results were used for the classification of rock mass and the determination of rock mass unit qualities along the tunnel alignment. RMR described the rocks as good to bad, and Q-system moderate to very bad. The RMR suggested bolt support and Shotcrete mounted in RS2 software models decreases the total displacement

*Corresponding Author Email: *temimi71@yahoo.com* (H. O. Abbas)

Please cite this article as: D. H. Ali, H. O. Abbas, T. H. Abdullah, Numerical Analysis of Stress Distribution During Tunneling in Clay Stone Rock, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 33, No. 8, (August 2020) 1472-1478

and thickness of the plastic zone around the tunnel [8]. Site Response Analyses (SRA) will assess the seismic excitation at the surface to compensate for the site's unique soil properties. However, the results obtained are largely determined by the choice and setting of the model and by the depth of the soil layer considered. Proposes a streamlined 3D analytical approach, by OPENSEES platform use. Special attention has been paid to the role of the soil depth considered in determining the seismic input from the surface [9]. During the initial stages of drilling projects, detailed data are not available on strength characteristics, model deformation, on-site pressure, and hydrological rock masses [10].

Digital modeling is receiving more attention in civil and rock engineering to predict the response of the rock mass to various drilling activities [11]. Numerical methods are convenient, less expensive, and less time consuming to analyze redistributive stresses and their effects on rock mass behavior and design the structures are in the center of the environmental stone block. numerical methods mathematical equation rest in problems in governance and engineering Input parameters physical and strong determinants of rock parameters [12, 13]. A more detailed examination of stress concentrations around the tunnel and in areas close to it is permitted in three-dimensional analysis using numerical modeling. The effects of three-dimensional stress have proven to be an important factor when the tunnel side is present, especially advanced with regard to induced stress concentrations and rock strength degradation [14, 15].

In general, estimating site stresses requires detailed descriptions of site geology and considerable judgment. Models (physical or numerical) can be developed to explore the influence of parameters such as the rock's foundational model, loading date, critical geological structures, terrain, and boundary conditions on-site pressures. It is common practice to make two basic assumptions when estimating the stress state at any depth, z, in a rock mass. The first assumption is that the stress condition can be described with two components: vertical component, (σv), due to the rock's excess weight at this depth equal to γz, A uniform horizontal component, σh = (σH equals K times σv. The second assumption is that both σv and σh are two main stresses. Another expression often used in the literature for the coefficient of K is Ko = v / (1 -v) where v is the Poisson ratio of the rock.

This expression was derived by assuming (1) that the rock mass is half of an ideal linear homogeneous linear parallel area with the surface of the horizon, (2) that the rock mass is under gravity alone with the disappearance of horizontal positions, and (3) that the loading record has no effect on how it accumulated pressure on the site [16]. The main objective of this study is to predict the horizontal and vertical stresses around the tunnel during the advance of tunneling with TBM progress in the rocks.

2. CASE STUDY

The purpose of the numerical analysis of a mechanical tunnel model is that it takes into account the large number of operations performed during tunnel excavation and construction. The 3D object model consists of several different components such as rock parameters, rock layers, tunnel boring machine, hydraulic jacks, tunnel liner application, all of these parameters are analyzed and simulated in the 3D FEM model.

2. 1. Model Dimensions and Rock Properties

The simulation of the tunnel construction is carried out using FEM, and because the model is symmetric, half of the tunnel model is taken for calculations by a numerical solution. The tunnel diameter (D) assumes 6m and its length is 9m. The geometrical shape of the tunnel and the estimated network are shown in Figure 1.

The tunnel model depends on the actual data of the rock properties. The criteria obtained from the basic tests on the rock hole of the project and some other standards were adopted from literature [17]. The obtain data from field and laboratory tests of the project are shown in Table 1. In this study, the model has used the behavior of rock is the Hoek-Brown model (HB).

2. 2. Type of Element Used in Numerical Study In engineering problems (geotechnical problems) and in order to obtain accuracy, for the three-dimensional finite element, the grid with the nested four-dimensional nested elements is used which is also used to model the tunnel lining. The functions of the shape Ni has the size of the

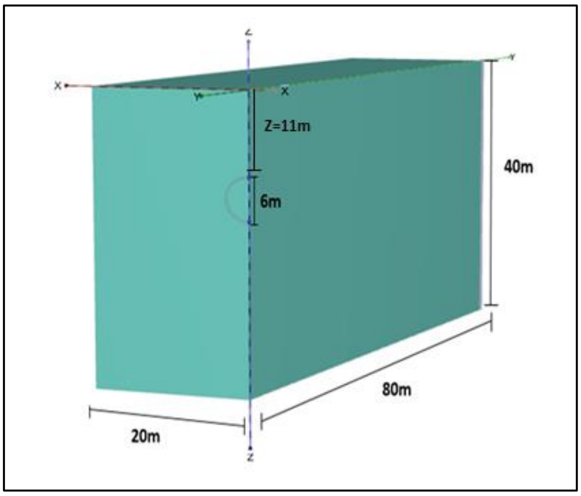

Figure 1. The geometry of the tunnel for the 3D model

TABLE 1. The rock parameters of the Hoek-Brown model (HB)

Depth(m)	40
Saturated unit weight of rock (kN\m³)	23
Unsaturated unit weight of rock (kN\m³)	23
Young's modulus×10^6 * (kN\m²)	14
Uni-axial compressive Strength×10^3 * (kN\m²)	25
Intack Rock parameter*	4
Geological Strength Index*	38
Disturbance factor	0
Poisson's Ratio *	0.3

*[17]

function equal to the unit in node i and zero in the other nodes. Interface elements are observed with a limited thickness, in some program output diagrams, but the coordinates of each node pair are identical in the formulation of the finite element (FE), meaning that the interface element has zero thickness. The stiffness matrix of trigonometric elements depends on the characteristics specified in the material data sets that were acquired by Gaussian integration using 6 integration points.

2. 3. Structural Elements Properties Tunnel boring machine (TBM) is designed as plate elements and is supposed to be 9m in length, and segmental tunnel liner is designed as plate elements. Table 2 shows the parameters of the tunnel machine [17]. In the concrete lining used, each part is assumed to be 1.5m wide, and so, TBM advances 1.5m in each severity of the tunneling stages. The segments of the concrete lining are formed by using structural elements with flexible linear behavior of the formed properties. The material properties of lining elements are shown in Table 3.

TABLE 2. Material of properties of the TBM [17].

Parameter	Unite	TBM
Thickness	Meter	0.35
Elastic Modulus	(kN\m²)	23.0*10^6
Unit Weight	(kN\m³)	70
Poisson's Ratio	-	0.1

TABLE 3. The material properties of the concrete lining element.

Parameter	Unite	Lining	TBM
Thickness	Meter	0.25	0.35
Elastic Modulus	(kN\m²)	23.5 *10^6	23.0*10^6
Unit Weight	(kN\m³)	25	70
Poisson's Ratio	-	0.1500	0.1

In this paper, the volume of the face pressure is determined in relation to the vertical pressure caused by the weight of the rock deposits and is related to the unit weight of the bentonite suspension while the volume of the pressure has been defined by increasing the face pressure at the crown of the tunnel. The pressure of the filling increases linearly from the crown of the tunnel to its reversal as a face pressure depending on the weight of the unit of the plaster material.

The first six drilling steps represent a 9-meter advance at long TBM, and the veneer elements are activated with the dedicated TBM material, then the liner is fixed by setting the liner material to the corresponding veneer elements [17].

2. 4. Mesh Generation In PLAXIS 3D, an unstructured, automatically generated network that can be chosen to improve the local and global network is used. PLAXIS 3D shows five network density options spread from a very rough mesh to a very fine mesh. In this paper, a medium network is applied. The network is refined in areas where stresses and strains are expected to be high and critical, i.e. the tunnel, the liner of the tunnel, and the surrounding rocks, as shown in Figure 2.

3. RESULTS AND DISCUSSION OF NUMERICAL MODEL

The modeling process for building a tunnel using TBM is a summary of the construction stages that include rock drilling and the installation of a lined concrete part. The results obtained from rock tunnel pressure by using a finite element method with rock failure criteria are the HB model, displaying the location of sections taken tunnel model at x-direction shown in Figure 3.

3. 1. Stresses of Section A-A This section represents the data through tunnel (x=0 with variations at x-direction=26.5m, and different depths z). It should be noted that the stress depth curves in this case show the vertical and horizontal stress at different depths, while y-

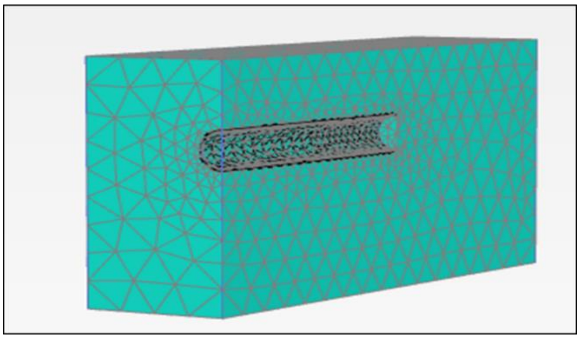

Figure 2. Medium type mesh of 3D geometrical of the tunnel for (HB) model

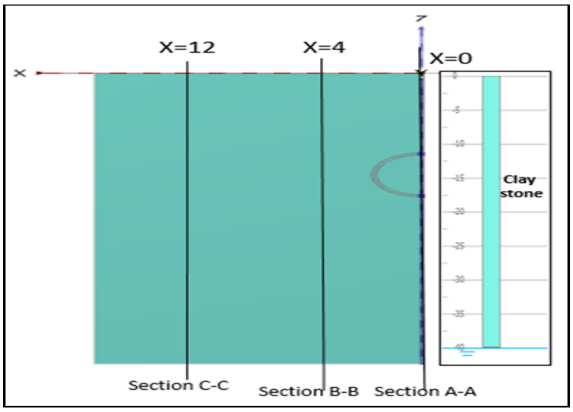

Figure 3. Displaying location of sections taken tunnel model at x-direction

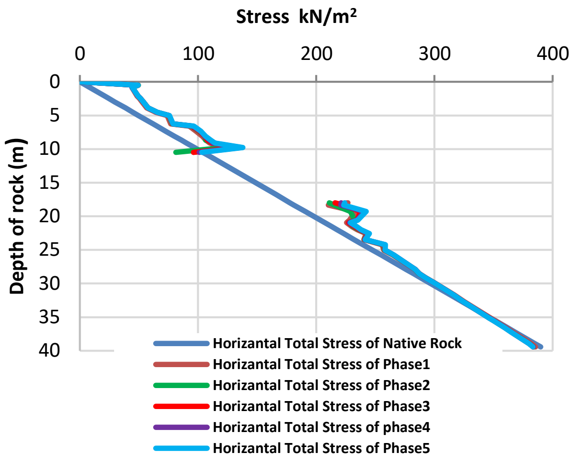

Figure 5. Distribution of the total horizontal stress during construction phases of tunnel at x=0 with find deviations

direction = 26.5 with deviations and x-direction = 0 with deviations. The first stage marks the beginning of TBM construction work and the drilling of the first part of the tunnel liner, in addition to the following other phases that will serve as a model for 1.5m rendering.

Figure 4 represents the distribution of the vertical stresses during the construction stages of the tunnel model. In general, the vertical stress decreases with increasing the depth from all phases. During the advancing of TBM in rock, the vertical stress from the upper region of the tunnel begins less than native rock at a percentage of 75%. This is due to machine vibration of TBM and the effect of lateral stress. For the region under the tunnel, the vertical stress from all phases also less than native rock at percentage 42% and became close to the native rock with increasing the depth because the effect of tunneling is not significant. Figure 5 represents the total horizontal pressure distribution during the construction stages of the tunnel model. In general, the horizontal stress increase with increasing the depth from the native and all phases. During the advancing of TBM in rock, the horizontal stress from the upper region of the tunnel begins more than native rock at a percentage of 30%. This is due to machine vibration of TBM and the effect of horizontal ratio k. For the region under the tunnel the horizontal stress from all phases also more than native rock at percentage 22% and became close to the native rock after depth 30m because the effect tunneling is not significant beyond this depth.

3. 2. Stresses of Section B-B It is obvious from Figure 6 that the vertical stresses increase with increasing depth for native rock and all phases. During the advancing of TBM in rock the differences in vertical stress is begin approximately at a depth of 9m from ground surface. For the region between depth (9-19)m, the vertical stress of all phases is more than the native

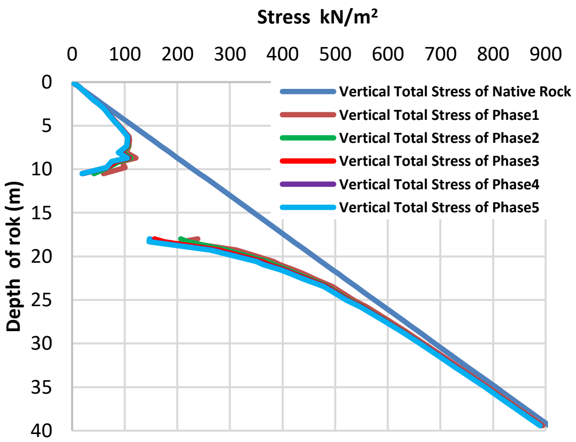

Figure 4. Distribution of the total vertical stress during construction phases of tunnel at x=0 with find deviations

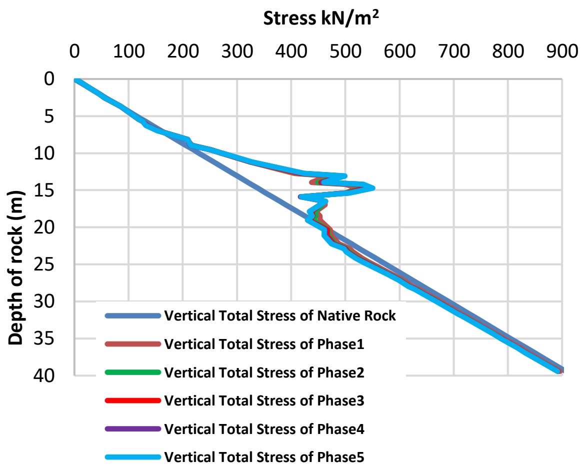

Figure 6. Distribution of the total vertical stress during construction phases of tunnel at x=4 with find deviations

rock at a percentage of 29%. This is due to tunneling in this region and the effect of lateral stresses. In addition, for the region between(19m and 30m) the vertical stress of all phases begins to decrease and become less than native rock at a percentage of 5%. This is because of lateral forces induced from TBM machine. Beyond the depth of 30m the vertical stress of native and all phases are similar, the effect of tunneling is not significant beyond this depth.

From Figure 7, it is obvious that the horizontal stress in the upper region of the tunnel can be seen the same behavior of deviation at all stages, at depth o.5m appear largely deviation due to several reason such as machine vibration (TBM) during drilling and the effect of horizontal ratio k. For the region between depth (7m-22m) the horizontal stress of phases less than the native rock at percentage 24% except phase one and phase two at depth(13m-15m) became more the native rock at percentage 26% for phase one and 3% for phase two and return less after this depth. This is due to tunneling in this region and the effect of horizontal ratio k. For the depth (22-40)m the horizontal stress of native rock and all phases are similar because the effect of tunneling is not significant beyond this depth.

3. 3. Stresses of Section C-C In this section, we focused on the distance from X-direction =12m Y-direction=26.5m and different depth of Z. It is obvious from Figure 8 that the vertical stresses of all phases close to the vertical stress of native rock because this region is located far away from the drilling zone of the tunnel.

Figure 9 shows the distribution of the horizontal stresses through the stages of building the tunnel model. In general, the overall horizontal stress behavior can be clearly observed and is the same as the direction of behavior for all stages with a slight difference between all stages. This is due to several reasons such as the distance is far away from the machine vibrations (TBM) during drilling of the tunnel, (the effect of the horizontal ratio (K).

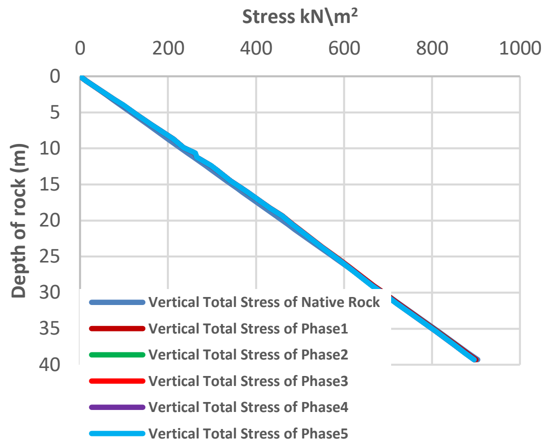

Figure 8. Distribution of the total vertical stress during construction phases of tunnel at x=12 with find deviations

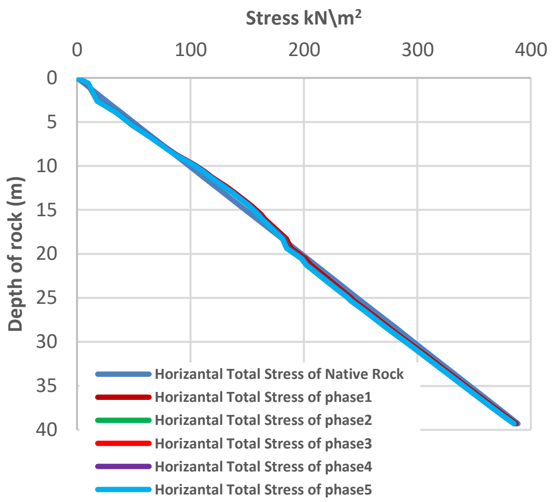

Figure 9. Distribution of the total horizontal stress during construction phases of tunnel at x=12 with find deviations

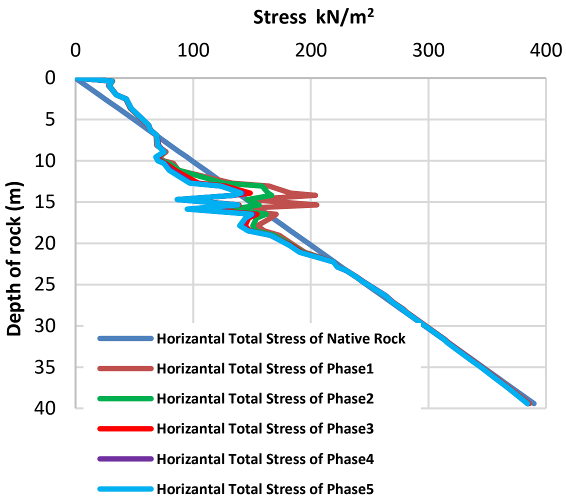

Figure 7. Distribution of the total horizontal stress during construction phases of tunnel at x=4 with find deviations

4. CONCLUSIONS

In this study, the analysis focuses completely on the difference of state (pressure) before and after TBM construction. Thus, all the curves presented in this research are displayed rock stress conditions for pre-drilling state (original rock state) with rock stress during construction of the tunnel. The following points are drawn:

i. The vertical stress in the centreline of the tunnel(X/ D = 0), at the top of the tunnel for all phases, is 75% less than the original rocks, while at the bottom of the tunnel is 42% less than the original rocks. This is due to several reasons, including the vibrations of the TBM tunnelling machine during the progress of the tunnel and the effect of lateral pressure. As for the horizontal stress, the top of the tunnel is 30% larger than the original rocks, while the bottom of the tunnel is 22% more than the original rocks. This is due to the advancing of the TBM machine and the effect of horizontal ratio k.

ii. At each side of the tunnel (X/ D = 0.67), the vertical stress values for the phases of the original rocks within the depth are increased from 9 m to 19 m, with an increase of 29%, due to the tunnel in this area and the side effect pressure after depth (19-30)m. The vertical pressure of all stages has become 5% less than the original rock due to the effect of induced stress, after depth 30m the stress values of the original rock have converged with the rest of the stages. As for the horizontal stress, it will be at all stages less than the original rocks at depth from 7m to 22m, with a decrease of 24% except for the depths from 13m to 15m. Then it returns to diminishing after this depth 22m and the reason for that is the presence of the tunnel in this area and the effect of the ratio of horizontal stress k until the values of horizontal stress for all stages converge with the stress of the original rocks.

At each side of the tunnel (X/ D =2), the vertical stress values for all the phases close to the original rocks, due to this region away from the drilling zone. As for the horizontal stress, it will be at all stages close to the original rocks with slightly difference due to the effect of the ratio of horizontal stress k. Tunneling progress is not affected by stresses in rock mass beyond (X/ D=2).

5. REFERENCES

1. Maynar, M.J. and Rodríguez, L.E., "Discrete numerical model for analysis of earth pressure balance tunnel excavation", ***Journal of Geotechnical and Geoenvironmental Engineering***, Vol. 131, No. 10, (2005), 1234-1242. https://doi.org/10.1061/(ASCE)1090-0241(2005)131:10(1234)
2. Shaalan, H.H., Azit, R. and Ismail, M.A.M., "Numerical analysis of tbm tunnel lining behavior using shotcrete constitutive model", ***Civil Engineering Journal***, Vol. 4, No. 5, (2018), 1046-1065. Doi.org/10.28991/cej-0309155
3. Zhang, N., Wang, W., Yang, Z. and Zhang, J., "Numerical simulation on the stability of surrounding rock of horizontal rock strata in the tunnel", ***Civil Engineering Journal***, Vol. 3, No. 12, (2017). Doi.org/10.28991/cej-030948
4. Beer, G., "Numerical simulation in tunnelling, Springer Science & Business Media, (2003). https://doi.org/10.1007/978-3-7091-6099-2
5. Jing, L. and Hudson, J., "Numerical methods in rock mechanics", ***International Journal of Rock Mechanics and Mining Sciences***, Vol. 39, No. 4, (2002), 409-427. https://doi.org/10.1016/S1365-1609(02)00065-5
6. Harrison, J.P., Hudson, J.A. and Popescu, M., "Engineering rock mechanics: Part 2. Illustrative worked examples", ***Appl. Mech. Rev.***, Vol. 55, No. 2, (2002), B30-B31. https://doi.org/10.1115/1.1451165
7. Jing, L., "A review of techniques, advances and outstanding issues in numerical modelling for rock mechanics and rock engineering", ***International Journal of Rock Mechanics and Mining Sciences***, Vol. 40, No. 3, (2003), 283-353. https://doi.org/10.1016/S1365-1609(03)00013-3
8. Akram, M.S., Ahmed, L., Ullah, M.F., Rehman, F. and Ali, M., "Numerical verification of empirically designed support for a headrace tunnel", ***Civil Engineering Journal***, Vol. 4, No. 11, (2018), 2575-2587. Doi.org/10.28991/cej-0391182
9. Forcellini, D., Tanganelli, M. and Viti, S., "Response site analyses of 3d homogeneous soil models", ***Emerging Science Journal***, Vol. 2, No. 5, (2018), 238-250. Doi.org/10.28991/esj-2018-01148
10. Andriani, G.F. and Parise, M., "Applying rock mass classifications to carbonate rocks for engineering purposes with a new approach using the rock engineering system", ***Journal of Rock Mechanics and Geotechnical Engineering***, Vol. 9, No. 2, (2017), 364-369. https://doi.org/10.1016/j.jrmge.2016.12.001
11. Vakili, A., "An improved unified constitutive model for rock material and guidelines for its application in numerical modelling", ***Computers and Geotechnics***, Vol. 80, No., (2016), 261-282. https://doi.org/10.1016/j.compgeo.2016.08.020
12. Bobet, A., "Numerical methods in geomechanics", ***The Arabian Journal for Science and Engineering***, Vol. 35, No. 1B, (2010), 27-48.
13. Rasouli, M., "Engineering geological studies of the diversion tunnel, focusing on stabilization analysis and support design, iran", ***Engineering Geology***, Vol. 108, No. 3-4, (2009), 208-224. https://doi.org/10.1016/j.enggeo.2009.07.007
14. Abel, J.F. and Lee, F.T., "Stress changes ahead of an advancing tunnel", in International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, Elsevier. Vol. 10, No. 6, (1973), 673-697. https://doi.org/10.1016/0148-9062(73)90013-2
15. Martin, C.D., "Seventeenth canadian geotechnical colloquium: The effect of cohesion loss and stress path on brittle rock strength", ***Canadian Geotechnical Journal***, Vol. 34, No. 5, (1997), 698-725. https://doi.org/10.1139/t97-030
16. Hoek, E. and Brown, E., "Underground excavations in rock. Inst. Of mining and metallurgy", Stephan Austin And Sons London, 527s, (1980). http://worldcat.org/isbn/0900488557
17. Brinkgreve, R. and Vermeer, P., "Plaxis 3d-finite element code for soil and rocks analysis", Balkema, Rotterdam, The Netherlands, (2012).

Persian Abstract

چکیده

در سالهای اخیر از فن آوری مدرن برای ساخت تونل ها با استفاده از ماشین های حفاری (TBM) استفاده شده است که برای کارهای مهندسی عمران در شهرهای بزرگ مورد استفاده قرار می گرفت تا اثرات مضر هزینه ها را روی سطح زمین بطور قابل توجهی کاهش دهد. برای ساخت تونل ، از مدل سازی عددی بر اساس روش المان محدود برای پیش بینی رفتار تنش در طی مراحل ساخت تونل استفاده شده است. مدل شبیه سازی تونل با استفاده از روش عددی (FEM) با مدل هوک–براون ، که شامل محاسبه رفتار پیش بینی استرس–است که در طی فرایند ساخت تونل ، تونل و آنالیز را احاطه کرده و با وضعیت طبیعی سنگها در طول مراحل مختلف ساخت تونل. تنش های عمودی در بالا و پایین تونل در طول پیشروی تونل زنی کاهش می یابد در حالی که تنش های افقی افزایش می یابد. پیشرفت TBM در مراحل از طریق یک تا پنج با انجام یک تجزیه و تحلیل متقارن محوری محور FE منعکس می شود ، نتایج محاسبه ریاضی تغییرات تنش قابل توجهی را در مناطق سنگی نزدیک مرز تونل نشان می دهد. به عبارت دیگر ، نزدیکی به سنگها بیشتر تحت تأثیر تونل قرار دارد. این تغییرات فشار با کاهش فاصله از تونل به صورت افقی کاهش می یابد و درزها برای مسافت های بیشتر از (D۲) متر از لبه تونل ، جایی که D قطر تونل است ، به مقادیر بسیار کمی می رسند.