Amirkabir Journal of Civil Engineering

Amirkabir J. Civil. Eng., 51(2) (2019) 95-97
DOI: 10.22060/ceej.2018.13477.5418

Influence of Interaction between Tunnel Boring Machine and Ground on Thrust Force and Penetration Rates-Case study: Karaj-Tehran Water Conveyance Tunnel (Lot-2)

M. Gholami, R. Ajalloeian

Engineering Geology, Faculty of Science, Isfahan University, Isfahan, Iran

ABSTRACT: In mechanized tunneling with Tunnel Boring Machine (TBM), some parameters such as thrust force and penetration rate have an important role and they can be recorded and compared with values achieving from theoretical models. Karaj-Tehran water conveyance tunnel has been bored by hard rock TBM machine to supply the water for Tehran capital. This project is finished by two parts called Lot1 and Lot2. After investigating the tunnel face of each section in Lot2, ground characteristics and Geological Strength Index (GSI) were recorded respectively. After that, Uniaxial Compressive Strength (UCS) and Cerchar Abrasiveness Index (CAI) are measured by testing on rock samples. The boring thrust force of TBM was calculated by using above mentioned data and by using other common and applicable models. Beside, achieved data from TBM specially thrust force and penetration rate had been recorded at the same time. A comparison of measured and calculated thrust force by using TBM data showed that it is possible to analyze the differences between them at each section of tunnel. For this, some parameters such as database selection, sampling and tunnel face control have an important role on analysis. At the end, CSM model and tunnel face data are selected to evaluate the thrust force and their results are presented to describe the eight classes of rock mass.

Review History:

Received: 26 September 2017
Revised: 20 December 2017
Accepted: 20 January 2018
Available Online: 12 February 2018

Keywords:

Geological Strength Index (GSI)
Cerchar Abrasiveness Index (CAI)
Tunneling Boring Machine (TBM)
Thrust force
Penetration Rate

1- Introduction

One of the most important challenges for staffs in mechanized tunnel project is to inform about engineering geology characteristics of tunnel face in Tunnel Boring Machine (TBM) to evaluate the interaction between TBM and ground. In some projects having no probe drilling system and geophysics data, it is possible to use TBM data logger for relation between excavation parameters and ground condition.

There are different models to measure cutter disc shear force. Two models obtaining reliable equations by using rock mechanics properties and cutting tools with penetration test results have presented CSM model by Rostami (2013) [1] and Roxborough and Philips (1975) [2].

The main purpose of this paper is to investigate the causes of excavation parameter changes and to analyze them with mining at the same time.

Karaj-Tehran water conveyance tunnel project has designed and performed by Hard-Rock TBM. Lot-2 of this project has different geology condition from Lot-1 and is selected for this research. Geological access from tunnel face and other tests on rock samples are used as data by using this data and CSM and Roxborough-Philips models and thrust force in defined sections of tunnel have been calculated.

In this research, differences between actual and calculated thrust forces are defined on the basis of rock mass stability in tunnel path and they can be investigated by data analysis.

Corresponding Author, Email: Ajalloeian@ui.ac.ir

In sight of geology, tunnel is located in southern part of central Alborz and consists of various sedimentary environments of Karaj formation with early to middle Eocene age. In lithology, tunnel units are composed of Tuff, Sandstone, Siltstone, Lava and agglomerate are folded and have some intrusive masses and dykes of Diorite and Gabbro [3].

2- Methodology

Investigating the correlation for actual parameters of TBM and ground conditions in tunnel face needs to achieve the first database of TBM measurement of some parameters such as Geological Strength Index (GSI) in tunnel face and in laboratory.

To obtain a complete database, geological changes have recorded and rock samples achieved. In next step, total mining parameters in each defined section is recorded from TBM data logger. In this paper parameters such as thrust force and penetration rate are used as main parameters of TBM.

Tunnel face control and data recording such as lithology type, joint orientation, joint spacing and filling, fault effects and influences of cutter disc on tunnel face have carried out. Testes on rock samples which have performed are Cerchar Abrasiveness Test (CAI) and Point load test (to determine UCS).

Study region in this research can be divided to eight classes by completing the database including rock sample tests and TBM parameters and tunnel face observations. The results are shown in Table 1.

Table 1. Data acquired during excavation from rock mass

Chainage (m)	Lithology	UCS (MPa)	CAI	GSI	Thrust Force (kN)	Penetration Rate (mm/rev)
100-1100	Diorite-Gabbro	125-135	3.3	55-60	4533	7.5
1100-2000	Tuff- Andesite	100-110	1.5	40-45	4766	11.5
2000-3400	Tuff	100-110	2.5	50-60	3933	8.5
3400-6050	Basalt-Tuff	85-100	2.5	40-50	4100	12
6050-6700	Tuff	60-75	1.5	30-35	3750	15
6700-7800	Tuff- Andesite and Basalt	95-110	2.5	50-60	4425	8.5
7800-9200	Diorite-Monzodiorite	160-190	4	75-80	6500	6
9200-13450	Tuff	75-95	1.5	55-60	5550	9

2-1- Effective Parameters on interaction between TBM and ground

As a result of interaction between TBM and ground, thrust force in each part of machine can be differed by mining. Total thrust requirement of the shielded TBMs is suggested as sum of 6 thrust components by [4, 5]:

$$F_{Total} = F_1 + F_2 + F_3 + F_4 + F_5 + F_6 \quad (1)$$

where (F) is total thrust (normal) force requirement of the TBMs, (F1) is thrust force required to overcome friction (adhesion) between shield and ground due to earth pressure, (F2) is thrust force required to overcome the chamber pressure acting on bulkhead, (F3) is thrust force required to overcome the drive force caused by direction changes in curved alignments (If the tunnel is straight; (F3) is taken to be 0), (F4) is thrust force required to overcome the frictional force acting between the segments and the tail seals, and (F5) is thrust force required to overcome the hauling force of trailing (backup) units (If the backup is self-propelled; (F5) is taken to be 0), (F6) assumes thrust force to overcome the penetration force of the cutting tools.

Different models are presented to determine the normal force of cutter discs and each one have advantages and disadvantages. From them, Roxborough-Philips and modified CSM models have more efficiency and utility [1, 2] that those are utilized for this research. The main equation of Roxborough-Philips for normal thrust force (FN) is following [2]:

$$F_N = 4.\sigma_c.d.\sqrt{\left(D.d - d^2\right)}.\tan(\frac{\delta}{2}) \quad (2)$$

where (σc) is uniaxial compressive strength of intact rock(UCS), (d) is depth of penetration for cutter disc, (D) cutter ring diameter and (δ) is edge angle of cutter ring.

And Equation 3 is presented following by Rostami (2013) for CSM model [1]:

$$F_t = T.R.\varphi.P_r \quad (3)$$

Where:

$$\varphi = \cos^{-1}\left(\frac{R-p}{p}\right) \quad (3\text{-}1)$$

$$P_r = C.\sqrt[3]{S.\frac{\sigma_C^2.\ \sigma_t}{\varphi.\sqrt{R.T}}} \quad (3\text{-}2)$$

where R is the disc cutter radius (mm or inch), T is the disc cutter tip width (mm or inch), φ is the angle of theoretical contact area (rad), p is depth of cutter penetration or penetration per revolution, Pr is the nominal average pressure (psi or MPa), S is the cut spacing (mm or inch), σc is the uniaxial compressive strength of the rock (MPa or psi), σt is the Brazilian Tensile Strength of the rock (MPa or psi), C is a constant and for the general case (not rock type specific), C=2.12 [6].

FN component have to be calculated from following equation to calculate the normal thrust force and finally put into Equation 4:

$$F_N = F_t.\cos\left(\frac{\varphi}{2}\right) \quad (3\text{-}3)$$

In this paper, in accordance with calculated normal force of cutter discs in each tunnel section and with regarding to 31 number cutter discs on TBM cutter head and also putting the FL=1.2 (in according to [5]), the FN values are resulted that are presented in Table 2.

3- Results and Discussion

FN values are resulted and are presented in Table 2. Some differences between thrust force due to models and TBM machines are recognized by calculating the forces of above mentioned models. A comparison with applied thrust force (F') and calculated thrust force (F) is shown in Table 2. Delta values (Δ) have a range of negative or positive values. Positive values of Δ express that F is higher than F' and vice versa.

Calculate thrust force by CSM model shows higher values than Roxborough-Philips model. In this paper CSM model defined as an adjusted model to reality by evaluating the excavation parameters of TBM and it is possible to describe the permissible range of thrust force.

4- Conclusions

Using the GSI to evaluate the mechanical properties of rock mass with TBM advance has an important role in mining. By applying the high thrust force and low penetration rate, high thrust force can be achieved from joint orientation in tunnel face. On the other hand, curve radius of each section and capability of TBM machines in various geological conditions have important role to apply a wide range of thrust force. Another result is about modified CSM model that can be used to define the permissible applied thrust force. To explain the model, availability of some indexes such as CAI, UCS, UTS are efficient. Finally, it is essential to explain that applying a model to investigate the TBM performance needs to present the quality description in addition to quantitative description of models.

Table 2. comparison of calculated and applied thrust force in tunnel

Class	F value by CSM (kN)	F value by Roxborough-Philips (kN)	Applied Thrust Force F' (kN)	Δ=F-F' By CSM	Δ=F-F' by Roxborough-Philips
100-1100	8576	5166	4500	+4376	-633.5
1100-2000	5849	3720	4800	+1182.3	-1046.7
2000-3400	5764	3846	3900	+2114.3	-87.1
3400-6050	5396	3589	4100	+1546.4	-510.1
6050-6700	3270	2113	3750	-579.4	-1637
6700-7800	6680	3756	4400	+1746.7	-668.4
7800-9200	9038	4582	6500	+3538.7	-1917.5
9200-13450	5713	3476	5500	+163.8	-2073.3

References

[1] J. Rostami, "Study of pressure distribution within the crushed zone in the contact area between rock and disc cutters," International Journal of Rock Mechanics & Mining Sciences, vol. 57, p. 172–186, 2013.

[2] Roxborough, F. F., & Phillips, H. R., "Rock Excavation by Disc Cutter," International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, vol. 12, no. 12, pp. 361-366, 1975.

[3] SCC, "Geology Report and Asbuilt Maps of Amirkabir Water Conveyance Tunnel Project," Sahel Consulting Company, Tehran, 2011-2013 (in Persian).

[4] JSCE, Standard Specifications For Tunneling- Shield Tunnels., Tokyo: Japan Society Of Civil Engineers, 2007.

[5] Bilgin, N., Copur, H., Balci, C., Tumac, D., Akgul, M., Yuksel, A., "The selection of a TBM using full scale laboratory tests and comparison of measured and predicted performance values in Istanbul Kozyatagi-Kadikoy metro tunnels," in Underground Facilities for Better Environment and Safety, Agra, 2008.

[6] Eftekhari, M., Baghbanan, A., Bagherpour, R, "The Effect of Operational Parameters on Penetration Rate of a TBM Using Artificial Neural Networks- A case study: Zagros Tunnel," Tunneling & Underground Space Engineering, pp. 29-98, 2013.

Please cite this article using:

M. Gholami , R. Ajalloeian, Influence of Interaction between Tunnel Boring Machine and Ground on Thrust Force and Penetration Rates-Case study: Karaj-Tehran Water Conveyance Tunnel (Lot-2) ,Amirkabir J. Civil Eng., 51(2)(2019)315-325.

DOI: 10.22060/ceej.2018.13477.5418