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Introducing New Equation for Predicting Penetration Rate of Tunnel Boring Machine

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ABSTRACT: Tunnel Boring Machines (TBM) is among the most important machines for tunnel excavation purposes. Evaluation of the performance of these machines for excavation is of special importance due to the high cost of these machines. Prediction of the penetration rate is one of the indicators in evaluation of TBMs. There are various methods and equations for predicting the penetration rate, which are based on parameters related to the rock mass and specifications of the machine, and each of them has its own particular characteristics. Multivariable linear regressions, artificial neural networks, and adaptive neuro-fuzzy inference systems are among the highly efficient modeling and data pattern recognition methods. In this research, some equations have been proposed for predicting the penetration rate in Zagros I Tunnel by employing multivariable linear regression method and by considering the key parameters of the rock mass and the specifications of the TBM; the best equation was selected according to the results of statistical analysis. For verifying the validity of this equation, the penetration rate was calculated at certain parts of Ghomrood Tunnel. In comparison with the real values and results of other models, the outcomes of calculations indicated that predicted values for the penetration rate are of acceptable accuracy. .

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1- Introduction

Various approaches for predicting penetration rate of hard rock Tunnel Boring Machines (TBMs) have been studied by researchers since the early stages of TBM application in the 1950s. These studies resulted in the development of several penetration prediction models.

They have been continuously transformed by improving their installed cutter-head power, size of machines, cutter loading capacity and designs for application in various ground conditions, even some adverse grounds [1]. During the past three decades, numerous TBM performance prediction models have been introduced based on theoretical, empirical and semi empirical investigations, all in all to answer a basic question, 'How is it possible to accurately estimate TBM Rate of Penetration (ROP) and evaluate the interaction between rock mass conditions and the design and operational characteristics of the TBM?"

TBM performance has a dominant impact on tunnel completion time and cost. A key component in the successful planning of TBM tunneling is the accurate prediction of TBM performance parameters, notably the penetration rate (PR, the rate of TBM penetration during boring times).

Early applications of TBMs were mainly undertaken in relatively massive rocks. In such rock masses research modelers focused primarily on evaluating the influence of intact rock properties on PR for a given set of TBM parameters. As the use of TBMs and related manufacturing technology has evolved, the range of application of the TBM has expanded. TBMs are now frequently used in a wider range of rock mass conditions. Since joints and discontinuities within a rock mass may impact TBM performance, a need for an improved penetration rate predictive model for TBMs operating in fractured rock units became evident. Many of the earlier models could not address the impact of discontinuities on TBM PR. Consequently, attempts were made to either modify existing models or develop new models that included rock mass parameters. In this research, some equations have been proposed for predicting the penetration rate in Zagros I Tunnel by employing multivariable linear regression method and by considering the key parameters of the rock mass and the specifications of the TBM.

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2- Methodology, Discussion, Results

Data for TBM performance analysis have been obtained from Zagros I tunnel which is under construction in sedimentary rock. It is one of tunneling projects undertaken by the Iran Water and Power Resources Development Co. In Zagros tunnel, the use of double shield TBM with segmental lining prevented a continuous surveying of excavated rocks. Due to the continuous segmental lining, inspection and surveying of the rock mass were performed during the daily maintenance of the boring machine, accessing the face from the TBM cutter-head.

Multiple linear regression analysis attempts to explain the

relations between the independent variables and a dependent variable. In this study, a multiple linear regression analysis was carried out between PR (Penetration Rate) and UCS (Uniaxial Compressive Strength), the joint spacing (DPW), thrust force, torque, RPW and the angle between tunnel axis and discontinuity plane (Alpha). From the statistical analysis, the predictive model of linear multiple regression from five independent variables is as follows:

$$\begin{aligned} PR = & -0.00008thrust + 0.001torque + 0.066RPM \\ & -0.003\alpha - 0.56DPW - 0.013UCS + 5.42 \end{aligned} \quad (1)$$

3- Conclusion

By employing a multiple linear regression analyses on field data collected from bored section of Zagros I tunnel, an attempt was made to provide a practical predictor equation of the penetration rate by considering the key parameters of the rock mass and the specifications of the TBM; the best equation was selected according to the results of statistical analysis. A multi-variable linear regression showed the best correlation between the penetration rate and the independent variables, with correlation coefficient of 0.62. For verifying the validity of this equation, the penetration rate was calculated at certain parts of Ghomrood Tunnel. In comparison with the real values and results of other models, the outcomes of calculations indicate that predicted values for the penetration rate are of acceptable accuracy.

References

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