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Prediction of TBM penetration rate in excavating underground spaces using genetic, artificial immune system, dolphin echolocation and gray wolf algorithms-A case study

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Abstract

Penetration rate prediction is one of the most important issues in mechanized drilling. Thus, it is important to know the factors affecting productivity, accurate estimation of stopping time, drilling and operating costs. Tunnel boring machines (TBM) are one of the most important drilling machines for tunnels and underground spaces, and due to the high price of this machine, it is very important to evaluate the performance in drilling using these machines. One of the indicators for evaluating the performance of a tunnel drilling machine is predicting the penetration rate of this machine. There are various methods and relationships for predicting the penetration rate, each of which has its own characteristics and are presented based on the parameters related to the rock mass and the characteristics of the machine. In this study, genetic, artificial immune system, dolphin echolocation and grey wolf algorithms were used to predict the penetration rate of TBM. In this regard, the database consists of 153 data (122 data for train and 31 data for test) including parameters of intact rock such as strength and brittleness and rock mass characteristics such as distance between planes of weakness and orientation of discontinuities along with TBM machine performance in Queens tunnel has been collected. Mean square error (MSE) and square correlation coefficient (R^2) have been used to estimate the error rate between the developed methods. Considering the key parameters of rock mass and intact rock and TBM, relationships to predict the penetration rate are presented and based on statistical analysis, the best relationship is selected. The results are compared with the real data and the results of other models show that the values penetration rate predicted by the genetic algorithm with MSE_{Train}=0.012, MSE_{Test}=0.02, R^2_{Train}=0.9319 and R^2_{Test}=0.8473,has acceptable accuracy compared to other methods.

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Keywords: *Penetration rate of TBM, Genetic algorithm, Artificial immune system algorithm, Dolphin echolocation algorithm, Grey wolf algorithm*

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Extended Abstract:

1. Introduction

The prediction of tunnel boring machine (TBM) performance is one of the complex and crucial tasks encountered frequently to excavate the mechanical tunnels. Estimating the machine performance may reduce the risks related to high capital costs typical for excavation operation. Since the first TBM was built, various prognosis models have been developed based on both intact and mass rock properties together with machine specifications. Prediction of TBM performance requires the assessment of the penetration rate (ROP), the ratio of excavated distance to the operating time during continuous excavation phase and advance rate (AR), and the ratio of both mined and supported actual distance to the total time. Developing the prediction models is one of the main tasks and it has been under progress since many years.

The aim of the current study is develop a TBM performance prognosis using the genetic, artificial immune system, dolphin echolocation and grey wolf algorithms. To obtain the goal, the database including strength and brittleness of intact rock, orientation and distance between planes of weakness in the rock mass, machine specifications and performance data, have been established by collecting the field and laboratory data from completed hard rock tunnel in the City of New York, USA. Afterward, using the established dataset, the models are developed for predicting the machine performance by means of the rate of penetration in both fractured and mass rock conditions.

2. Materials and methods

The evolutionary computational techniques showing its potential and good aspects for solving various optimization problems are the genetic, artificial immune system, dolphin echolocation and grey wolf algorithms. These techniques are introduced to estimate the TBM penetration based on intact and mass rock properties herein. To achieve the aim, input parameters for development of models have been selected after evaluating the dataset. The database including intact rock parameters comprising of strength and brittleness, and rock mass properties such as distance between planes of weakness and orientation of discontinuities, together with field machine performance data, was established using data collected along a 7.5 km long hard rock mechanical tunnel. It is worth mentioning, the brittleness has an insignificant effect on the ROP in fractured rock mass condition, it is discarded from the proposed models. Subsequently, the models are developed as a function of relevant rock properties.

3. Results and Discussion

One of the critical issues in estimating the construction costs and execution time of tunnel projects is to predict the performance of TBMs. The performance of TBM is highly dependent on the penetration rate of the device. In this study, genetic, artificial immune system, dolphin echolocation and grey wolf algorithms were used to predict the penetration rate of TBM in hard rock. Based on data obtained from 7.5 km of Queens Tunnel No. 3 measured at 151 stations, was formed to create predictive models of TBM performance. To validate the relationships obtained for each model, relative errors and statistical indicators such as square correlation coefficient (R^2) and mean square

error (MSE) for two sets of training data (122 data) and test data set (31 data) to evaluate performance. Each model was used. Based on the obtained values, it was found that the genetic algorithm has the best predictor and the most reliable model compared to other models due to its low error rate and proximity to the measurement value. According to the results of this paper, it can be seen that optimization algorithms have a high ability to solve underground space engineering problems in other areas.

References:

Armaghani DJ, Mohamad ET, Narayanasamy MS, Narita N, Yagiz S (2017) Development of hybrid intelligent models for predicting TBM penetration rate in hard rock condition Tunn Undergr Sp Tech 63:29-43.

Gao B, Wang R, Lin C, Guo X, Liu B, Zhang W (2021) TBM penetration rate prediction based on the long short-term memory neural network Underground Space 6:718-731.

Hamidi JK, Shahriar K, Rezai B, Rostami J (2010) Performance prediction of hard rock TBM using Rock Mass Rating (RMR) system Tunn Undergr Sp Tech 25:333-345.

Hassanpour J, Rostami J, Khamehchiyan M, Bruland A, Tavakoli H (2010) TBM performance analysis in pyroclastic rocks: a case history of Karaj water conveyance tunnel Rock Mechanics and Rock Engineering 43:427-445.

Liu B, Wang R, Zhao G, Guo X, Wang Y, Li J, Wang S (2020) Prediction of rock mass parameters in the TBM tunnel based on BP neural network integrated simulated annealing algorithm Tunn Undergr Sp Tech 95:103103.

Mahdevari S, Shahriar K, Yagiz S, Shirazi MA (2014) A support vector regression model for predicting tunnel boring machine penetration rates Int J Rock Mech Min Sci 72:214-229.

Mansouri M, Moomiv H (2010) Influence of rock mass properties on TBM penetration rate in Karaj-Tehran water conveyance tunnel Journal of Geology and Mining Research 2:114-121.