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Developing the empirical models for predicting the EPB operating parameters in strong Limestone

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Abstract

The operation parameters of EPB-TBM have always been significant factors in tunnel constructions. So it is crucial to estimate the cutterhead torque and thrust force of the machine. Significantly, the calculation requisiteness in this situation is most signifying if the machine is not designed to be used in these particular conditions.

In this study, by employing the multilayer perceptron artificial neural network (ANN-MLP) and multivariate regression (MVR) methods, the empirical models were developed to estimate the EPB operating parameters, including cutterhead torque and thrust force, in the rock section of the Tehran metro line 6, South extension (TML6-SE) project. In this section, the excavation was performed in a strong, blocky to massive rock. The machine was equipped with the disc cutters on the cutterhead as a cutting tool instead of rippers and drag bits. The mechanized excavation in this situation is unusual with using the EPB machines. The input data included the performance parameters such as penetration rate, earth pressure, cutterhead rotation speed, and cutter load. The statistical indices were used to verify the developed models.

The results confirmed the accuracy of the models. The MAE loss function determined for torque in both training and testing stages predicted by the ANN was 0.0001 and 0.005, respectively. The MAE loss function determined for thrust force in both training and testing stages predicted by the ANN was 0.00016 and 0.010, respectively. The relationships between parameters in the dataset were investigated to obtain and offer new equations using the multivariable regression statistical method (MVR). The MAE loss function determined for cutterhead torque and thrust force was 0.0018 and 0.0010, respectively.

Key words*: Deep learning, Mechanized excavation, Operating parameters, Cutterhead torque, EPB machine*

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Extended Abstract:

The operation parameters of EPB-TBM have always been significant factors in tunnel constructions. So it is crucial to estimate the machine's cutterhead torque and thrust force. Significantly, the calculation requisiteness in this situation is most signifying if the machine is not designed to be used in these particular conditions.

In the present paper, the empirical models were introduced that can be used for prediction of operating parameters of EPB machines in rock. Furthermore, the ANN-MLP, a powerful predictor network, has been employed to assess the operating parameters by considering the best correlation between the effective parameters on the target value. Verification of the proposed models was done using monitoring data obtained from the Tehran Metro Line 6, Southern Extension (TML6-SE), Iran, where the tunnel has passed trough two distiguishing parts, 1) Cretaceous limestone beds and 2) Quaternary sandy to clayey soils. In the first part, the excavation was performed in a strong, blocky to massive rock. The machine was equipped with the disc cutters on the cutterhead as a cutting tool instead of rippers and drag bits. The mechanized excavation in this situation is unusual with using the EPB machines. The results of the proposed empirical model are in good agreement with the measured data. The selection of input parameters required for artificial intelligence techniques in TBM tunneling is a complex challenge in soft computing methods; therefore, correlation analysis should enhance the predictive models' accuracy. Consequently, penetration rate, earth pressure, thrust per cutter, and rotational speed of cutterhead are chosen to predict cutterhead torque. Moreover, penetration rate and earth pressure are selected to analyze the total required thrust force.

Artificial neural networks are simplified mathematical models vaguely inspired by the brain's biological neural networks and functioning. Neural networks consist of input and output layers and a hidden layer consisting of units that transform the input into something that the output layer can use. The hidden layer can include more than one layer depending on the complexity of the training system. A neuron usually receives many simultaneous inputs. Each of them has its relative weights, giving the information the impact it needs on the processing element's summation function. This study aimed to calculate the best possible values of the above weights. The summation function can select the minimum, maximum, majority, product, or several normalizing algorithms. The summation function results are transformed into a working output through an algorithmic process known as the transfer function. Then the results can pass through various procedures that scale and limit. This scaling multiplies a scale factor times the transfer value and then adds an offset. Limiting is the mechanism which ensures that the scaled result does not exceed an upper or lower bound. Each processing element is allowed one output signal, which it may give to hundreds of other neurons. This process is summarized in Equations 1 and 2.

$$I_j = \sum_{i=1}^{n} (Wij\ Xi) + \theta j \quad \text{(summation units)} \quad (1)$$

$$Yj = f\ (Ij) \quad \text{(transfer function)} \quad (2)$$

The MVR method results and comparison to the thrust force and actual torque data were indicated in Figures 1 and 2, respectively. Enter regression analyses have been used to evaluate each input variable's influence on the EPB torque and thrust force through SPSS software version 22. Empirical equations for prediction of torque and thrust force are defined as follows:

$$Tq = 2.278 + 0.882 * S + 0.167 * P + 1.817 * Fn - 0.455 * RPM \quad (3)$$
$$Th = 11.06 + 8.843 * S + 0.130 * P \quad (4)$$

Where S is an earth pressure, P, Fn and RPM refer to the penetration rate (mm/rev), thrust per cutter (cutter load), and cutterhead rotation speed, respectively.
The ANN-MLP method results with consideration of the 2,2,1 structure were shown in Figure 3 for thrust force prediction. The neural model structure was determined 4,5,1 for torque estimation, and the comparison between the measured and predicted data were presented in Figure 4.

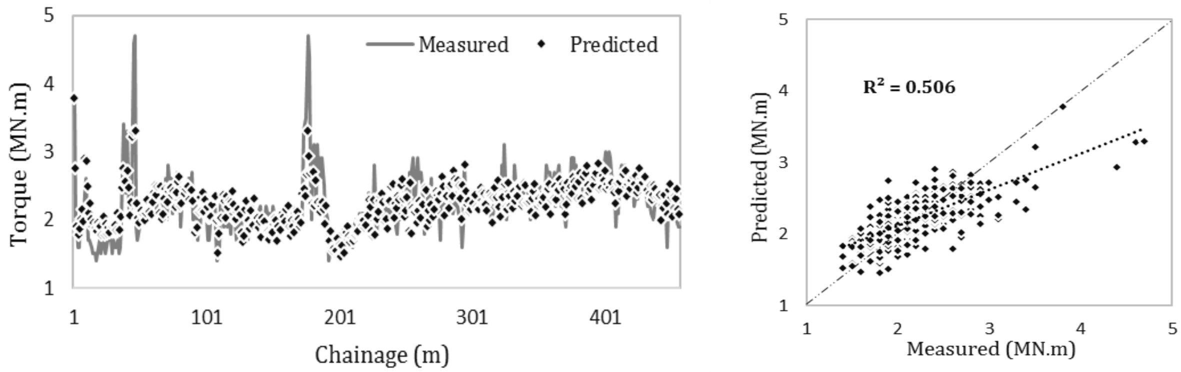

Fig.1. Results of MVR model; Comparison of measured and predicted values of torque.

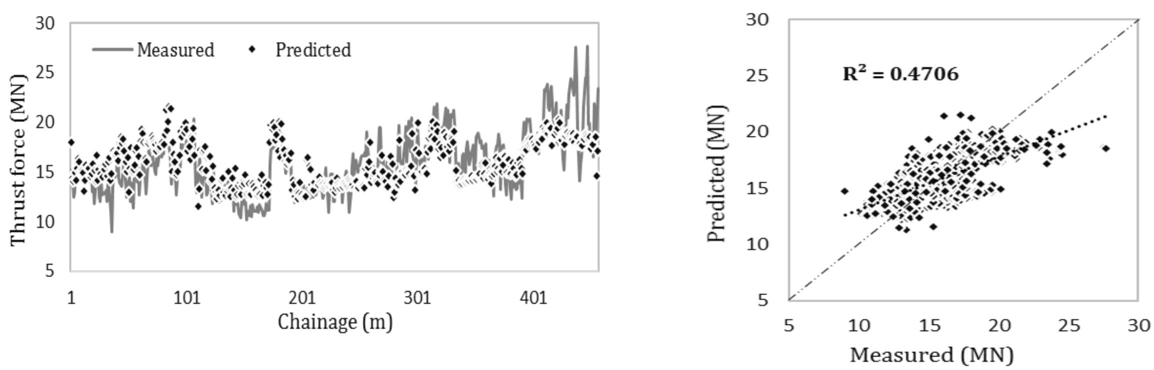

Fig.2. Results of MVR model; Comparison of measured and predicted values of thrust.

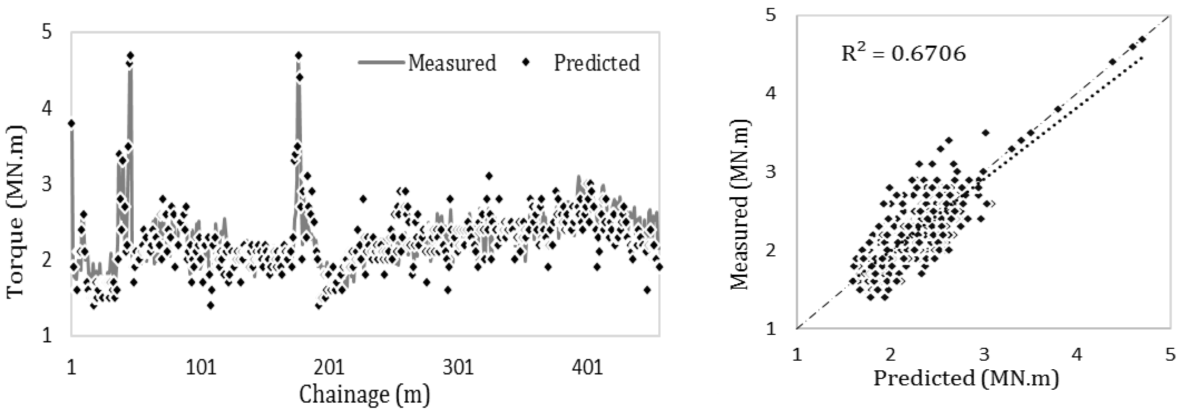

Fig.3. Results of ANN model; Comparison of measured and predicted values of torque.

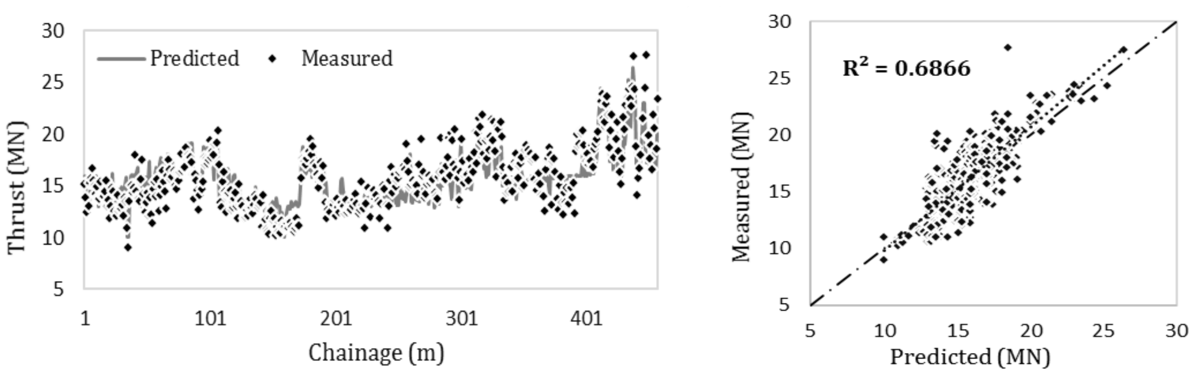

Fig.4. Results of ANN model; Comparison of measured and predicted values of thrust.