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A UNIVERSAL MODEL TO PREDICT ROADHEADERS' CUTTING PERFORMANCE

UNIWERSALNY MODEL DO PROGNOZOWANIA POSTĘPU PRAC KOMBAJNÓW DO DRĄŻENIA TUNELI

The paper intends to generate a universal model to predict the performance of roadheaders for all kinds of rock formations. In this regard, we first take into account the outcomes of previous attempts to explore the performance of roadheaders in Tabas Coal Mine project (the largest and fully mechanized coal mine in Iran). During those investigations, rock mass brittleness index (RMBI) was defined in order to relate the intact and rock mass characteristics to machine performance. The statistical analysis of data acquired from Tabas field demonstrated that RMBI was highly correlated to instantaneous cutting rate (ICR) of roadheaders ($R^2 = 0.92$). With the aim to construct a universal model for predicting the roadheader performance, we have now tried to establish a database consisting measured cutting rate of roadheaders as well as the data gathered from field studies of Tabas Coal Mine project and Besiktas, Kurucesme, Baltalimani, Eyup and Halic tunnels in Turkey. A broad modeling and analysis found a fair relationship, resulting in a new universal predictive model to predict the cutting rate of roadheaders with correlation of 0.73 ($R^2 = 0.73$). The application of local and universal models at Tabas Coal Mine showed a remarkable difference between measured and predicted ICR. The mean relative error of 0.359% was found with universal model but it represented lower value (mean relative error of 0.100%) while using local model. It can thus be concluded that instead of generating a universal model, separate localized models for different ground and machine conditions should be developed to improve the accuracy and reliability of the performance prediction models.

Keywords: performance prediction, roadheader, tunneling, Rock Mass Brittleness Index, Tabas Coal Mine

W pracy podjęto próbę opracowania uniwersalnego modelu do prognozowania postępu prac kombajnów do drążenia tuneli we wszystkich rodzajach skał. W pierwszym etapie przeprowadzono analizę wyników badań w tym zakresie prowadzonych uprzednio w kopalni węgla Tabas (jest to największa i w pełni

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zmechanizowana kopalnia węgla w Iranie). W ramach badań zdefiniowano współczynnik kruchości skał (RMBI) w celu określenia zależności pomiędzy właściwościami nienaruszonych warstw skalnych a postępami pracy kombajnów. Analiza statystyczna danych uzyskanych w kopalni Tabas wykazała wysoki poziom korelacji pomiędzy wskaźnikiem RMBI a chwilową prędkością urabiania (ISC) kombajnów do drążenia tuneli ($R^2 = 0.92$). Mając na celu opracowanie uniwersalnego modelu do prognozowania postępu prac kombajnów do drążenia tuneli, autorzy podjęli najpierw próbę stworzenia bazy danych obejmującej zmierzone prędkości urabiania oraz dane uzyskane w trakcie badań polowych w kopalni węgla Tabas, oraz z projektu drążenia tuneli w kopalniach w Besiktas, Kurucesme, Baltalimani, Eyup i Halic w Turcji. W wyniku modelowania i analiz znaleziono w miarę dokładną zależność, prowadzącą do stworzenia uniwersalnego modelu prognozowania prędkości urabiania przy użyciu kombajnów do drążenia tuneli, przy poziomie korelacji 0.73 ($R^2 = 0.73$). Zastosowanie lokalnego i uniwersalnego modelu w kopalni węgla Tabas wykazało znaczne różnice pomiędzy mierzoną a prognozowaną chwilową prędkością urabiania. Średni błąd względny dla modelu uniwersalnego wyniósł 0.359%, w przypadku modelu lokalnego średni błąd względny był na poziomie 0.100%. Stąd też należy wnioskować, że dla poprawy wiarygodności i dokładności prognozowania zamiast tworzenia uniwersalnego modelu, zasadne jest opracowanie odrębnych modeli „lokalnych" uwzględniających konkretne uwarunkowania gruntowe oraz sprzętowe.

Słowa kluczowe: prognozowanie postępu prac, maszyna do drążenia tuneli, drążenie tuneli, wskaźnik kruchości skał, kopalnia węgla w Tabas

1. Introduction

Currently, the world industries are moving toward more profitable, productive and competitive arenas and therefore, mechanization is becoming an inevitable alternative to gain these objectives. Mining and civil construction industries, too, lead this trend; hence, the ever-increasing applications of mechanical miners such as roadheaders, TBMs, continuous miners, etc. are some of the outcomes of project mechanizations, leading to their more extensive use in the mining and civil construction industries in recent years.

Roadheaders have remarkable advantages including high productivity, reliability, mobility, flexibility, safety, selective excavation, less strata disturbances, fewer personnel and lower capital and operating costs. To achieve these benefits as well as successful roadheader application, performance prediction of the machine needs to be accomplished appropriately. This generally deals with machine selection, production rate and pick (bit) consumption. The machine selection is performed on the basis of tunnel dimensions and its ground conditions such as profile size and shape, floor material condition (with respect to resistance against machine weight and ground pressure), slope, etc. Moreover, performance prediction mainly involves the assessment of instantaneous cutting rate (ICR) which is defined as the production rate during actual cutting time (tons or m^3/cutting hour) and pick consumption rate (PCR) which refers to the number of picks changed per unit volume or weight of rock excavated (picks/m^3 or m^3/pick). The following are the most affecting parameters on the roadheader production rate and pick consumption rate (Rostami et al., 1994):

- Rock parameters, such as rock compressive and tensile strength, etc.
- Ground conditions, such as degree of joint (RQD), joint conditions, ground water, etc.
- Machine specification, including machine weight, cutter head power, sumping, arcing, lifting, and lowering forces, cutter head type (axial or transverse), bit type, size, and other characteristics, number of allocation of bits on the cutter head, and the capacity of back up system.
- Operational parameters including shape, size, and length of opening, inclination, costs, etc (Jaszczuk & Kania, 2008).

The paper, first gives a brief background of roadheaders performance prediction models and then it establishes a database from the detailed field data including machine performance and geotechnical parameters in tunnels as well as entries from the Tabas Coal Mine project (the largest and fully mechanized coal mine in Iran) and Besiktas, Kurucesme, Baltalimani, Eyup and Halic tunnels in Turkey (Bilgin et al., 1988, 1990, 1996). Thereafter, the paper highlights some of the previous attempts made to construct a model to predict the roadheaders performance in Tabas coal mine. Applying whole data in the established database, subsequently, a universal performance prediction model is developed.

2. Brief background

Sandbak (1985) and Douglas (1985) used a rock classification system to explain changes in roadheader's advance rates at San Manuel Copper Mine in an inclined drift at an 11% grade (Bilgin et al., 2004). Gehring (1989) studied the relationship between *ICR* and rock uniaxial compressive strength (*UCS*) for a milling type roadheader with 230 kW cutter head power and an Alpine Miner AM 100 ripping type roadheader with 250 kW cutter head power. He developed following equations without giving correlation coefficients:

$$L_c = \frac{719}{c^{0.78}} \tag{1}$$

for ripping type roadheaders, and

$$L_c = \frac{1739}{c^{1.13}} \tag{2}$$

for milling type roadheaders

Where L_c denotes as cutting performance (m^3/hr), and c as the uniaxial compressive strength (MPa). Based on rock compressive strength and rock quality designation, Bilgin et al. (1988, 1990, 1996, 1997, 2004) had also developed a performance equation as:

$$ICR = 0{,}28 \times P \times (0{,}974)^{RMCI} \tag{3}$$

$$RMCI = \sigma_c \times (RQD/100)^{2/3} \tag{4}$$

where *ICR* is the instantaneous cutting rate (m^3/cutting hour), P is the power of cutting head (hp), *RMCI* is the rock mass cuttability index, σ_c is the uniaxial compressive strength (MPa) and *RQD* is the rock quality designation (%). Copur et al. (1997, 1998) studied the variation of cutting rate with *UCS* based on available field performance data for different types of roadheaders at different geological conditions. They stated that if power and weight of roadheaders were considered together, in addition to rock compressive strength, the cutting rate predictions would be more realistic. The predictive equations for transverse (ripping type) roadheaders are as follows:

$$ICR = 27{,}511e^{0.0023(RPI)} \tag{5}$$

$$RPI = P \times W/UCS \tag{6}$$

Here, *ICR*, *RPI*, *UCS*, *W*, *P* and *e* denote instantaneous cutting rate (m³/hr), roadheader penetration index, uniaxial compressive strength (MPa), roadheader weight (*t*), power of cutting head (kW), and base of natural logarithm, respectively. Thuro and Plinninger (1999) determined the relationship between the cutting rate and the uniaxial compressive strength for 132 kW roadheader. They found that the correlation between *UCS* and cutting performance is not sufficient in predicting the cutting rate. They obtained higher correlation by putting the cutting performance against specific destruction work (kJ/m³). Specific destruction work (W_z) is defined as the measurement for the quantity of energy required for destruction of a rock sample or – in other words – the work, necessary to built new surfaces (or cracks) in rock. They presented the following predictive equation:

$$CR = 107.6 - 19.5\ln(W_z) \tag{7}$$

where CR and W_z are the cutting performance (m³/hr) and the specific destruction work (kJ/m³), respectively.

Another way of predicting the machine instantaneous cutting rate is to use specific energy described as the energy spent to excavate a unit volume of rock material. Widely accepted rock classifications and assessments for the performance estimation of roadheaders are based on the specific energy found from core cutting tests. Detailed laboratory and in situ investigations by McFeat-Smith and Fowell (1977, 1979) showed that there was a close relationship between specific energy values obtained separately from both core cutting tests and cutting rates for medium and heavy weight roadheaders. One of the most accepted methods to predict the cutting rate of any excavating machine is to use, cutting power, specific energy obtained from full scale cutting tests and energy transfer ratio from the cutting head to the rock formation as indicated in the following equation (Rostami et al, 1994):

$$ICR = k\frac{P}{SE_{opt}} \tag{8}$$

where *ICR* is the instantaneous production rate (m³/cutting hour), *P* is the cutting power of the mechanical miner (kW), SE_{opt} is the optimum specific energy (kWh/m³), and k is the energy transfer coefficient depending on the mechanical miner utilized. Rostami et al. (1994) strongly emphasized that the predicted value of the cutting rate was more realistic if the specific energy value in the equation was obtained from the full-scale linear cutting tests in optimum conditions using real life cutters. Rostami et al. (1994) pointed out that k changed between 0.45 and 0.55 for roadheaders and from 0.85 to 0.90 for TBMs.

3. Previous predictive models in Tabas coal mine

Tabas Coal Mine is the largest and fully mechanized mine, located at about 75 km from the city of Tabas in the central Iranian province of Yazd. The mine area is a part of Tabas-Kerman coal field which is divided into three parts, the biggest being the Parvadeh region with an extent of 1200 Km² and estimated 1.1 billion tones of coal reserve. This is the main part to be excavated and fulfillment the future needs. In the Tabas mine, four DOSCO MD 1100 roadheaders of 34 t in weight, with an 82-kW axial cutting head were mainly used in driving galleries with coal measure rocks (coal, siltstone and mudstone). Figs. 1 and 2 show DOSCO MD 1100 roadheader and typical view of rock formations encountered in the tunnels route. Table 1 indicates the basic specifications of these roadheaders (Dosco Ltd, 2008).

As main part of study, a comprehensive database of field performance from Tabas Coal Mine was formed out of the detailed data including machine performance and geomechanical parameters for 62 cutting cases in tunnels and entries of the proposed project (Ebrahimabadi, 2010).

After statistical analysis of database, the rock mass brittleness index (RMBI) is defined in order to investigate the influence of intact and rock mass characteristics on roadheaders perform-

Fig. 1. DOSCO MD1100 roadheader fitted with axial boom used in Tabas Coal Mine project (Dosco Ltd, 2008)

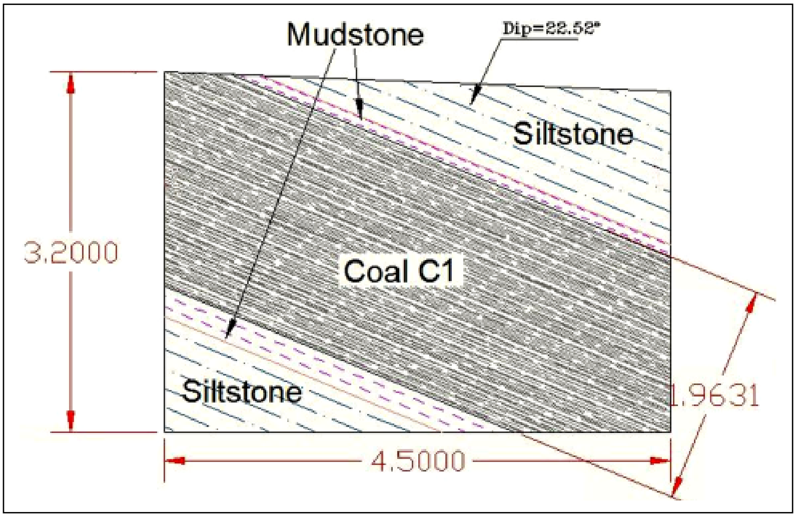

Fig. 2. Typical view of rock formations encountered in the tunnels route. (All dimensions are in meter)

ance. Results demonstrated that *RMBI* is correlated to instantaneous cutting rate (*ICR*) ($R^2 = 0.92$). The predictive equations are as follows (Ebrahimabadi, 2010; Ebrahimabadi et al., 2011):

$$RMBI = e^{\left(\frac{\sigma_c}{\sigma_t}\right)} \times \left(\frac{RQD}{100}\right)^3 \tag{9}$$

$$ICR = 9.07\ln(RMBI) + 29.93 \tag{10}$$

where *RMBI* is the rock mass brittleness index, σ_c is the uniaxial compressive strength of rock (MPa), σ_t is the Brazilian tensile strength of rock (MPa), and *RQD* is the rock quality designation of the rock mass (%).

TABLE 1

Typical specifications of DOSCO MD 1100 roadheaders

Machine weight (Base machine)	34 tons
Total power (Standard machine)	From 157 kW
Power on cutting boom (Standard machine)	82 kW axial, 112 kW transverse
Hydraulic system working pressure	140 bar
Tracking speeds – Sumping/Flitting	0.038/0.12 m/sec
Ground pressure	1.4 kg/cm²
Machine length	8060 mm
Machine width	3000 mm
Machine height	1700 mm

4. Database completion

As cited before, during excavation stages in Tabas Coal Mine, the authors gathered the related field data including machine performance and geotechnical parameters, in order to establish a database for performance estimation of the roadheaders. The instantaneous cutting rates were continuously recorded under highly controlled condition for each cutting case. Moreover, in order to establish a more comprehensive database for generating a universal model, the data collected by BILGIN et al [2-4] from Besiktas, Kurucesme, Baltalimani, Eyup and Halic tunnels were added to the database from Tabas mine. However, it should be noted that the tensile strengths of some data (except Tabas Coal Mine) were not available; hence, their values were determined from one tenth of their uniaxial compressive strengths.

5. Model construction

After establishing the database, statistical analysis was used to investigate the relation between parameters.

Consequently, first, the *RMBI* was applied to the database and then, the relation between *ICR* and *RMBI* was investigated that showed a poor correlation with (R^2) of 0.31, not allowing any trends to be deduced from them, as shown in Fig. 3. It shows the need of a further analysis to find a more accurate and reliable relation between these parameters.

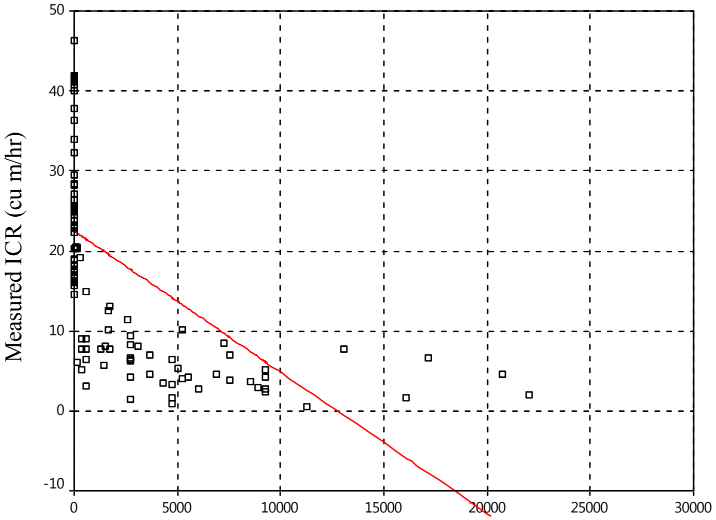

Fig. 3. Relation between measured *ICR* and *RMBI* for all cutting cases ($R^2 = 0.31$)

After a broad modeling and analysis, the absolute values of *RMBI* logarithm ($|\log RMBI|$) as shown in Fig. 4 found to have a higher correlation with the measured *ICR* values ($R^2 = 0.73$). Table 2 highlights the summary of statistical model. The prediction model is as:

$$ICR = 35.22e^{-0.54\times|\log RMBI|} \tag{11}$$

Here, *ICR* and *RMBI* are the instantaneous cutting rate (m³/hr) and the rock mass brittleness index, respectively.

Fig. 5 shows the comparison between the measured and predicted *ICR* (Eq. (11)). Using the proposed equation, relationship between the predicted and the measured *ICR* were achieved with $R^2 = 0.62$. It can be concluded that this model can be fairly used to predict the *ICR* in excavation of all kinds of rock formations with medium duty roadheader fitted with axial cutter head.

TABLE 2

Summary of statistical model

Model Type	R^a	R^2	Adjusted R^2	Std. error of the estimation
Exponential	0.85	0.73	0.73	0.50820

Dependent variable: Measured *ICR* (m³/hr)

a. Predictors: (Constant), $|\log RMBI|$

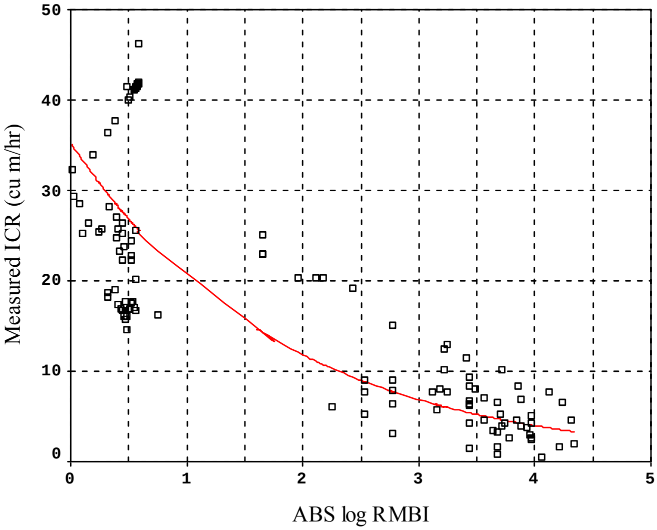

Fig. 4. Relation between measured *ICR* and $|\log RMBI|$ ($R^2 = 0.73$)

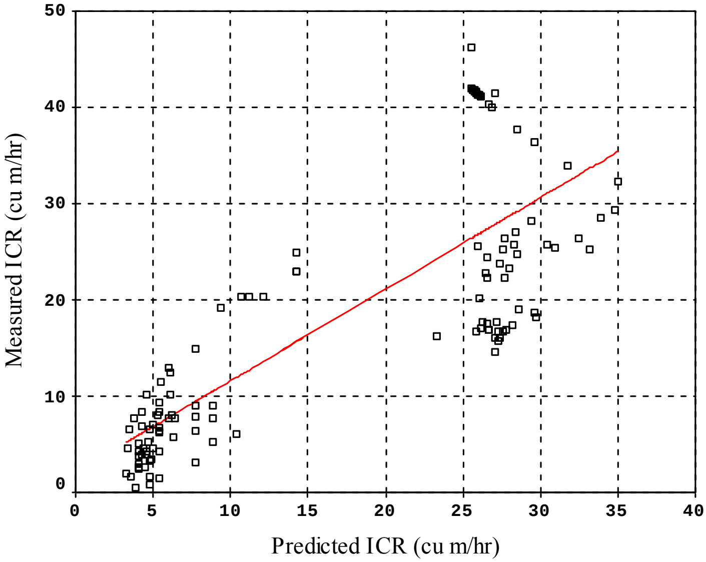

Fig. 5. Linear regression between measured and predicted *ICR* for all cutting cases using universal model ($R^2 = 0.62$)

6. Comparison of local and universal models

In order to verify the universal model for an specific project (Tabas Coal Mine), measured and predicted *ICR* at Tabas was compared using local (Eq. (10)) and universal (Eq. (11)) models. In this respect, as Table 3 shows, relative errors were calculated for each cutting case and mean relative errors regarding values predicted by the above equations were subsequently compared together.

TABLE 3

Measured and predicted *ICR* (using Eqs. (10) and (11)) with percentage of their relative errors in Tabas Coal Mine

Case No.	**Measured instantaneous cutting rate (m^3/hr)**	**Predicted instantaneous cutting rate using Eq. (10) (m^3/hr)**	**Predicted instantaneous cutting rate using Eq. (11) (m^3/hr)**	**Relative error between measured and predicted *ICR* using Eq. (10) (%)**	**Relative error between measured and predicted *ICR* using Eq. (11) (%)**
1	22.2	20.8	27.7	0.066	0.246
2	25.3	20.6	27.6	0.186	0.091
3	24.8	21.8	28.5	0.121	0.148
4	23.7	20.3	27.4	0.142	0.156
5	23.2	21.2	28.0	0.090	0.205
6	22.8	19.0	26.5	0.166	0.164
7	27.1	21.7	28.4	0.199	0.050
8	25.7	21.5	28.5	0.163	0.111
9	25.6	18.3	26.0	0.287	0.015
10	20.2	18.3	26.0	0.093	0.286
11	28.2	23.0	29.4	0.185	0.042
12	24.4	19.1	26.6	0.217	0.088
13	26.4	20.8	27.7	0.215	0.048
14	25.7	24.4	30.5	0.051	0.186
15	41.5	40.0	27.1	0.035	0.346
16	46.2	42.3	25.5	0.086	0.448
17	32.2	30.1	35.0	0.065	0.086
18	16.7	20.2	27.3	0.205	0.630
19	17.4	21.4	28.2	0.227	0.620
20	16.8	19.3	26.7	0.145	0.586
21	17.0	18.5	26.2	0.088	0.539
22	17.5	19.1	26.6	0.093	0.520
23	16.8	20.9	27.8	0.239	0.651

TABLE 3

Measured and predicted *ICR* (using Eqs. (10) and (11)) with percentage of their relative errors in Tabas Coal Mine (Continued)

Case No.	Measured instantaneous cutting rate (m³/hr)	Predicted instantaneous cutting rate using Eq. (10) (m³/hr)	Predicted instantaneous cutting rate using Eq. (11) (m³/hr)	Relative error between measured and predicted *ICR* using Eq. (10) (%)	Relative error between measured and predicted *ICR* using Eq. (11) (%)
24	16.7	18.1	25.9	0.089	0.555
25	16.1	20.3	27.4	0.259	0.699
26	17.7	20.1	27.2	0.136	0.540
27	16.0	19.8	27.1	0.239	0.693
28	17.0	19.2	26.6	0.135	0.569
29	14.6	19.9	27.1	0.358	0.850
30	19.0	21.9	28.5	0.150	0.497
31	17.7	18.7	26.3	0.055	0.485
32	15.7	20.2	27.3	0.283	0.737
33	18.7	23.3	29.6	0.244	0.580
34	16.8	20.6	27.6	0.228	0.643
35	18.3	23.4	29.7	0.281	0.625
36	26.4	26.8	32.4	0.013	0.226
37	25.3	27.7	33.2	0.093	0.311
38	28.5	28.4	33.9	0.001	0.191
39	25.4	24.9	30.9	0.019	0.215
40	29.4	29.5	34.8	0.002	0.183
41	22.4	19.2	26.6	0.144	0.189
42	36.4	36.6	29.6	0.005	0.187
43	37.7	38.0	28.5	0.007	0.245
44	40.4	40.7	26.6	0.007	0.341
45	41.1	41.3	26.1	0.007	0.364
46	41.1	41.4	26.1	0.007	0.365
47	41.4	41.6	25.9	0.006	0.374
48	41.6	41.9	25.8	0.006	0.380
49	41.8	42.0	25.7	0.006	0.385
50	34.0	33.9	31.8	0.003	0.065
51	40.0	40.3	26.9	0.008	0.328
52	41.3	41.5	26.0	0.006	0.370
53	41.3	41.6	26.0	0.006	0.371
54	41.5	41.7	25.9	0.006	0.375
55	41.5	41.8	25.8	0.006	0.379
56	41.6	41.8	25.8	0.006	0.380
57	41.7	41.9	25.7	0.006	0.383
58	41.8	42.0	25.7	0.006	0.384
59	41.8	42.0	25.7	0.006	0.385
60	41.9	42.1	25.6	0.006	0.389
61	41.8	42.0	25.7	0.006	0.385
62	41.9	42.2	25.6	0.006	0.390
Mean relative error				0.100	0.359

As Table 3 shows, the mean relative error of the predicted *ICR* using local model (0.100%) is lower than the mean relative error of the predicted *ICR* using universal model (0.359%) hence; shows a remarkable difference between the values. Consequently, as indicated before by Copur et al (1998), it is strongly suggested that the site specific rather than universal models should be developed to improve the accuracy and reliability of the predictive models.

7. Conclusions

The proposed research, in order to provide a universal model to investigate the cutting performance of roadheaders primarily presented the results achieved from previous attempts at the Tabas Coal Mine project. Those investigations defined rock mass brittleness index (*RMBI*) in order to relate the intact and rock mass characteristics to machine performance. The statistical analysis of Tabas demonstrated that *RMBI* is highly correlated to instantaneous cutting rate (*ICR*) of roadheaders ($R^2 = 0.92$). Consequently in the latest effort, in order to construct a universal model for predicting the roadheader performance, the authors established a database consisting of the measured cutting rate of roadheaders as well as data from Tabas Coal Mine and Besiktas, Kurucesme, Baltalimani, Eyup and Halic tunnels. Here, *RMBI* is calculated for each cutting case of the database and then the relation between *ICR* and *RMBI* was investigated that showed a poor correlation with (R^2) of 0.31, not allowing any trends to be deduced between them. With a further modeling and analysis, the absolute values of *RMBI* logarithm found to have a higher correlation with the measured *ICR* values ($R^2 = 0.73$), resulting in a new predictive model for roadheaders performance. The correlations between the measured and predicted *ICR* using the new model was found to be relatively fair ($R^2 = 0.62$). It means that the new predictive model can cautiously be used to predict the performance of roadheaders for different rock formations. In other words, it can be a useful primary guide to evaluate the roadheader cutting performance before starting a tunneling project to compare with the other excavation methods. Moreover, results acquired from application of two above models for Tabas Coal Mine showed that there was a remarkable difference between measured and predicted *ICR*. The mean relative error of 0.359% was found with universal model but it represented lower value (mean relative error of 0.100%) while using local model. It can thus be concluded that instead of generating a universal model, separate localized models for different ground and machine conditions should be developed to improve the accuracy and reliability of the performance prediction similar to the one presented for the performance prediction of roadheaders employing in Tabas project.

References

Bilgin N., Seyrek T., Shahriar K., 1988. *Roadheader performance in Istanbul, Golden Horn clean-up contributes valuable data*. Tunnels and Tunnelling, June, 41-44.

Bilgin N., Seyrek T., Erdinc E., Shahriar K., 1990. *Roadheaders glean valuable tips for Istanbul Metro*. Tunnels and Tunnelling, October, 29-32.

Bilgin N., Yazici S., Eskikaya S., 1996. *A model to predict the performance of roadheaders and impact hammers in tunnel drivages*. Proceedings of Eurock '96, Balkema, 715-720.

Bilgin N., Kuzu C., Eskikaya S., 1997. *Cutting performance of rock hammers and roadheaders in Istanbul Metro drivages*. Proceedings of the Word Tunnel Congress'97, Tunnels for People, Balkema, 455-460.

Bilgin N., Dincer T., Copur H., Erdogan M., 2004. *Some geological and geotechnical factors affecting the performance of a roadheader in an inclined tunnel*. Tunnelling and Underground Space Technology, Vol. 19, 629-636.

Copur H., Rostami J., Ozdemir L., Bilgin N., 1997. *Studies on performance prediction of roadheaders*. Proceedings of the 4th International Symposium on Mine Mechanization and Automation, Brisbane, Qld., Australia, A4-1–A4-7.

Copur H., Ozdemir L., Rostami J., 1998. *Roadheader applications in mining and tunneling*. Mining Engineering, Vol. 50, 38-42.

Douglas W., 1985. *Roadheaders open new horizons at San Manuel*. Engineering and Mining Journal, Vol. 186, 22-25.

DOSCO Overseas Engineering Ltd, Newark Nottinghamshire, England, www.dosco.co.uk, 2008.

Ebrahimabadi A., 2010. *A model to predict the performance of roadheaders in tunneling*. Ph.D. Thesis, Azad University, Science and Research Branch, Tehran, Iran (Unpublished).

Ebrahimabadi A., Goshtasbi K., Shahriar K., Cheraghi Seifabad M., 2011. *A model to predict the performance of roadheaders based on rock mass brittleness index*. Journal of the South African Institute of Mining and Metallurgy, Vol. 111, No. 5, 355-364.

Ebrahimabadi A., Goshtasbi K., Shahriar K., Cheraghi Seifabad M., 2011. *Predictive models for roadheader's cutting performance in coal measure rocks*. Yerbilimleri, Vol. 32, No. 2, 89-104.

Gehring K.H., 1989. *A cutting comparison*. Tunnels and Tunnelling, November, 27-30.

Jaszczuk M., Kania J., 2008. *Coal production costs components and coal price as crucial factors in the designation of coal output*. Archives of Mining Sciences, Vol. 53, No. 2, 183-214.

McFeat-Smith I., Fowell R.J., 1977. *Correlation of rock properties and the cutting performance of tunnelling machines*. Conference on Rock Engineering, UK, organized jointly by the British Geotechnical Society and Department of Mining Engineering, The University of Newcastle Upon Tyne, 581-602.

McFeat-Smith I., Fowell R.J., 1979. *The selection and application of roadheaders for rock tunneling*. Proceedings of the Rapid Excavation and Tunnelling Conference, Atlanta, Vol. 1, 261-279.

Rostami J., Ozdemir L., Neil D.M., 1994. *Performance prediction: a key issue in mechanical hard rock mining*. Mining Engineering, November, 1263-1267.

Rostami J., Ozdemir L., 1996. *Modeling for design and performance analysis of mechanical excavators*. Proceedings of the Conference on Mechanical Excavation's Future Role in Mining, World Rock Boring Association, Sudbury, Ont., Canada, September, 17-19.

Sandbak L.A., 1985. *Roadheader drift excavation and geomechanical rock classification at San Manuel, Arizona*. Proceedings of the Rapid Excavation and Tunnelling Conference, New York, Vol. 2, 902-916 (Chapter 54).

Thuro K., Plinninger R.J., 1999. *Predicting roadheader advance rates*. Tunnels and Tunnelling, Vol. 31, 36-39.

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