A Model to Predict The Performance of Roadheaders and Impact Hammers in Tunnel Drivages

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ABSTRACT: In this paper the recent sewerage and metro tunnel projects in Istanbul are summarized. A model improved as a part of NATO - TU Excavation project, that relates the cutting performance of mechanical excavators to rock mass cuttability index, is discussed with the recent data collected. The model may serve as a useful guide to contractors and machine manufacturers prior starting a tunnel project.

RESUME: Dans cet exposé on a resumé les derniers travaux dans les tunnels d'Istanbul. On a realisé ce model soutenu par le projet " NATO-TU Excavation" et on a défini l'index de rupture des roches en tenant compte la performance mécanique des tunneliers à l'état de creusement. On a critiqué aussi ce model en prenant base les données obtenues durant les travaux dans les tunnels. Nous pouvons dire que ce modele sera guide aux autres participants aux creusement des tunnels.

ZUSAMMENFASSUNG: Mit dieser Arbeit werden die jüngsten Tunnelprojekte in Istanbul vorgestellt. Im Rahmen NATO-Excavation Project wurde ein Modell, das die Leistungen der mechanischen Vortriebsmaschinen mit Hilfe eines definierten Schneidindex für Gesteine feststellt, entwickelt. Das Modell wird mit den hier gesammelten Daten getestet. Es wird noch erklärt, daß das hier vorgestellte Modell schon in der Planungpshase des Tunnels für den Zulieferer- und Tunnelbaufirmen ein Wegweiser sein wird.

1 INTRODUCTION

Roadheaders have been widely used both in civil and mining industries since 1970. The main advantages are mainly; high advance rates, safety, less strata disturbances and less labor. The capital cost of these machines is very high, so if they are not selected considering rock mass properties the consequences might be a nightmare for tunnel engineer. A contractor is always interested in predicting the machine performance prior to starting a tunnel project that will definitely define the tunnel drivage economy. The past few research works were focused on the prediction of the performance of roadheaders or TBM's from laboratory rock cutting tests. The work originated in Newcastle Upon Tyne University dealt with the correlation of in-situ data with the results of core cutting tests (Fowell and McFeat-Smith, 1976; McFeat-Smith and Fowell, 1977, 1979). In that study the specific energy obtained from small scale rock cutting test was the key factor in the machine performance prediction. A more realistic model was developed by using full scale rock cutting test results in Earth Mechanics Institute of Colorado School of Mines by Ozdemir and Rostami, et al. (1994); Ozdemir (1995). However, the work described in this paper differs from the two previously mentioned in the fact that it is based on the statistical interpretation of the field data that has been collected since 1988 from different sewerage tunnels in Istanbul (Bilgin, et al., 1988, 1990; Seyrek, et al., 1994).

2 FACTORS AFFECTING THE CUTTING PERFORMANCES OF ROADHEADERS AND IMPACT HAMMERS

Factors affecting the cutting performances of mechanical excavators can be summarized as below:

-Job organization and skill of machine operator affect the machine utilization time that plays an important role in determining job duration time. Machine utilization time for roadheaders increases to 60 % with a well organized job site and an experienced operator.

-The design of cutter head and the machine cutting power,

-Impact hammer design characteristics and

-Rock intact and mass properties.

The model described in this paper only deals with the one aspect of performance prediction, i.e. instantaneous cutting rate defined as net cutting rate obtained when the machine is in cutting mode.

3 THE GEOLOGY

Paleozoic sedimentary formations from Lower Devonian to Middle Carboniferous are prevalent in the area. Many faults and geologic discontinuities developed due to Hercinian and Alpine Orogenies. The rock formation, locally named Trakya Formation is formed of fine grained, laminated, fractured and interbedded siltstone and mudstone. RQD values vary between 0 and 90%. Some diabase dykes have also been encountered while driving the tunnels and these affected progress rates as they are significantly harder than rock excavated along the major part of the tunnel routes.

4 METHOD OF STUDY AND DESCRIPTION OF TUNNELS

Different zones were chosen for detailed site investigations in Beşiktaş, Kuruçeşme, Baltalimani, Eyüp and Haliç sewerage tunnels where Herrenknecht shielded roadheaders of 95 Hp cutting power were used. Levent Metro Tunnel was also chosen to study the performance of Montabert BRH 625 type impact hammer mounted on a Hitachi FH 200 E excavator. This hammer has an input power of 33 Hp.

The criteria used to select data collection zones depended mainly on geology. In each zone, data on tunnel geology, rock mass structure, intact rock properties and machine cutting performance were collected. Detailed studies of Eyüp and Haliç tunnels already published by the author (Bilgin, et al., 1988, 1990) showed that the main factors governing the performance of roadheaders were the rock compressive strength and RQD. Net cutting rate or instantaneous cutting rate could be best predicted from rock mass cuttability index as given by the following formula:

$$RMCI = \sigma_c \left(RQD/100 \right)^{2/3} \qquad (1)$$

where;

RMCI= Rock mass cuttability index, MPa,

σ_c= the rock compressive strength, MPa and

RQD= rock quality designation, %.

The field data collected in six different tunnels gave the opportunity to check the validity of this statistical relationship. In the following sections all the data will be interpreted as a whole to find a generalized relationship to define a model to predict the performance of mechanical excavators from rock mass properties

5 DATA ANALYSIS

Instantaneous cutting rates of roadheaders, rock compressive strength, rock quality designation and rock mass cuttability index values for Beşiktaş, Kuruçeşme, Baltalimani, Eyüp, and Haliç tunnels are listed in Table 1. The values obtained for impact hammers applications in Istanbul Levent Metro Tunnel are also given in this table. The analysis of field data both for roadheaders and impact hammers are explained below.

5.1 The analysis of data obtained from roadheader applications

For five different tunnels the instantaneous cutting rates of roadheaders are plotted against rock compressive strength in Figure 1. It can be concluded that there is no significant statistical relationship between these two variables. However if these two variables are plotted for the data having grouped values of RQD > 50 % and RQD < 50 % as seen in Figures 2 and 3, the effect of compressive strength on instantaneous cutting rate looks more significant for rock formations having rock quality designation values greater than 50 %. The relationship between instantaneous cutting rate and RQD for compressive strength values ranging between 90 and 100 MPa are given in Figure 4. It is apparent from the Figures 2 and 4 that RQD and rock compressive strength values should be considered in combination for performance prediction of roadheaders. The variation of instantaneous cutting rate with rock mass cuttability index is shown in Figure 5. The improved correlation strengths the conclusions previously published for Haliç and Eyüp Tunnels (Bilgin , et al., 1988, 1990). The relationships given in the figures were determined using a multiple curvilinear statistical methods.

5.2 *The analysis of field data for impact hammers*

The same statistical analysis technique as described above was also applied to data obtained from impact hammer applications in Istanbul Levent Metro Tunnel. The high correlation coefficient obtained from the relationship between instantaneous cutting rate of hydraulic hammers and rock mass cuttability index strongly emphasizes that for a performance prediction model of any mechanical excavator RQD and compressive strength should be considered together.

6 CONCLUSIONS

The analysis of field data in six different tunnels gave the opportunity to improve the roadheader performance predictor equations already published by Bilgin, et al. (1988 and 1990). The improved equations are stated below:

For roadheaders having cutting power of 95 Hp

$$ICR = 26.13 \, (0.974)^{RMCI} \qquad (2)$$

For impact hammers having input power of 33 Hp

$$ICR = 140.82\ (RMCI)^{-0.567} \qquad (3)$$

where;

ICR= instantaneous or net cutting rate, m^3/hr and

RMCI = rock mass cuttability index, MPa.

RMCI can be formulated as given below.

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

However, if the constants of the above equations are accepted proportional to the power of the machine as described by Breeds and Conway (1992) the above formulas may be generalized as given below:

For roadheaders

$$ICR = 0.28\ P\ (0.974)^{RMCI} \qquad (5)$$

For impact hammers

$$ICR = 4.24\ P\ (RMCI)^{-0.567} \qquad (6)$$

where;

P = the power of the machine, Hp.

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Table 1. Field data of roadheaders and impact hammer

ICR (m^3/h)	UCS (MPa)	RQD (%)	RMCI (MPa)
Beşiktaş Tunnel, Roadheader, 95 Hp			
9	106.4	25	42.2
5.3	106.4	61	76.5
7	65.4	55	43.9
8.3	69.4	50	43.7
4.6	98	68	75.8
1.6	98	90	91.3
4.2	100	63	73.5
6.4	70	50	44.1
8	70	41	38.6
Kuruçeşme Tunnel, Roadheader, 95 Hp			
3.9	71.7	70	56.5
2.9	71.4	74	58.4
2.7	103.4	75	85.3
3.7	103.4	73	83.8
3.4	103.4	58	71.8
Balta Limani Tunnel, Roadheader, 95 Hp			
5.1	69	75	57
2.4	69	75	57
4.6	70	55	47
4	106.4	62	77.4
4.3	67.9	75	56
5.7	67.9	40	36.9
Haliç Tunnel, Roadheader, 95 Hp			
6.9	104.1	70	82.1
6	150.2	20	51.3
9.4	82.9	50	52.2
6.7	69.5	50	43.8
6.3	72.7	50	45.8
4.2	76	50	47.9
0.5	155.7	80	134.2
1.5	157.1	50	98.9
3.3	82.2	60	58.5
6.5	94.3	60	67.9
1.7	126.2	60	89.8
0.8	127.9	60	91
7.7	159.1	25	63.1
5.2	146.5	25	58.1
2.7	106.2	65	79.8
9	102.8	30	46
6.4	89.2	30	40
3.1	154.1	30	69
7.8	132.8	30	59.5
15	42.0	30	18.8
Eyüp Tunnel, Roadheader, 95 Hp			
25	93.5	1	4.3
10.2	76	42	42.6
20.4	86.2	16	25.4
20.4	67.1	18	21.4
16.2	97.5	2	7.2
20.3	60.8	19	20.1

ICR (m^3/h)	UCS (MPa)	RQD (%)	RMCI (MPa)
Eyüp Tunnel, Roadheader, 95 Hp			
11.5	87.8	49	54.5
12.5	96.5	42	54.1
23	144.5	1	6.7
7.7	135.4	39	72.2
13	87.4	43	49.8
10.2	56.6	62	41.1
8	93	52	60.1
7.7	52.1	43	29.7
23	36.6	1	1.7
19.2	49.9	23	18.7
8.4	58.3	69	45.5
7.7	70.6	84	62.9
2	101.2	100	101.2
4.6	89.1	98	87.9
6.6	86.5	92	81.8
Levent Metro Tunnel, Impact Hammer, 33 Hp			
6	53	22	19.3
9.8	90	24	34.7
9	90	24	34.7
8.5	95	20	32.7
10	90	18	28.7
29	55	18	17.5
26	60	20	20.5
16.3	62	24	23.9
24	62	27	25.9
14.8	64	27	26.8
35	60	27	25.1
10	90	38	47.2
16	62	32	29
21.6	58	28	24.8
17.5	54	24	20.8
23.6	58	18	18.5
20	60	20	20.5
13	62	25	24.6
25	55	20	18.8
35.4	52	23	19.5
18.7	42	21	14.8
7.3	105	82	92
11.2	85	78	72
5	85	82	74.5
3.7	105	85	94
7.4	58	83	51.2
3.8	118	85	66.9
0.4	111	84	97.9
4	90	80	77.6
2.3	125	85	112.2
3.8	105	83	92.7
6.3	105	84	93.5
6.8	96	80	82.7
3.2	105	84	93.7

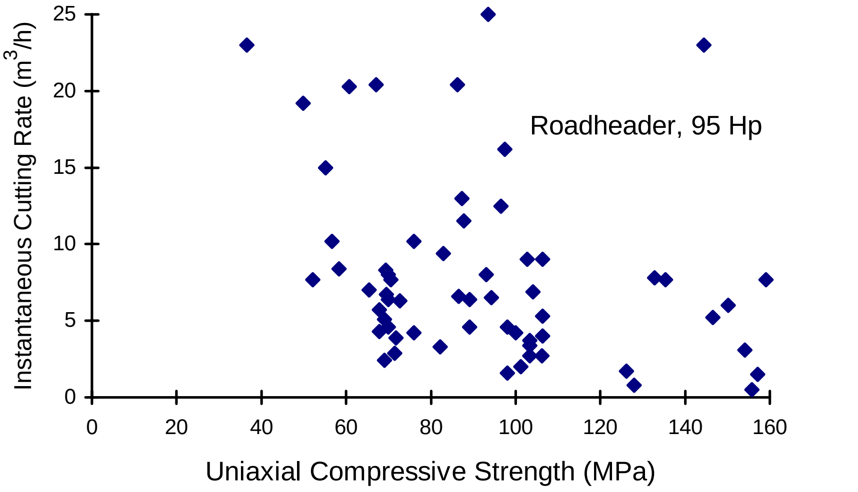

Figure 1. The variation of instantaneous cutting rate with uniaxial compressive strength of rock

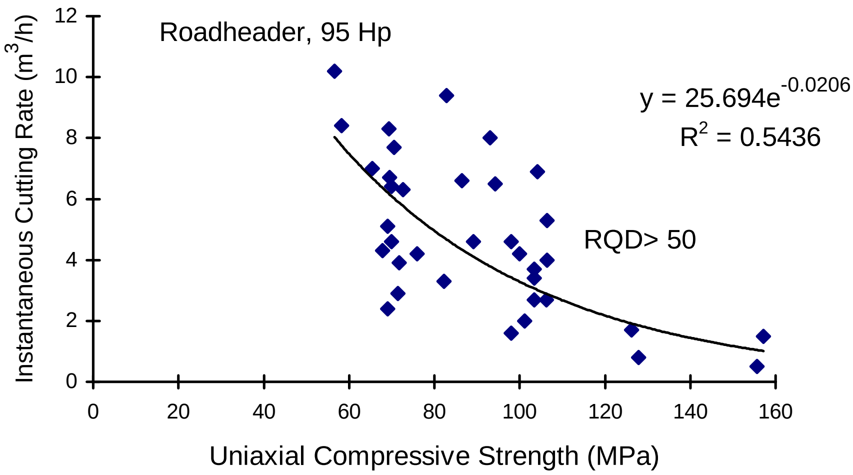

Figure 2. The variation of instantaneous cutting rate with uniaxial compressive strength of rock, RQD>50

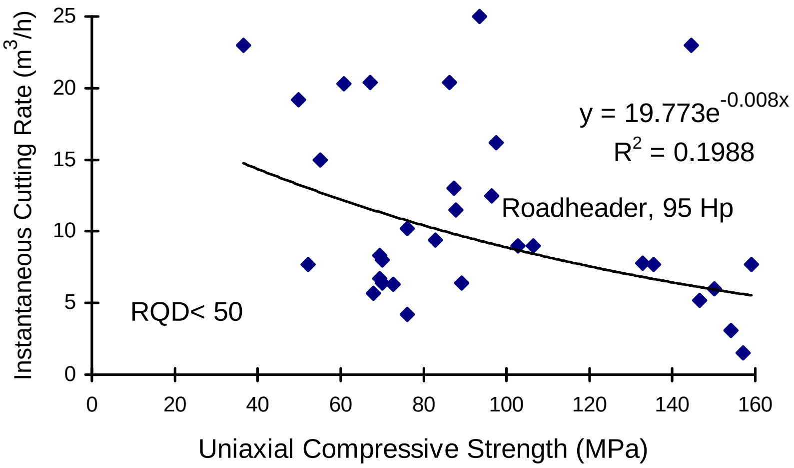

Figure 3. The variation of instantaneous cutting rate with uniaxial compressive strength, RQD<50

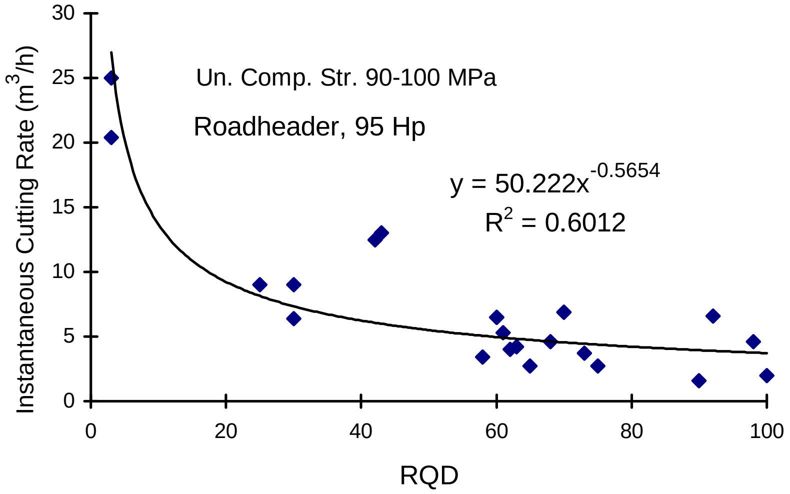

Figure 4. The variation of instantaneous cutting rate with RQD, σ_c= 90 - 100 MPa

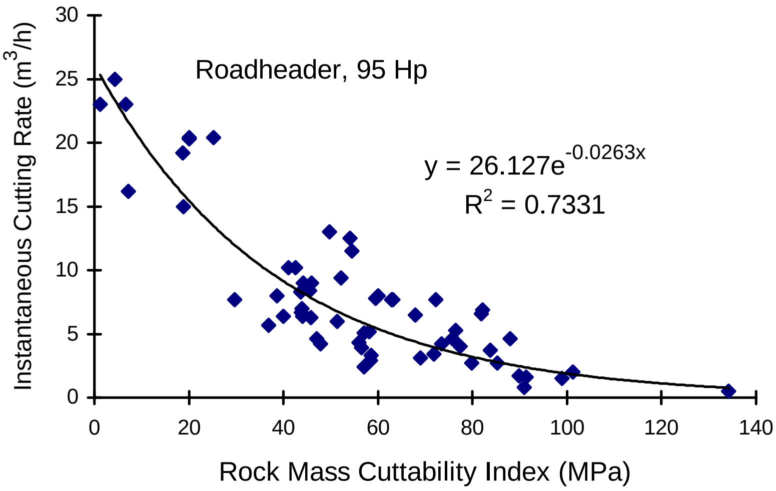

Figure 5. The variation of instantaneous cutting rate with Rock Mass Cuttability Index

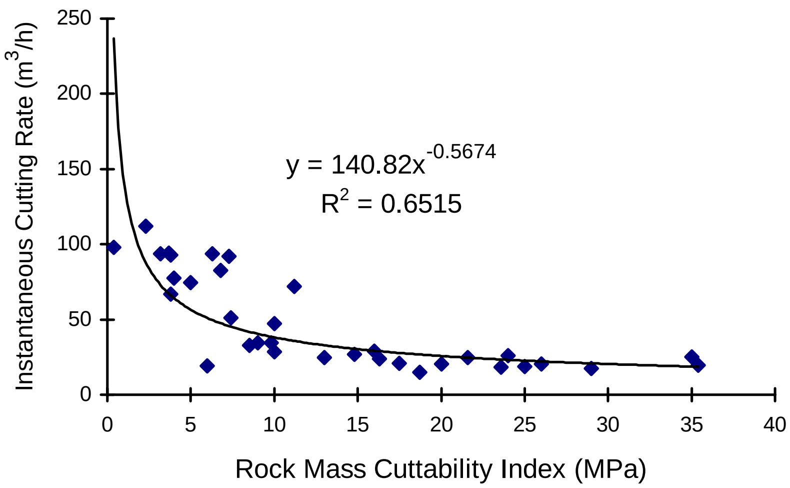

Figure 6. The variation of instantaneous cutting Rate With Rock Mass Cuttability Index for impact hammers