Cutting Performance of Jack Hammers and Roadheaders in Istanbul Metro Drivages

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ABSTRACT: The population of Istanbul, Turkey's biggest metropolitan area, the most important historical city and commercial center, has increased in the last two decades to more than a 10 million. Its ancient character and historical monuments severely restrict the construction of wide roads, consequently municipal authorities planned to solve the transportation problem in the city by starting the construction of 16 km, two lines metro at the end of 1992. This paper summaries first, Istanbul Metro project, construction method, the geology of the area and physical and mechanical pro-perties of the rock formation. All the shift data were collected carefully during the construction of the tunnels by the shift engineers of the contractor. The data was analyzed statistically as a main abjective of NATO TU-Excavation Project and the cutting performance of two roadheaders, ALPINE ATM 75 and EICKHOFF ET 250 used in Taksim line were compared with the performance of Jack Hammers, the main part of the conventional drivage technique used in most of the Istanbul Metro Tunnels. Rock mass properties were correlated with the performance of different mechanical excavators and general conclusion was drawn for further efficient applications.

ZUSAMMENFASSUNG: Istanbul, die wichtigste historische Stadt und Handelszentrum, ist die größte Metropolstadt der Türkei. Die Einwohnerzahl der Stadt hat die 10 Millionengrenzen besonders in letzten zwei Jahrzehnten sprunghaft überschritten. Sowohl die Antik-Karakter der Stadt als auch die zahlreichen historischen Bauten von denkmalischer Art erlaubt es nicht, in der Stadt weiten Straßen anzulegen. Dementsprechend wurde von der Stadtverwaltung ein U-Bahnprojekt vorgesehen, um Verkehrsproblemen lösen zu können. In diesem Rahmen wurde am Ende 1992 angefangen, eine 16 km lange doppelte U-Bahnstrecke aufzufahren. Hier werden die kurzgefaßten Informationen über das erste U-Bahnprojekt von Istanbul, über das Tunnelauffahrungsverfahren, über die Umgebungsgeologie und physikalisch-mechanischen Eigenschaften der Umgebungsformationen berichtet. Die Schichtdaten des Tunnelbauprojektes der Istanbuler U-Bahn wurde von den Schichtingenieuren des Tunnelbauunternehmers mit großer Vorsicht gesammelt. Die Daten werden statistisch analysiert und als Hauptbestandteil eines sog. anderen NATO-TU Excavation Research Project wurde die Schneidleistungen von in Taksim eingesetzten zwei Schneidkopfmaschinen von Typ ALPINE ATM 75 und EICKHOFF ET 250 wurden mit Schneidleistung der entsprechend dem ausgewählten Tunnelvortriebsverfahren im größten Teil der Istanbuler U-Bahn eingesetzten Schlagkopfmachine verglichen. Sog. rock mass-

Eigenschaften werden mit verschiedenen mechanischen Exkavatorleistungen korreliert und daraus für weitere Anwendungen Schlüsse gezogen.

1 INTRODUCTION

One of the most important factors in determining the job duration time of a tunnel project is the performance of the mechanical excavator used and the prediction of the performance plays a major role in decision making for the contractor.

The wide variation of geologic and geotechnical characteristics of the rock formations encountered around Istanbul gave the unique opportunity to correlate, in the past, the rock mass properties with the performance of spiral type or longitudinal roadheaders used to drive the tunnels of Istanbul sewerage project (Bilgin et al. 1988, 1990). It was clearly shown that instantaneous cutting rate of spiral type of roadheaders was related directly to the power of the machine and rock mass cuttability index defined as the product of the uniaxial compressive strength of the rock samples representing the tunnel face and RQD (Bilgin et al. 1996).

The performance data of tunnel drivages in Istanbul metro with jack hammers and roadheaders having transverse cutting heads were collected in the light of the findings mentioned above and the results were discussed in the following section of the paper. It is expected that the model developed will serve a sound basis in decision making for future application.

2 ISTANBUL METRO PROJECT

The construction of the first metro line in Istanbul between Galata and Beyoglu was realized by a French Engineer Henry Gavand in January 1875. Six different metro projects were submitted since then to the Turkish authorities and the final project planed by Istanbul Rail-Tunnel Consultants (Parsons Brinckerhoff, Kaiser Engineers etc.) in 1988 became the basis of the current undergoing metro project (Yalçin, 1994).

In 1992 Istanbul City Council appointed Yüksel Proje and IGT (Salzburg) to undertake the tendering, executive planning and supervision of the initial construction of 7 km long metro line, phase 1. The tendering documents were completed in June 1992 and the contractors Tekfen-Garanti, Koza, Enka, Doğuş, were rewarded the construction of the first and second section of the phase 1.

The dimensions of the main underground structures phase 1 of Istanbul Metro is given in table 1 (Ayaydin 1994). The construction of the tunnels were completed recently and it is expected that the phase 2 of the project will start soon. The route of metro line phase 1 and 2 is shown in figure 1.

Table 1: Characteristics of Istanbul Metro Tunnels (Ayaydin, 1994)

	Excavation area (m²)	Lengt h (m)
Single track tunnels (Type A)	36	11364
Platform tunnels (Type P)	64	1366
Connection tunnels-stations (Type B1)	42	418
Cross passage tunnels (Type B2)	22	413
Inclined shafts escalators (Type B3)	44	348
Turnout tunnels (Type T)	100	631
Pedesterian tunnels (Type P)	64	350
Bored tunnel total length:		14890
Three access tunnels (app. 30 m²) with total length of 400 m and two approach shafts (app. 80 m²), each 25 m deep, were also provided for.		
Single track	25	206
Double track	55	248
Cut and cover tunnel total length:		454
Station construction		
Excavation 550.000 m³		
Prestressed anchors (l = 14 - 35 m) 3.200		
Concrete 250.000 m³		

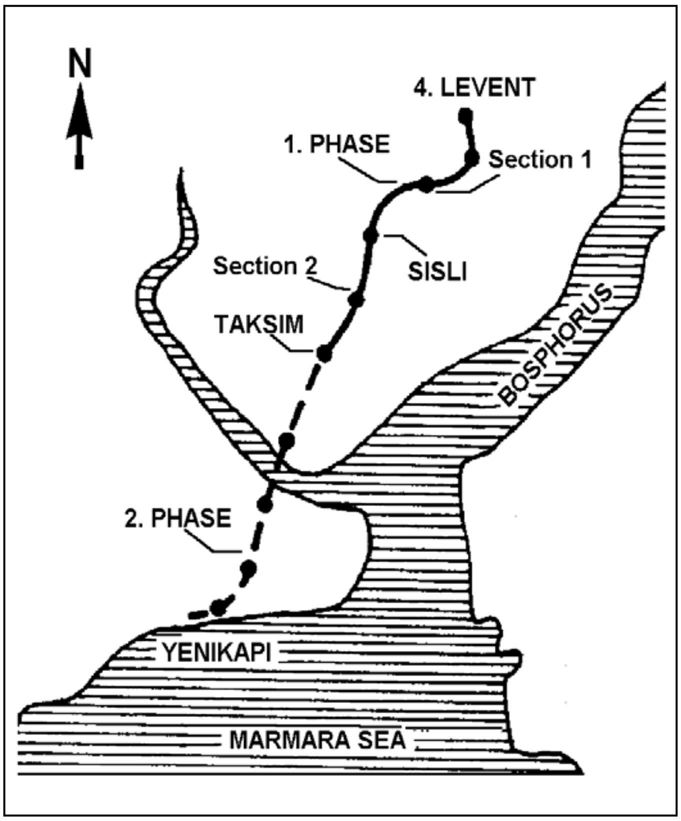

Figure 1. Main route of Istanbul Metro

2.1 *The Geology*

Trakya formation of the Carboniferous age is found in the area consisting of faine grained, laminated, fractured and interbedded siltstone, sandstone and mudstone. Some diabase or andezite 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 route. Many faults and geologic discontinuities are developed in the area due to Hercinian and Alpine Orogenies. RQD values varie between 0 % and 100 % and compressive strength between 30 and 150 MPa.

2.2 *Method of construction*

New Austrian Tunneling Method (NATM) has been used since the tunnel diameter and ground structure changes frequently along the route. 3-4 m long rock bolts, wire mesh and shotcrete were used as temporary tunnel support. Depending on tunnel diameters the final lining is undertaken with 35-45 cm thick in situ cast concrete.

Alpine ATM 75 and Eickhoff ET 250 type roadheaders were only used in small part of Taksim Tunnels. Jack hammers Krupp HM 185-720 and Montabert BRH 250 attached to Hitachi 200 Excavators were used mainly in the major parts of the metro tunnels. Drilling and blasting method was used when andezite and diabase dykes were encountered along the tunnel route.

3 THE PERFORMANCE OF ROADHEADERS AND JACK HAMMERS

Alpine ATM 75 transverse type roadheader having a cutting power of 200 kW was used in Taksim Platform Tunnel 2. Eickhoff ET 250 transverse type of roadheader having a cutting power of 250 kW was used in Taksim Platform Tunnel 1. Platform tunnels have a length of 238 m and cross section of 64 m^2. Krupp HM 185, HM 720 and Montabert BRH 250 Jack hammers attached to hydraulic excavators were used in Taksim-Levent line 2 tunnel. The hammer used in the part of the tunnel subjected to comparative study has a working power of 33 HP which is calculated by the product of oil pressure and flow rate.

The tunnel and machine performance data* are summarized in table 2 and figures 2, 3, 4, 5, 6, 7. The results show that the instantaneous cutting rates of roadheaders are almost twice than that of the jack hammers. Machine utilization time being 22 % for roadheader and 15 % for jack hammer can be resumed to be low for a succesful tunnel drivage. It may be conluded that the complexity of NATM tunneling method used for Istanbul metro is the main raison for such a low machine utilization time.

Table 2. Overall Performance of Roadheaders and Jack Hammers in Istanbul Metro

Advance Rate	Alpine ATM 75	Eickhoff ET 250	Jack Hammer
Average Ins. Cutting rate, m^3/h	23.2	21.3	11.9
Daily Advance, m	1.9	2.1	1.8
Avarage Weekly Advance, m	9.1	9.7	10.8
Avarage Monthly Advance, m	36.3	38.8	43.2
Best Daily Advance	4.5	3.8	3.6
Best Weekly Advance	2.3	2.6	2.2
Best Monthly Advance	2.3	2.7	2.2

* * Collected by shift engineers of the contractors Garanti-Koza-Enka-Doðuþ

4 THE COMPARAISON OF PREDICTED AND MEASURED DATA

A contractor is always interested in predicting the machine performance prior to starting a tunnel project that will definitely define the tunnel drivage economy. A model described by Bilgin et all (1996) gave the opportunity to predict the instantaneous cutting rate of roadheaders and jack hammers as described below.

For roadheaders

$$ICR = 0.28\ P\ (0.974)^{RCMI} \quad (1)$$

For Impact hammers

$$ICR = 4.24\ P\ (RCMI)^{-0.567} \quad (2)$$

In these equations

ICR = Instantaneous or net cutting rate, m^3/h
P = Cutting power of the machine, HP
RCMI = Rock mass cuttability index, MPa
RCMI = $\sigma_c\,(RQD/100)^{2/3}$ (3)
σ_c = Uniaxial compressive strength, MPa
RQD = Rock quality designation

The data collected by shift engineers of the tunnel contractors were revaluated in different zones where it was possible to obtain the mean values of the compressive strength and RQD representing the face. The zones marked from A to I are shown in figures 2, 3 and 4 and the values of the compressive strength and RQD of the face and the instantaneous cutting rates of mechanical excavators used in these zones are given in Table 3. The predicted values of instantaneous cutting rates given in table 3 are calculated using formulas 1, 2 and 3 which are given above. It is clearly seen from the relevant table 3 that the predicted values are very close to the actual values of net cutting rates suggesting that the model described by Bilgin at al (1996) is valid for both spiral and drum head roadheaders.

Table 3. Actual and Predicted Cutting Performance of Roadheaders and Impact Hammers in Selected Zones

Zone	Excavator	Compressive strength MPa	RQD	Actual ICR m^3/h	Predicted ICR m^3/h
A	Roadheader ATM 75	80	40	28	24
B		76	25	35	34
C		88	70	14	12
D	Roadheader ET 250	102	40	16	22
E		94	30	25	31
F		110	60	11	12
G	Impact Hammer BRH 250	118	70	10	11
H		120	80	8	10
I		85	30	14	18

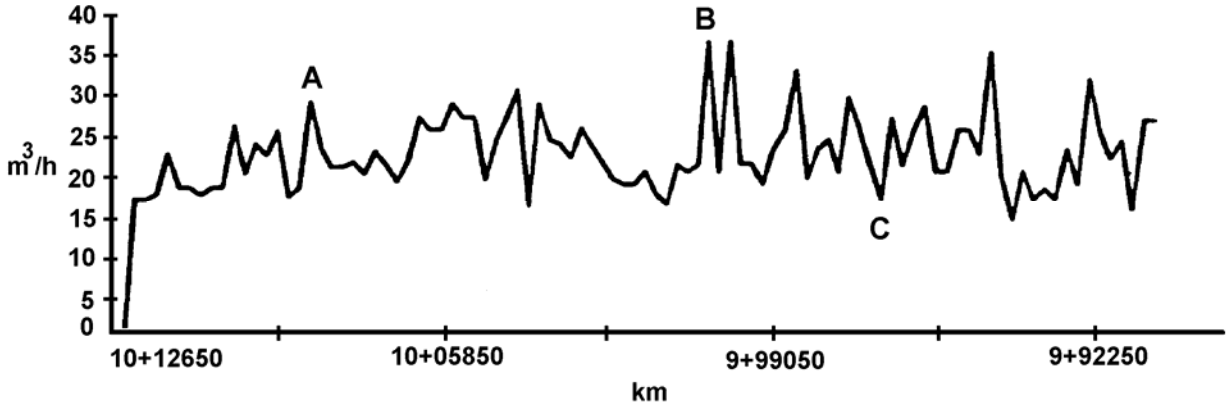

Figure 2. The Variation of Instantaneous Cutting Rate of Roadheader Alpine ATM 75 with Tunnel Chainage in Taksim Platform Tunnel 2

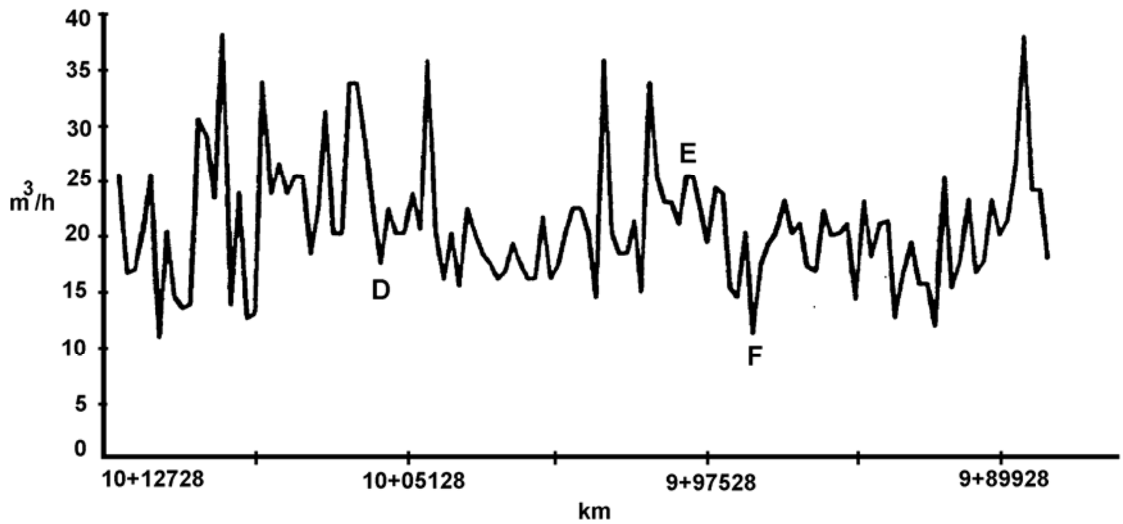

Figure 3. The Variation of Instantaneous Cutting Rate of Roadheader Eickhoff ET 250 with Tunnel Chainage in Taksim Platform Tunnel 1

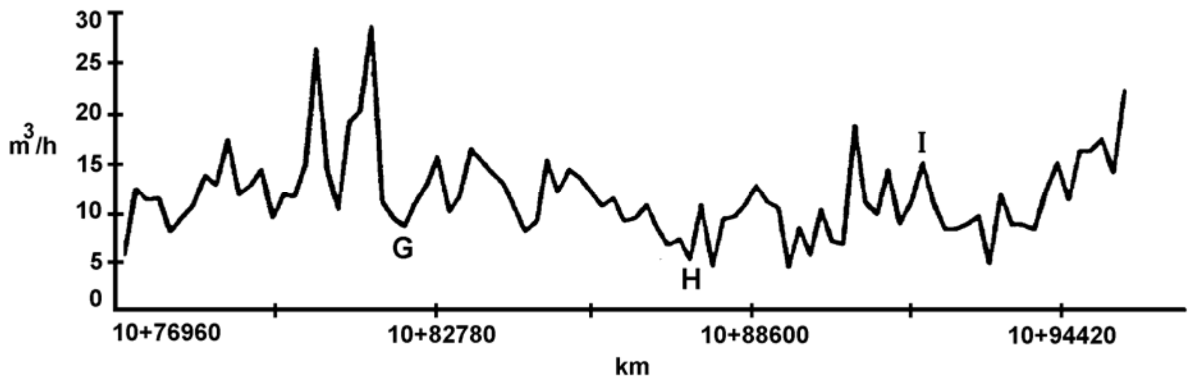

Figure 4. The Variation of Instantaneous Cutting Rate of Jack Hammer with Tunnel Chainage in Levent Line 2

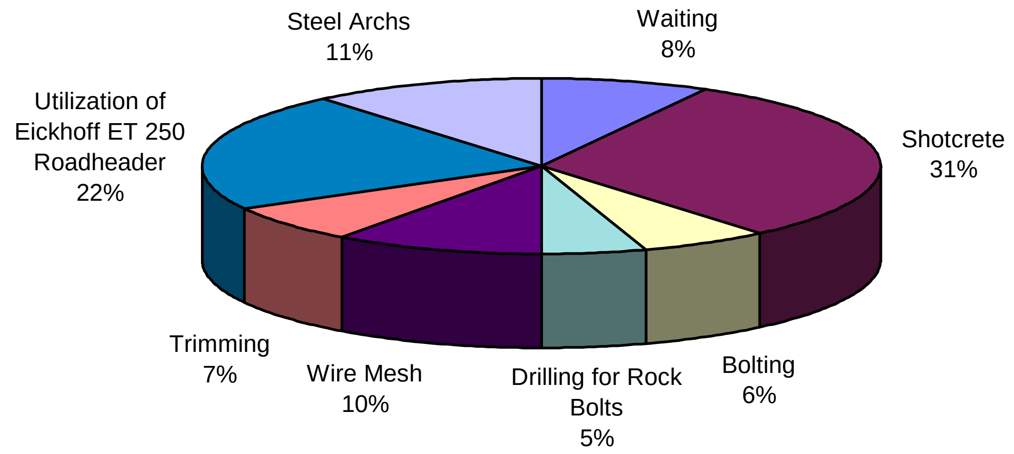

Figure 5: Overall Performance of Tunnel Drivage in Taksim Platform Tunnel 2

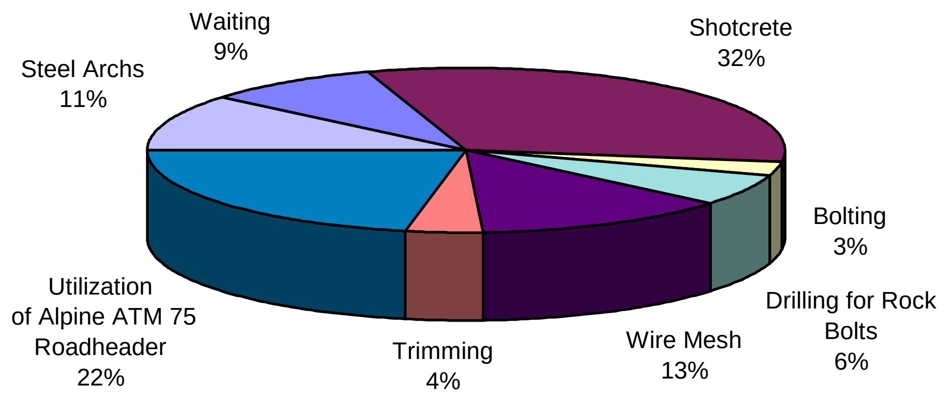

Figure 6: Overall Performance of Tunnel Drivage in Taksim Platform Tunnel 1

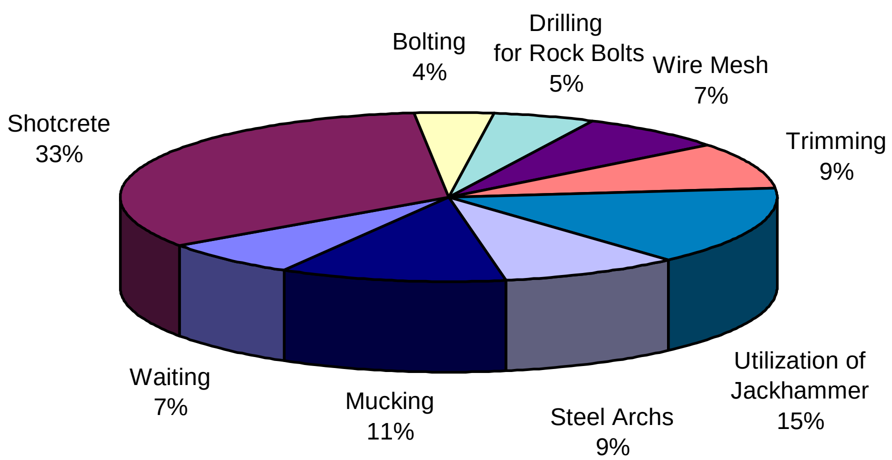

Figure 7: Overall Performance of Tunnel Drivage in Levent Line 2 Tunnel

5 CONCLUSIONS

The overall performance of Alpine ATM 75, Eickhoff ET 250 roadheaders and jack hammers used in Istanbul Metro drivages are compared in this paper. It was found that instantaneous cutting rates and machine utilization time of roadheaders are much higher than those of impact hammers. The complexity of NATM tunneling method used prevents the machine utilization time of roadheaders and jackhammers not to be greater than 22 % and 15 % respectively.

The model described by Bilgin et all (1996) to predict the instantaneous cutting head of spiral type roadheaders is tested for Istanbul Metro tunnels and it is proved that this method is also valid for drum or transverse type cutting heads.

6 ACKNOWLEDGEMENT

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