Tunnelling and Underground Space Technology 25 (2010) 181–187

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

# Comparative studies on the performance of a roadheader, impact hammer and drilling and blasting method in the excavation of metro station tunnels in Istanbul

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ARTICLE INFO

*Article history:*
Received 7 October 2008
Received in revised form 20 October 2009
Accepted 5 November 2009
Available online 26 November 2009

*Keywords:*
Tunnel excavation
Excavation performance
Machine utilization time

ABSTRACT

Drilling and blasting is the most widely used excavation method in mining and tunnelling especially in hard rock conditions. But in recent years, the application of roadheaders and impact hammers in hard rock, especially in fractured geological formations has increased considerably. However, it is strongly emphasized that the prediction of the machine performance plays an important role in the time scheduling and in the economy of tunnelling projects and accumulated data will serve a sound basis for performance prediction models.

This paper presents information on Istanbul Kadikoy–Kartal metro tunnels which are planned to be constructed in two stages, the first one which is in Kozyatagi–Kadikoy direction and the second in Kozyatagi–Kartal direction. The construction method of the Kozyatagi–Kadikoy station tunnels is first summarized and later, the performance of a roadheader, impact hammer and the results of drilling and blasting methods are compared.

The results of this study show that machine utilization time is 28.2% for roadheader and 14.2% for impact hammers. Average net cutting rates (NCR) are 32.26 $m^3$/h for roadheader (218.3 $m^3$/day), net breaking rate (NBR) 13.1 $m^3$/h (45 $m^3$/day) for impact hammers and production rate with drill and blast method (D&B) is found to be 187 $m^3$/day.



## 1. Introduction

The use of TBMs is found unfavourable in short tunnels and in these cases drilling and blasting method is preferred, however, this method is restricted in urban areas. In favourable conditions, roadheader and impact hammer are preferred due to many advantages over conventional methods. These include improved safety, minimal ground disturbances, elimination of blast vibration, reduced ventilation requirements and cost. Therefore, hydraulic impact hammers have been used widely in metro tunnelling projects in Istanbul since 1992. However, roadheaders have been also used in Taksim–Levent and Kadikoy–Kartal metro tunnels in some extend (Bilgin et al., 2002; Ocak et al., 2007).

Although many researchers investigated the factors affecting the performance of roadheaders and impact hammers it is believed that new published data will improve existing performance prediction models. (Bilgin et al., 1996, 1997, 2002, 2005, 2007; Copur et al., 1998; Thuro and Plinninger, 1998, 1999; Tumac et al., 2007; Ocak et al., 2007; Tuncdemir, 2007; Ocak, 2007, 2008). The main objective of this paper is to contribute to accumulated and published data from various tunnelling projects in Istanbul in order to improve predicting the machine performance to schedule and plan the tunnelling projects and determine the excavation efficiency.

The performances of a roadheader (Westfalia WAV 178) and impact hammer (MB 1700) mounted on the carriers, Volvo EC210B, Sumitomo SH200LC, and Caterpillar 3066T, are investigated. The main rock formations of study areas were Trakya and Kartal formations. The first stage of the project is commissioned to Yapi Merkezi–Yuksel–Dogus–Yenigun–Belen consortium. The metro tunnels are being currently excavated by two Herenknecht TBMs of 6.5 m diameter, detailed information about these machines may be found elsewhere (Bilgin et al., 2007). NATM is used only in the excavation of station tunnels which is the subject of this paper.

## 2. Description of the metro tunnel project

The population of Istanbul is approximately 14 million and one third of this population lives in Anatolian side. The project of Kartal

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doi:10.1016/j.tust.2009.11.002

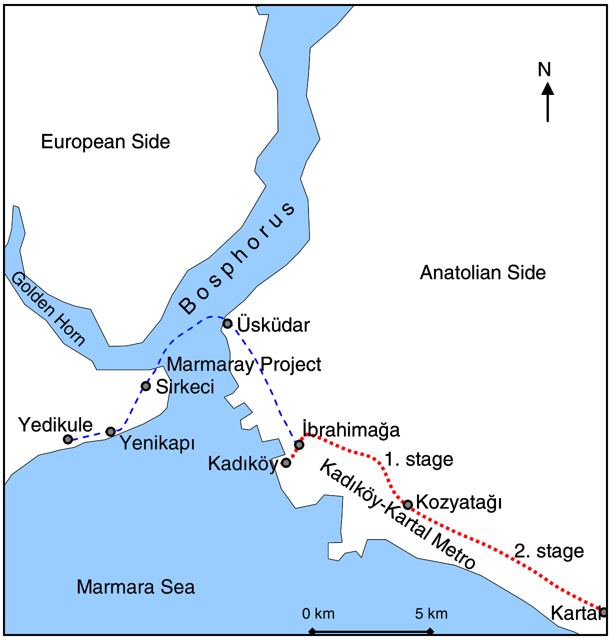


**Fig. 1.** The general layout of the Kadikoy–Kartal metro.

**Table 1**
Data of the project.

| | |
|---|---|
| Starting date of first stage excavation | May 2005 |
| The length of main line tunnels | 18.4 × 2 = 36.8 km |
| The length of station tunnels | 3.2 × 2 = 6.4 km |
| Cross section area of main line tunnel | 34.42 $m^2$ |
| Segment thickness of main line | 30 cm |
| Segment length | 1.5 m |
| Cross section area of station tunnels | 74.00 $m^2$ |
| Final lining for station tunnels | 40 cm |
| Number of stations | 16 |
| Capacity at peak hour | 60,000 passengers/h one direction |
| Maximum vehicle speed | 80 km/h |
| Mean vehicle speed | 43 km/h |

metro system is planned to meet the enormous transportation demand between East and West of Istanbul. The project will be integrated with Marmaray Project, which is under construction and which will connect European and Anatolian sides at Ibrahimaga station (Fig. 1).

The project of Kadikoy–Kartal metro system starts from Kadikoy square, joins the station of Marmaray Project at Ibrahimaga and extends up to Kartal. The metro project includes 16 stations in total. The project is composed of twin tunnels and the distance between the two tunnels is nearly 32 m. The excavation diameter of main tunnels is 6.62 m, and inner diameter is 5.70 m. Some of the data about the project are summarized in Table 1.

## 3. Site geology

Tunnels between Kozyatagi–Kadikoy are excavated generally in Trakya and Kartal formations (Fig. 2). Trakya formation of carboniferous age consists of sandstone–siltstone–claystone–mudstone–shale in sequences. Limestone and conglomerates layers are also rarely observed. Diabase and andesite dykes having some 10 m thickness are frequently encountered. In the east of tunnel alignment, Kartal formation of Devonian age is found. Kartal formation consists of fine-grained, laminated, fractured and interbedded siltstone, limestone, sandstone and shale. Water ingress is common in both Kartal and Trakya formations. Many faults dykes and geological discontinuities exist in the area due to Alpine Orogenies, creating alteration along discontinuity surfaces, the rock material in the contact zone between dykes and the main rock is highly weathered. The number of joint sets per meter occurring along the length of tunnel can be classified as class 3 (one joint set plus random) as defined by Brown (1981) and the number of discontinuities per meter as described by Brady and Brown (1985) changes between 15 and 20.

The overburden varies between 20 and 45 m, and the distance between twin tunnels is around 32 m. Geotechnical properties of two rock formations show a wide range of variance which are summarized in Table 2. A, B, C study zones are shown in Fig. 2.

## 4. Comparison of the performance of different excavation methods

The tunnel excavation of the first stage (Kozyatagi–Kadikoy) started in May 2005 with two TBMs and still continues. Impact hammers is used in the excavation of the station tunnels having length of 180 m. Roadheader is only used in Kozyatagi Station due to technical difficulties such as excessive cutter consumption and difficulty in transporting the machine within short length of station tunnels. Excavating machines are seen in Fig. 3 and main characteristics are given in Tables 3 and 4. The performances of these machines are recorded in detail during about 3 months. Table 5 gives a summary of overall performance of three different excavation methods for station tunnels.

MB 1700 type hydraulic hammers are used throughout the excavation of station tunnels. All the hammers are the same and have the following characteristics: weight 1.7 t, oil flow rate 130–160 lt/min, working pressure 160–180 bars, impact frequency 320–600 impact/min, impact energy 4170 J.

Determining the net cutting or breaking rate of mechanical excavators play an important role in tunnelling projects. The rela-

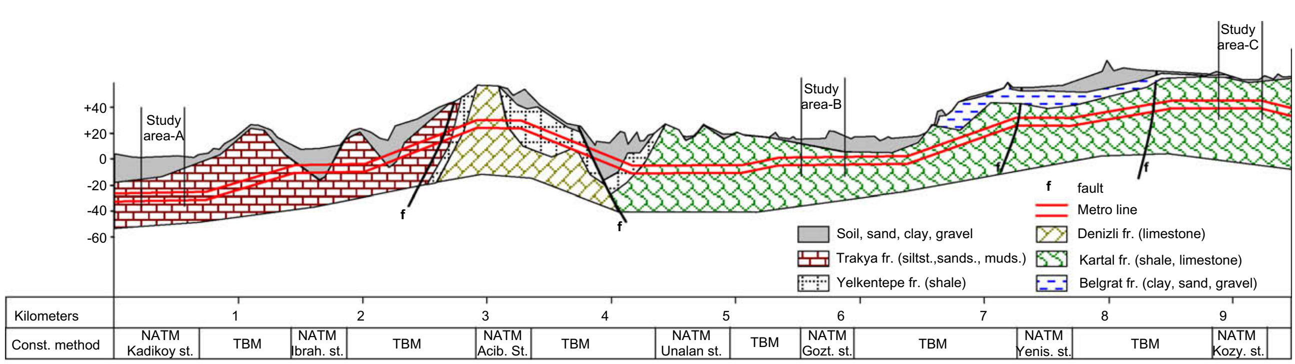


**Fig. 2.** Geological cross section of the Kadikoy–Kartal metro stage 1.