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Some contributions on the estimation of performance and operational parameters of raise borers – A case study in Kure Copper Mine, Turkey

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ABSTRACT

Excavation of shafts and other vertical structures in mining and civil engineering fields for material and human transportation and ventilation purposes is a difficult job taking quite long time to realize. Raise boring provides a safe means of excavating shafts between two levels of underground structures without using explosives. A Raise Boring Machine (RBM) operates by the principle of first drilling a small diameter pilot hole and then, reaming the hole in one or more stages to the desired size. Raise boring system is the most up-to-date, secure and fast way for boring large diameter shafts. This paper concerns about the estimation of the performance and operational parameters of a RBM used to excavate ventilation shafts in a copper mine located at the city of Kastamonu, Kure Province, on Northern Turkey. Length and diameter of the ventilation shaft are 22 m and 2.6 m, respectively. Borehole samples were collected during pilot hole drilling operation for performing physical and mechanical tests in the laboratory. Excavation performance parameters of RBM such as, penetration rate, cutterhead torque, and total thrust force were theoretically estimated based on the experimental results. Then, the realized and predicted values were compared to serve a useful guide for future applications. The main points emerging from this study is that Tunnel Boring Machines (TBM) and RBM cuts the rock applying the same basic principles of rock cutting mechanics. Specific energy values for both machines are in the same order for similar depth of cut and similar rock formation enabling to predict penetration rates of RBM from huge data of TBMs already published in the literature. It is also proved that the thrust forces for RBM may be predicted in massive rock as it is done for TBM based on projectile area of the cutter and rock compressive strength.

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1. Introduction

Raise boring technology was developed to meet the demands of mining industry, but has also found numerous applications in tunneling or infrastructural projects for ventilation purposes, even in very hard rock formations or in opening deep shafts. A raise boring machine operate on the principle of first drilling a small diameter pilot hole and the reaming the hole in one or more stages to the desired size. Raise boring machines are usually used for boring shafts and raises ranging from 0.7 to 9 m diameter and up to 2000 m length.

The basic history of the shaft excavation can be summarized based on Stack (1995) as follows: "Bade in 1949 did the first major breakthrough in shaft excavation. He tried to eliminate the necessity of intensive workmanship for shaft excavations in difficult conditions". Robert E. Cannon during the late 1950s embodied in German mine operation basic principles initiated by Bade, i.e., he drilled a small pilot hole and then enlarged this hole by back-reaming. Cannon 31R raise drill was used for drilling a 17 cm pilot hole and then back reamed with a 100 cm diameter reaming head, in Iron River Mine, Michigan in 1962. German Wirth Company in 1963 introduced an electro-hydraulic raise driller that the pilot hole was drilled from the lower level to the upper level then the hole was reamed downwards. Calweld-Smith Company introduced the first blind hole or box-hole raise borer in about 1967. In this machine rotational and thrust forces for the cutterhead provided via the drill string through the power unit located in the mine floor at the foot of raise. Robbins designed their 81R machine for using in Mt. Isa Mines, Queensland on Australia in 1971–72. This mine required 2.4 m diameter holes of varying length up to 600 m. Ingersoll-Rand produced large diameter raise drills in 1973 and installed at Copper Cliff North Mine for trial purposes. Subsequently, the drill was used to back-ream the raises of 2.10 m to the depth of 300 m.

Raise boring operations were also used in coal mines in Europe up to 8 m diameter (Bruemmer and Wollers, 1976; Grieves, 1981; Muirhead, 1982). Bruemmer (1979) published some case studies of

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a blind shaft borer with hydraulic muck removal system used in the German coal mining industry. Friant et al. (1985) illustrated combination of blind or reaming drill for raise construction. They stated that raise boring could be conducted with a predrilled pilot hole or blind (without pilot hole) at advance rate between 1.22 and 1.83 meter per hour. Hendricks (1985) investigated development of a mechanical shaft excavation system. Worden (1985) provided a detailed and pragmatic description of activities in the reaming cycle. Pigott (1985) stated variety of techniques and equipment for faster and cheaper drilling of shafts in soft to medium strength formations. Pugsley et al. (1989) explicated deep hole raise boring at Falconbridge operation, Sudbury Ontario. Stacey and Harte (1989) explained the problems when using of raise boring machine for excavation of deep level mines of South Africa; they stated that high cutter wear, jamming, and oscillation of the cutterhead occurred in deep level mines. Todd and Facchinetti (1993) explained down reaming at San Giacomo Al Vomano Hydro-Electric Power Plant Project in Italy. Oosthuizen (2004) stated that large diameter vertical raise drilling and shaft boring techniques are the basic alternatives to conventional shaft sinking techniques. Visser (2009) stated that rock formations having several geological discontinuities were risk factors prolonging the termination of shaft boring process. In such cases, a detailed geotechnical evaluation or 'raise bore rock quality assessment' based on the McCracken and Stacey method was recommended in the case of deep and/or large diameter shafts (Peck and Lee, 2008).

The performance and operational parameters of the excavating machine should be predicted prior to starting the excavation operations in order to fulfill the economical requirements of the project. In the light of this fact, the main objective of this investigation is to summarize a case study on raise boring machine performance and to compare the realized excavation performance with the results of previously developed a theoretical model and an experimental model by using concepts of rock cutting mechanics. In this study firstly, petrographic and physical and mechanical characteristics of the samples taken during pilot hole drilling operation were identified in the laboratory. Later, two prediction methods, by using the experimental results, were used to predict the excavation performance of the RBM used in Kure-Asikoy underground copper mine for excavating a ventilation shaft. One of the methods is based on the theoretical concept of disc cutting penetration (Roxborough and Phillips, 1975) and the other one is based on the experimental specific energy concept (Rostami et al., 1994; Copur et al., 2001). In order to validate (compare) the prediction results, the performance of the RBM was recorded in the field. It is proved that SE data already accumulated for TBMs which are easily available in the published literature may serve a sound basis to predict advance rates of RBM. The other point is that shaft sinking by RBM is safe, less costly and quick method of excavation compared to drill and blast method in competent rock.

2. Description of the project

2.1. General

The project area is situated at 60 km north of Kastamonu Province, Kure County and 25 km away from the Black Sea coast in Northern Turkey (Fig. 1). The mine management decided to excavate ventilation shaft by using RBM. This project ventilation shaft was excavated between the levels 660 m and 630 m. The total length and diameter of the shaft are 22 and 2.6 m, respectively. Daily working schedule was one shift of 8 h for pilot drilling and two shifts (16 h) for reaming operations. The RBM started running on the 1 February 2014 and the shaft excavation was finished on 11 February 2014.

2.2. Geology of the project site

The copper deposits in this region are known as Kure Copper Deposits. Kovenko (1944) stated that, MTA institute in 1938 was

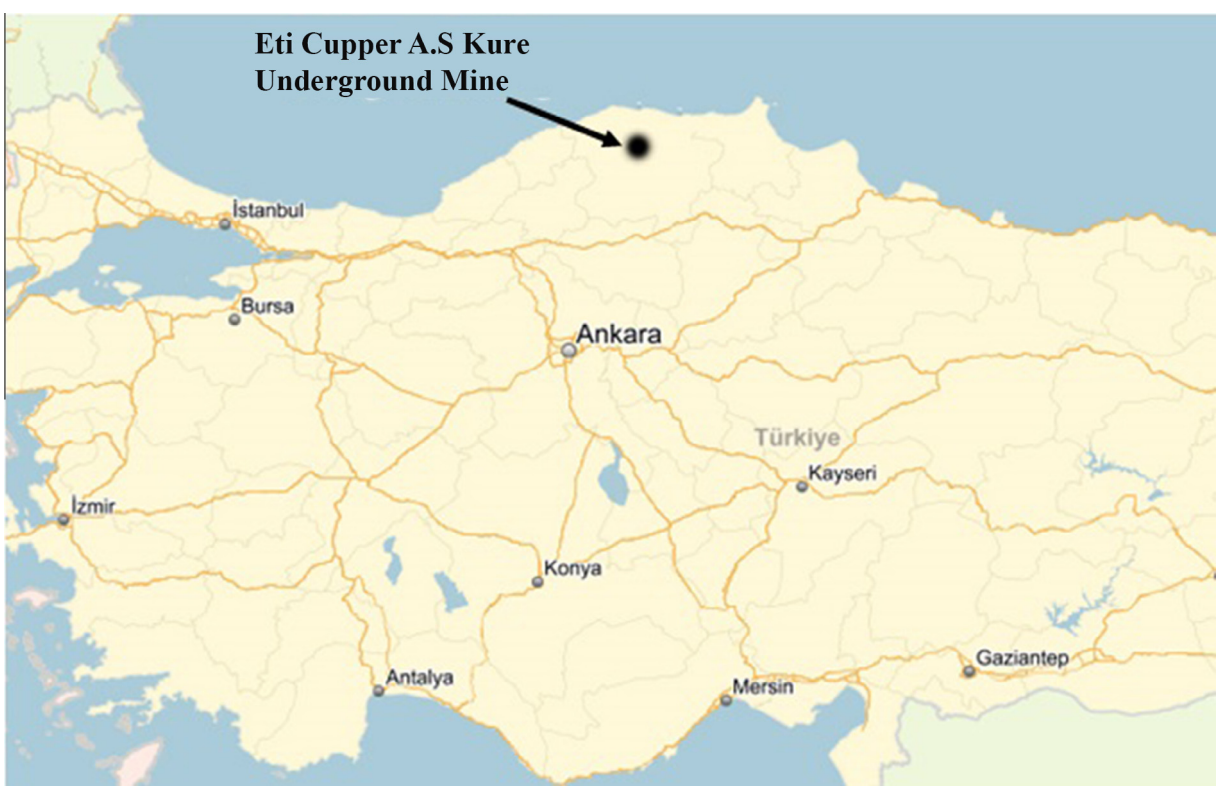

Fig. 1. Location of the Eti Copper A.S. underground mine.

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