Evaluation of the Performance of a Raise Boring Machine in Pb-Zn Underground mine, Balya, Turkey

Aydin SHATERPOUR MAMAGHANI [1], Tayfun ERDOGAN [2], Engin DOGAN [3], Nuh BILGIN [1]
[1] Istanbul Technical University, Turkey
[2] SARGIN Construction and Machinery Industry Trade Inc., Turkey
[3] Eczacibasi Esan, Turkey

ABSTRACT

Safety and more environment friendly operation are basic advantages of mechanical excavation over drill and blast method. Raise Boring Machine (RBM) is one of the mechanical excavation machines which the use has continuously been growing in Turkey. The excavated hole with RBM is more stable than other methods and has better air flow, making it ideal for ventilation shafts. This paper is a summary of the performance of a raise boring machine in Balya PB-Zn Mine in Turkey. The machine already excavated ventilation shafts in the mine having a diameter of 2.44 m and a length of 660 m. The geological and geotechnical characteristics of the strata excavated in the mine are first given and later the validity of a model developed to predict the machine performance is discussed. It is believed that the results of this study and the model given to estimate the performance of the raise boring machine will be useful guide for future applications.

Keywords: *Mechanical Excavation, Raise Bore Machine, Performance Estimation.*

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. RBM uses a small diameter drill rod, around 230-350 mm to drill a pilot hole down to the required depth up to around 2000 m. Once the pilot hole has been drilled to the desired depth, a reamer of up to 9 m diameter is attached to the drill rod. The reamer is then pulled back up to the upper level, creating a round shape. Continues operation provides a faster advance rate than other methods. RBMs are suitable both in hard and soft rock. The flexibility in different angles and diameters is a great advantage compared to drill and blast excavation method. RBM creates a shaft with smooth walls which usually does not require lining. The hole is more stable than a drilled and blasted method and has better air flow, making it ideal for ventilation shafts.

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 suggest a new model based on laboratory test results. Firstly, some general description about mine and project are mentioned. Then, the physical and mechanical characteristics of the samples taken from project area were identified in the laboratory. In the third section, performance and operational parameters of RBM are investigated due to understand the machine behavior in different rock characteristics and also to collect a useful database for further investigation. In the fourth section, a new model for performance estimation of RBM are recommended.

2 DESCRIPTION OF THE PROJECT

2.1 General overview of the project and RBM

The Balya Lead-Zinc underground mine located in the 50 km northwest of Balikesir city in western Turkey (Fig.1). Balya Lead-Zinc mine firstly mined by a French company at the end of 19th century. Eczacibasi Esan industrial group has been operated Balya mine since 2009. The ore deposit, generally had formed in contact area of limestone-dacite and crack of limestone. The sublevel stopping method is used for extraction. The incline ramp with slope of 8.5% used in mine main gallery due to less transportation distance from ore production area to gallery. In addition, the main gallery has been used to transportation of labors, waste and underground mine machines.

Fig. 1 Location of the Eczacibasi Esan Pb-Zn Underground Mine.

Eczacibasi Esan as an employer, decided to use raise boring machine for excavation mine ventilation shaft in 2013. Sargin Construction and Machinery Industry as a contractor, excavated two ventilation shaft in this year. The total depth and diameter of shafts are 660 m and 2.44 m, respectively. Recently the new shaft was excavated between 1200 and 1000 m levels as another ventilation shaft for Pb-Zn underground mine. Sandvik Rhino 1088 DC, used to excavate 200 m length and 2.44 diameter shaft. The specifications of raise bore machine are summarized in Table 1. Fig. 2 shows pilot bit which used to excavate the pilot hole before the back-reaming operation. Pilot hole drilling was based on rotational methods using a tricone roller bit of 311 mm diameter. In addition, Fig. 3 shows reamer head and raise bore machine used in Balya mine. The reamer head is equipped with 14 button cutters. Seven cutters are consist of five rows tungsten carbide bits and another seven cutters are consist of four rows tungsten carbide bits. This unique design of carbide buttons lead to highest possible rate of penetration.

Table 1. Main characteristics of Rhino 1088 DC Raise Bore.

Parameters	Value
Diameter (nominal)	2.10 m
Length (nominal)	610 m
Thrust	4000 kN
Reaming Torque	160 kNm
Break out Torque	300 kNm
Pilot Rotational Speed	0-60 rpm
Reaming Rotational Speed	0-21 rpm
Power Demand	400 kVA
Weight (without crawler)	16,500 kg

Fig. 2 Pilot Bit (diameter: 311 mm, weight: 100 Kg).

Fig. 3 The raise bore machine and reaming cutterhead.

2.2 Geology of the project area

Permian limestone, Triassic shale and sandstone, unconformable overlying Tertiary dacite and andesitic volcanic are the main rock formation in Balya deposit and other surrounding deposits (MTA, 2013). Although two main rock formations in main gallery of Balya mine are limestone and dacite. Two different fault has occurred in this area. The first fault is related to mineralization and the second is essentially devoid of mineralization. The mineralization of Balya ore deposit has occurred in three different types. There are vein, skarn, and contact type mineralization in the mine areas. Vein type mineralization commonly occurs in volcanic rocks. However, skarn type occurs in limestone blocks. Due to these types of mineralization, ore deposit goes to deep level in uniform shape and this help for high amount of concentrate production. Fig. 4 shows geological map of Balya mine and surroundings.

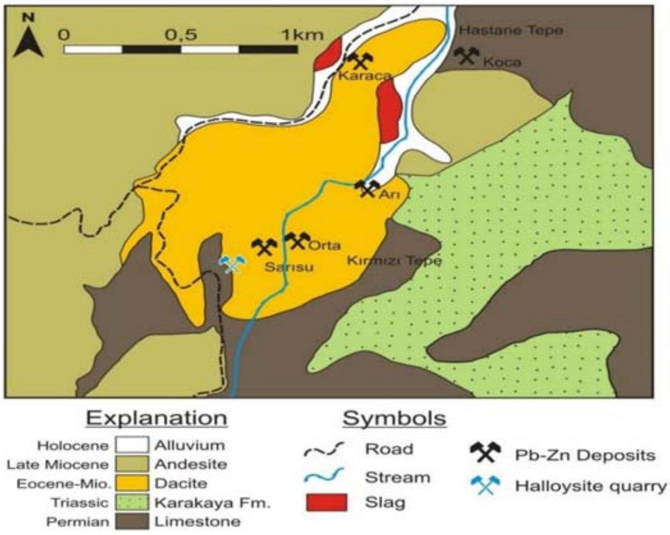

Fig. 4 Geological map of Balya Mine and surroundings (MTA, 2013).

2.3 Geotechnical parameters of rock samples

Rock samples (limestone and dacite) are collected from the project area due to performing some physical and mechanical property tests in laboratory. Physical and mechanical property tests include uniaxial compressive strength, Brazilian tensile strength, static elasticity modulus, Poisson's ratio and acoustic wave velocities (dynamic elasticity modulus and Poisson's ratio). Uniaxial compressive strength, Brazilian tensile strength, and static elasticity modulus tests are performed according to ISRM (International Society of Rock Mechanics) (Ulusay and Hudson, 2007). Acoustic wave velocities tests are performed according to ASTM (2005) standards. The results of geotechnical tests are presented in Table 2.

Table 2. Physical and mechanical properties of the rock samples tested (Ulusay and Hudson 2007; and ASTM 2005).

Properties	Dacite	Limestone
Uniaxial compressive strength (MPa)	71.97 ± 26.43	43.60 ± 13.92
Brazilian tensile strength (MPa)	4.63 ± 0.82	8.84 ± 0.71
Static Young's modulus (GPa)	15.7	10.5
Static Poisson's ratio	0.53	0.57
P-wave velocity (m/s)	2977.10 ± 73.01	4642.93 ± 551.49
S-wave velocity (m/s)	1633.89 ± 171.49	2612.06 ± 238.36
Dynamic Young's modulus (GPa)	16.97 ± 3.14	46.83 ± 8.69
Dynamic Poisson's ratio	0.27 ± 0.05	0.26 ± 0.02
Density (g/cm^3)	2.47	2.67

3 RBM FIELD STUDIES

The raise bore machine performance data such as torque, thrust force and revolution was collected in pilot drilling and reaming. The RBM excavated 200 m of limestone, andesite and dacite rocks between the depth of 1200 m (surface level) and 1000 m (underground level). The machine commenced excavation on 4 November 2014, then at the 21 November pilot drilling are finished. Fig. 5 shows the daily advance rate in pilot drilling. As seen from this figure, the daily mean advance rate is 11.05 m/day. In addition, the reaming operation started on 22 November and the 200 m length shaft enlargement finished at the 22 December 2014. Fig. 6 shows the daily advance rate in reaming. As seen from this figure, the mean advance rate in reaming is 11.70 m/day. Moreover, the mean measured values of raise boring machine operational parameters (rotational speed, force, torque, and penetration rate) in pilot drilling and reaming are summarized in Table 3. When pilot drilling finished, reaming excavation was started but after three days due to preparation of lower level (1000 m) working area, reaming operation had delayed for two weeks. In the beginning of shaft enlargement operator increases gradually the machine force until stable values are obtained. Also it should be noted that, the beginning of reaming operation is one of the difficult part of raise boring. In this shaft, the last rod (131 rod) pulled out after 20 hour and that indicate reamer head should be located well in the lower level to obtain effective contact with the bottom area of shaft.

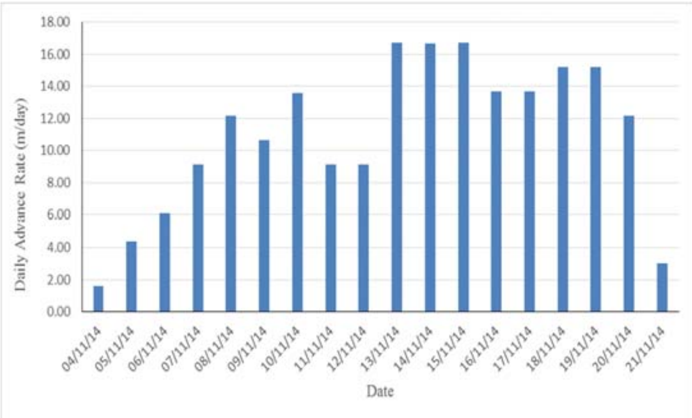

Fig. 5 Daily advance rate in pilot drilling.

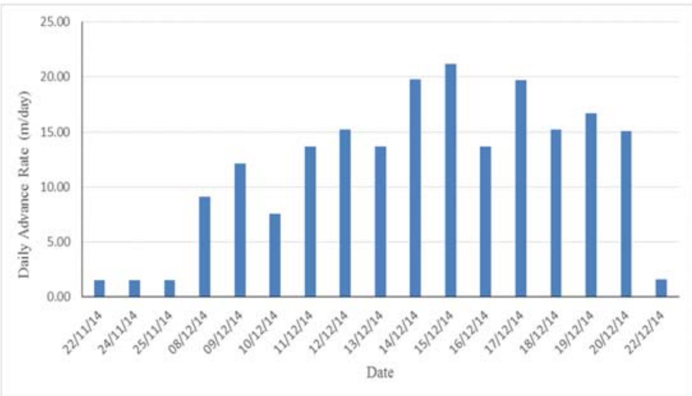

Fig. 6 Daily advance rate in reaming.

Table 3. The mean measured values of raise boring machine performance and operational parameters in pilot drilling and reaming.

Operation	Rotational speed (rev/min)	Force (kN)	Torque (kNm)	Penetration rate (mm/rev)	Advance rate (m/h)
Pilot Drilling	13.10	138	4	1.68	1.54
Reaming	3.84	960	55	7.52	1.64

4 DEVELOPMENT OF THE NEW MODEL FOR PREDICTION RBM PERFORMANCE

Performance 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 Table 4 and 5, the parameters which are used to development of new model for prediction of RBM performance are illustrated. It is not possible to obtain andesite rock sample from field. Due to this limitation, the andesite rock physical and mechanical parameters values are obtained from Ozturk et al. (2011).The Table 4 parameters are related to laboratory experiment results. The Table 5 parameters are related to machine date which collected from field studies.

Table 4. Parameters related to the laboratory experiments results.

Rock Samples	UCS (MPa)	BTS (MPa)	SYM (GPa)	Density (gr/cm^3)
Dacite	71.79	4.63	15.70	2.47
Limestone	43.60	8.84	10.50	2.67
Andesite	114.10	15.97	10.70	2.54

UCS: uniaxial compressive strength, BTS: Brazilian tensile strength, SYM: static young's modulus.

Table 5. Parameters related to the machine data in the field study.

Rock Samples	Torque (kNm)	Force (kN)	RPM (rev/min)	PR (m/h)	Penetration (mm/rev)	Power (kW)	AR (m^3/h)	SE (kWh/m^3)
Dacite	39	607	3.3	2.05	10.35	13.94	9.41	1.50
Limestone	62	1108	4.1	1.43	5.81	27.94	6.60	5.02
Andesite	63	1141	4.0	2.14	8.92	26.18	9.84	2.69

RPM: rotational speed, PR: penetration rate, AR: advance rate, SE: specific energy.

As the other mechanical excavation machine, the RBM thrust force, cutterhead torque, and penetration rate are main parameters which should be estimated before the using RBM in the field. By considering these important parameters, due to development a new model for RBM performance prediction, the relationship between experimental results and collected machine data from field are investigated to find more reliable relationship. The main reason to choose the uniaxial compressive strength as a main parameter to correlate with other field parameters is the easier procedure to determine the strength value of rock samples in the laboratory.

The relationship between uniaxial compressive strength, penetration rate, and specific energy are shown in Figs. 7 and 8. As illustrated in these figures, penetration rate and specific energy may be estimated using uniaxial compressive strength. However, UCS is found to give a less reliable correlation with SE. In addition, Figs. 9 and 10 emphasizes that cutterhead torque and machine force may be predicted from rock static young's modulus with higher reliability than uniaxial compressive strength values.

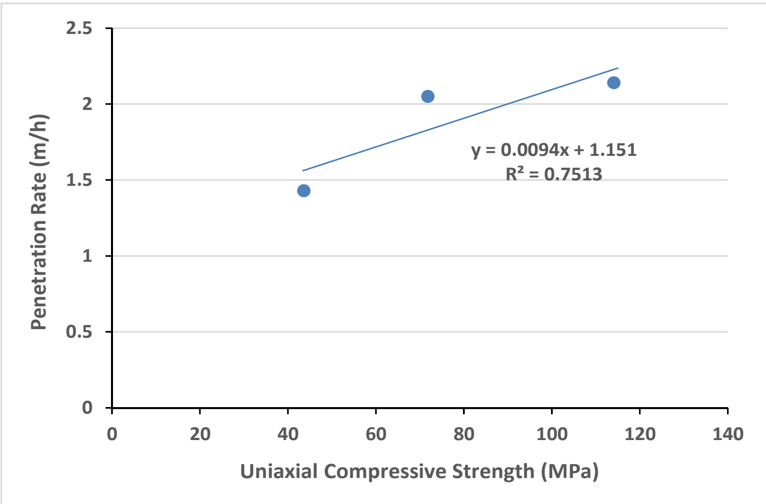

Fig. 7 Relationship between UCS and penetration rate.

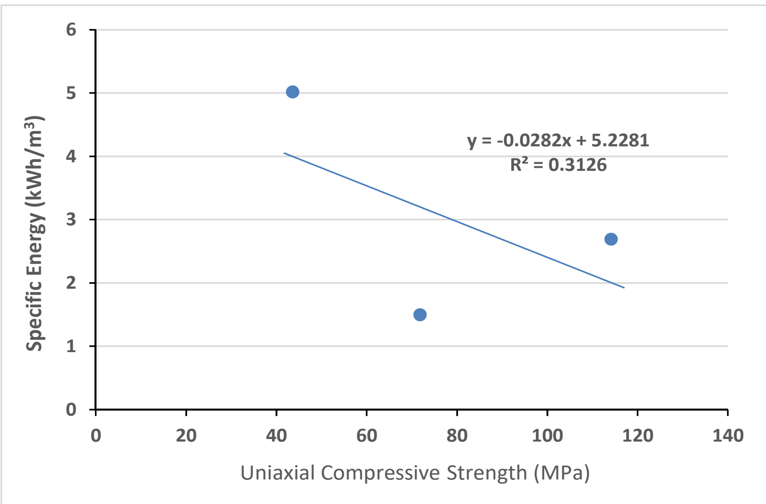

Fig. 8 Relationship between UCS and SE.

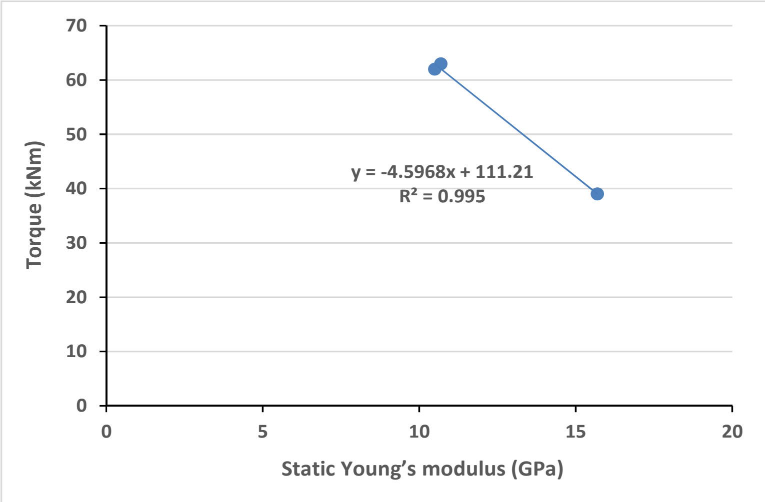

Fig. 9 Relationship between static Young's modulus and torque.

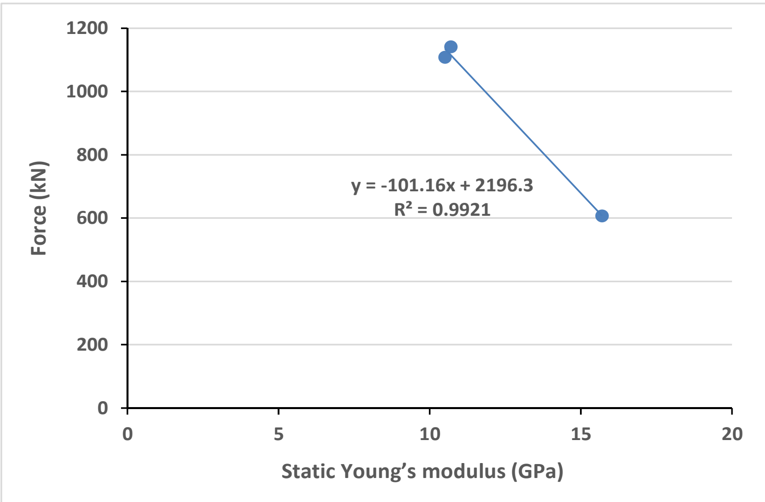

Fig. 10 Relationship between static Young's modulus and net force.

5 CONCLUSIONS

This study aimed to evaluate the performance of a RBM in Pb-Zn underground mine which located in Balya, Turkey. All machine data collected during the pilot drilling and reaming operation to investigate the relationship between some rock properties. In addition, borehole samples collected from the field due to determine some physical and mechanical parameters of rock samples. The obtained results are summarized as follows:

- The mean daily advance rate for pilot drilling was 11.05 m/day. However, the mean daily advance rate for reaming was 11.70 m/day.

- The RBM mean torque value changed between 39-63 kNm for three different rock types. The mean net force value changed between 607-1141 kN.
- The rock samples uniaxial compressive strength changed between 43.60-114.10 MPa. The static Young's modulus was 15.70, 10.50 and 10.70 GPa for dacite, limestone and andesite, respectively.
- Penetration rate and specific energy may be estimated using uniaxial compressive strength. However, UCS is found to give a less reliable correlation with SE.
- Cutterhead torque and machine net force may be predicted from rock static young's modulus with higher reliability than uniaxial compressive strength values.

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