Optimum Bit Selection and Operation for The Rotary Blasthole Drilling Through Horizontal Drilling Rig (HDR) - A Case Study at KBI Murgul Copper Mine

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ABSTRACT: This paper describes a new method to optimise roller-cone bit selection and operation by means of achieving the highest rate of penetration and bit life in a given formation that result in the lowest total cost for the hole. The performance in both areas can be maximised by controlling the weight applied and the rotary speed for the selected bit providing ideal hole cleaning. A Horizontal Drilling Rig (HDR) designed and used to perform full scale drilling tests in the laboratories of ITU Faculty of Mines. The block sample size of approximately 1.5x1.0x1.0 m. was taken from KBI Murgul Mine and the geotechnical parameters of the samples were investigated. According to the values obtained, the appropriate roller-cone bits were preliminary selected from the product lists of four different manufacturers. The optimum operating parameters were sought for each bit on HDR as rotational speeds and weight applied on bit were the controlled parameters and the penetration rate, torque, power consumption are recorded with the aid of advanced data acquisition system. Finally, the field test were carried out to determine the bit life under the optimum operating conditions obtained in laboratory as this leads the optimum bit selection and operation at KBI Murgul Copper Mine.

1 INTRODUCTION

The selection of drilling bits and operations for bench drilling at surface mine operations and also underground development and production are always a difficult problem. Different quarrying operations need different drilling equipment. In general, the rotary drilling is one of the most common applications in big open pit mines. The features of rotary drills are high feed force, which also indicates large drill size and high rotation torque. Selection of roller-cone bits and operations for an individual quarry are the critical parameters in economics of operation. The most direct way to optimise drilling practices is to decrease the costs per meter to drill a hole by increasing rate of penetration and the life of bit. A variety of bits are currently commercially available and all the important structural and the recommended operational parameters are defined in the documentation of bit manufacturers. The bit designers and manufactures specify sizes, location and configuration of roller-cone bits based on the intended application. Roller-cone bits are structurally described according to their design features such as pin angle, off set, twist angle, bearing configuration, shirt-tail, protection, pin connection, shipping weight. The classifications of roller-cone bits are made according to the type formations including the general description as well as the specific information about the operational parameters.

Many years ago, International Association of Drilling Contractors (IADC) identified a series of six basic formations in developing a classification system for milled tooth and insert roller bits. With two of the categories repeated for each of the two classes of bits, eight total groups or series were possible. Each series is identified by the first digit of the code number in order of increasing formation hardness. Within each series, the second digit of the code further denotes four sub-zones, also in order of increasing hardness (World Oil, 1988).

Formation types code roller bits as the following IADC series codes for roller bits are generally applicable:

- Soft formations with sticky layers and low compressive strength, such as clay, marls - correspond to IADC series 1 and 4.

- Soft formations with low compressive strength and high drillability, such as marl, salt, anhydrite and shale (IADC series 1 and 4).

- Soft to medium formations with low compressive strength and interbedded with hard layers, such as sands, shale and chalk (IADC series 5)

- Medium to hard dense formations with high to very high compressive strength, but with non-abrasive or small abrasive layers, such as shales, mudstone, sandstone, limestone, dolomite and anhydrite (IADC series 2 or 6).

- Hard and dense formations with very high compressive strength and some abrasive layers, such as siltstone, sandstone and mudstone (IADC series 3 or 7).

- Extremely hard and abrasive formations such as quartzite and volcanics (IADC series 8).

Manufacturers documentation provide bit name and model number, IADC code, size range, recommended bit weight and rotational speed, and other specific structural and operational features (Varel, 1991; Walker, 1998; Huges, 1988; Rokmore, 1996).

Choosing the best bit for the job is important if optimum drilling and cost efficiency are to be maximised. To improve bit selection and operation requires thorough examination of bits recommended from the different manufacturers. Preliminary bit selection can be made according to the definition given in the manufacturer documentation. After carrying out the preliminary selection the full size laboratory test can be a useful aid in obtaining optimal operating conditions for each selected bit for a given formation and the field tests leads optimal bit selection among the preliminary selected bits. The new method is explained and the results of a case study at KBI Murgul Copper mine are reported in this paper.

2 A METHODOLOGY TO OPTIMISE SELECTION AND OPERATION OF ROLLER CONE BITS

The factors affecting the rotary blasthole drilling are the selection of drill rig and the operations. The latter are affected by corrrect selection of drill bit for a given rock formation, bit weights, rotational speed and the hole cleaning.

As seen in Figure 1, the penetration rate is low for insufficient bit weight values. For optimum bit weight, penetration rate is higher and debris size is comparatively higher, for excessive values of weight the penetration of a single bit or tooth is much deeper which make difficult the removal of the debris hence the wear of the drill bit is much higher. However, the optimum bit weight is calculated empirically as defined by Praillet (Praillet, 1990; Praillet, 1998).

$$W_i = \frac{\sigma_c D}{2} \qquad ...(1)$$

where, W_i is optimum bit weight (kg), σ_c is rock comprehensive strength (kg/cm^2) and D is bit diameter (cm). Besides the bit weight, the rotational speed plays also an important role in achieving an efficient drilling. A revolution speed of 30- 40 rpm is preferable for very high strength rocks and these values may rise up to 60 - 120 rpm in medium strength rocks and to 70 - 140 rpm in soft rocks (Cummins, 1973; Bit Manufacturers' Catolog, 1998). The strength of the rock affects also the correct choice of the shape of a single bit or tooth as they change according to the hardness of rocks drilled.
Bits selection depends on ;

- Formations and the respective properties
- Speeds of rotations
- Bit weight
- Hole cleaning
- Diameters
- Depth or interval to be drilled.

All the important parameters governing the efficiency of a drilling process are explained above and as a summary it may be emphasized that the horizontal drill rig which is the main topic of this paper is suitable for investigations of these parameters under controlled conditions.

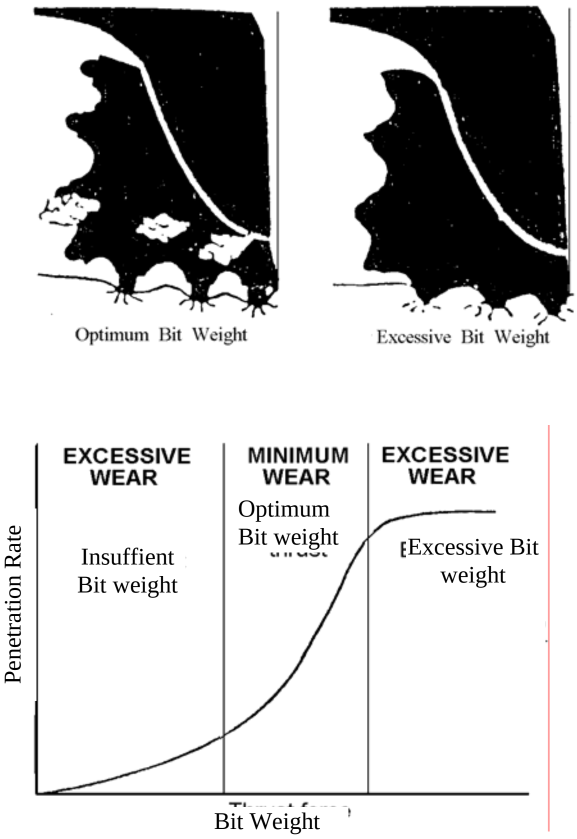

Figure 1 The theoretical relationship between bit weight, penetration rate and the bit wear

A new method is developed to select and operate roller cone bits for open pit blasthole drilling as shown in Figure 2. This method consists of five steps;

Steps 1: To take representative samples from field and to perform laboratory tests for identifying the rock geotechnical parameters, which affect the drillability.

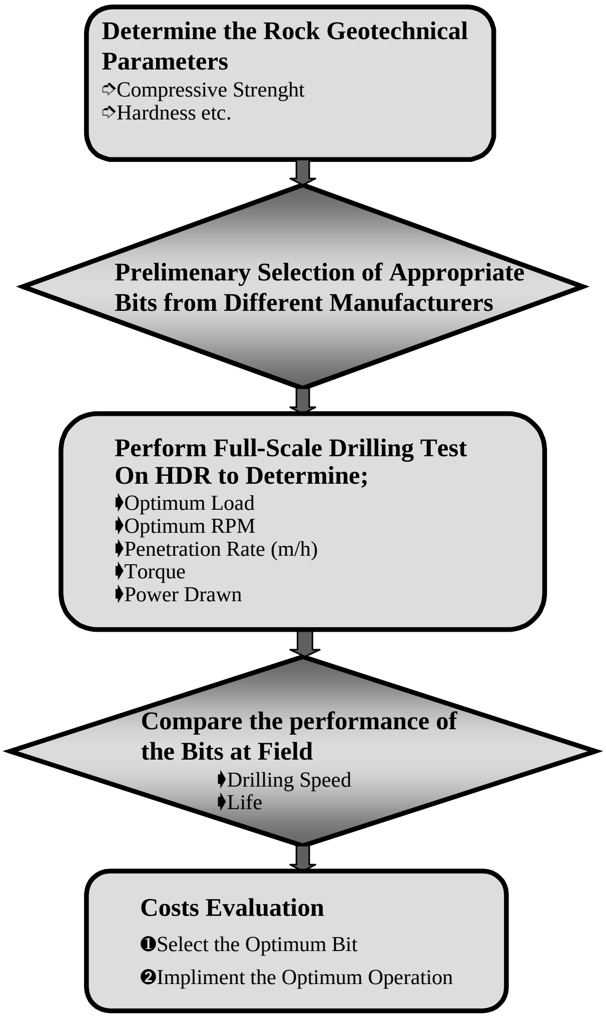

Figure 2. Methodology of optimum bit selection and operation.

Step 2: To select the most appropriate bits for the formation drilled, which are described in the manufacturers product documentation lists.

Step 3: To perform full-scale drilling tests on HDR. Operating conditions can be optimised by systematically change of operational setting which are the bit weight and rotary speed (RPM). Under the different operating conditions, the penetration rate, torque and power draw are measured to achieve the most economical performance.

Recommended bit weights depend on two factors: bit size and formation hardness. The larger the bit size the more weight that can be applied. Also, formation hardness dictates the bit weight. As previously outlined, the lighter and heavier bit weight cause fast wearing on bits therefore the optimum bit weight must be provided to the bit.

Rotary table revolutions per minute for roller-cone bit may range 30 to 140 rpm. Therefore, rotary speeds should be adjusted according to formation drilled as soft, wet formation would require a faster rpm, a hard formation would require slower rpm.

Comparison of the performance of bits are carried out to determine the optimum operational setting in laboratory tests.

Step 4: To compare the performance of the bits at field.
The bits are tested to compare the total drill hole opened and the drilling speed of the bits.

Step 5: Cost evaluation. Finally, the cost evaluation of the bits tested have to be performed to select the optimum bit among the preliminary selected bits as this leads the optimum bit selection and the operation (Borquez, 1981; Wijk, 1991).

3 HORIZONTAL DRILLING RIG AND DATA ACQUISITION SYSTEM

DESIGN AND CONTRUCTION:

The horizontal drilling rig is equipped with an electric motor of 132 kW and it is full hydraulic controlled. It is designed to have a maximum torque of 3500 kgm, a penetration rate of 0 - 60 m/h, maximum bit weight of 50 t and a maximum lateral thrust of 20 t. The experimental table may be easily accommodate the rock specimen in size of 1.5x1.0x1.0 m (Figure 3). The rotational speed may be adjusted between 0 - 40 rpm or 0 - 80 rpm by connecting two hydraulic motors in series or parallel as shown in Figure-4.

The hydraulic motors have a constant capacity of 160 cm^3/rev. The revolution speed values of 0 - 40 rpm are obtained in the case of hydraulic motors are connected in parallel and the total capacity of the oil pumped is augmented when the hydraulic motors are connected in series and a range of the revolution speed of 0 - 40 rpm is obtained. The internal diameter of the main thrust cylinder is 196,8 mm, and the diameter of the shaft is 127 mm, having a working pressure of 200 kg/mm^2, for the lateral movement the cylinder diameter is 130 mm, shaft diameter of 70 mm and a working pressure of 200 kg/mm^2.

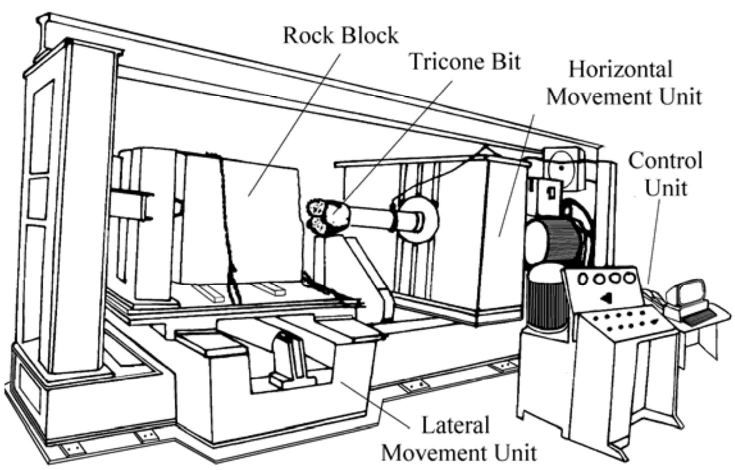

Figure 3. The general view of the HDR

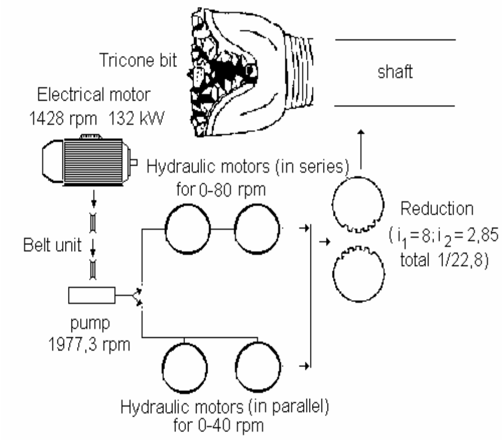

Figure 4. Motors and the transmission units in HDR.

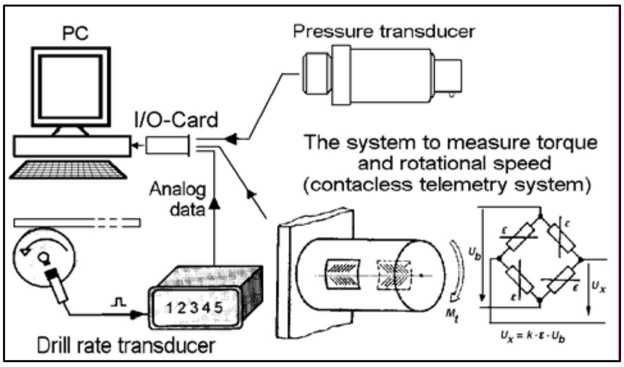

Figure 5. Data acquisition system of HDR.

DATA ACQUISITION SYSTEM

All the operational parameters of the drill rig (bit weight, penetration rate, rotational speed and torque values) are instantaneously recorded and visualized with the aid of a PC (Figure 5). For this purpose an I/O card of ESAM 2000 series (16 single ended, 8 differential channel, 12 bit resolution and a capacity of 100 kS/s) has installed in a PC of 486 μP. The input signals are in analogue type and the signals coming from the transducers vary between ± 10 V. The data are instantaneously visualized in the computer. The following transducers are used for the data acquisition system and all the output signals of ± 10 V values are fed directly to I/O card and to PC thereafter:

- Pressure transducers for thrust force measurements (horizontal and lateral),
- Rotational speed and torque transducers,
- Horizontal displacement transducers for the measurement of penetration rate.

The Manner Sensor Telemetrie System is used for the measurement of torque and rotational speed. In this system the strain gauges forming the whetstone bridged are fixed on the main shaft with an angle of 45° as seen in Figure 5. The input and output signals are transferred via an antenna which is the main unit of the contacless system. The output signals are amplified on the shaft by a transformation principle.

4 A CASE STUDY AT KBI MURGUL COPPER MINE

KBI Murgul Copper mine is situated in Murgul, Artvin in the north-east of Turkey. There are two main mining fields called Damar and Çakmakkaya. Characteristic feature of the deposit has constituted volcanic rocks and tufas; furthermore, it can be seen that andesit and dasit has dominated in mining fields. The seam including copper ore consists of sponge dasit increased copper content. Especially, hydrothermal mineral groups silicated, caolinated and covered sponge dasit is to be found the shape of stockwork. This mineral groups consists of pyrite, chalcopyrite, kovelin, tetrahydride and bornite.

According to recent reserve calculations, Damar mine deposit has 15 million tonnes ore with a average copper content of 1.11 % and Çakmakkaya deposit has 17 million tonnes ore with a average copper content of 0.99% ; totalling 32 million tonnes with 1.05 % Cu content. Open pit mining operation is performed at the mine where the excavation are carried out at the benches from the top level of 1156 m to bottom level of 1072 m. The bench height is 12 m. and the width is 15 m. The operation is performed in cycles of drilling, blasting, loading and haulage. Annually, around 180 to 200 roller-cone bits are consumed to open the blasthole in KBI Murgul copper mine, which costs 225 000 to 250 000 US-$. Therefore, it is an important matter that the drilling operations should be optimised.

The remainder part of this paper will describe how the various roller-cone bits perform in the KBI Murgul Copper Mine.

Step 1: Four pieces block samples sized approximately 1.5x1.0x1.0 m. were taken from KBI Murgul copper mine which represent the area where the drilling works will be carried out in the following time period. The samples were tested to determine the physical and mechanical features. The mean compressive strength and the tensile strength were 783±170 kg/cm^2 and 61±6.7 kg/cm^2 respectively. The density of samples was measured as 2.7 kg/cm^3. The Schmidt Hammer values are 53 with N type and 60 with N type hammer.

Step 2: Four appropriate roller-cone bits were selected to investigate the performance from different manufacturers' products. All bits investigated were 6 inch OD. The features of preliminary selected bits are given in Table 1.

Table 1 The specification of the selected bits

Product Specifications	Bit Type			
	I	II	III	IV
Bit Size (inch)	6	6	6	6
IADC	731-742	723	812-832	unknown
Formation Type	hard-very abrasive	hard-very abrasive	very hard-abrasive	medium-medium hard
Compressive Strength (kg/cm^2)	704-1400	563-1400	845-1760	563-1400
Rotational Speed (rpm)	50-90	40-70	40-80	35-70
Recommended Bit weight (ton)	9-18	9-14	15-24	9-18
Shipping weight (kg)	14.5	22	20.4	20.9

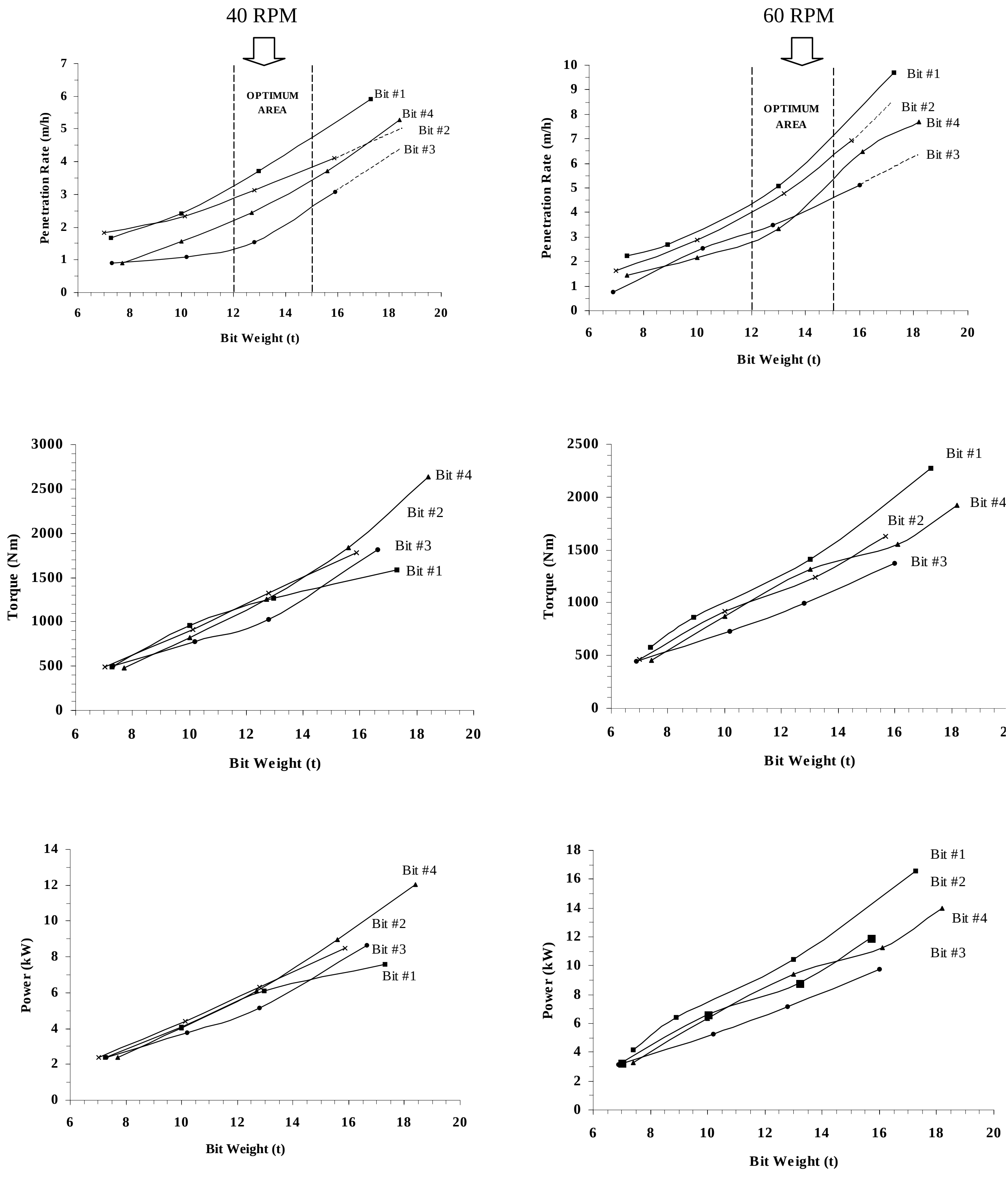

Figure 6 The performance of the selected bits on HDR

Step 3: The selected roller-cone bits were run with the rotary speeds of 40 and 60 rev/min. while the weight on bits ranged from 6 ton to 18 ton.

Step 4: The performance of the bits were investigated at the field with obtained operational parameters in Laboratory. Ingersoll-Rand DM 45 rotary drilling rig is used to perform the experiments as are the available rig in the pit. The flow rates varied somewhat, but were fairly consistent, and the assumption here is that each bit was run to achieve its optimum penetration rate. The results of field test are summarised in Figure 7 in terms of the achieved medium penetration rate (m/h) of each bit and the meters of hole realised by each bit before they get worn out.

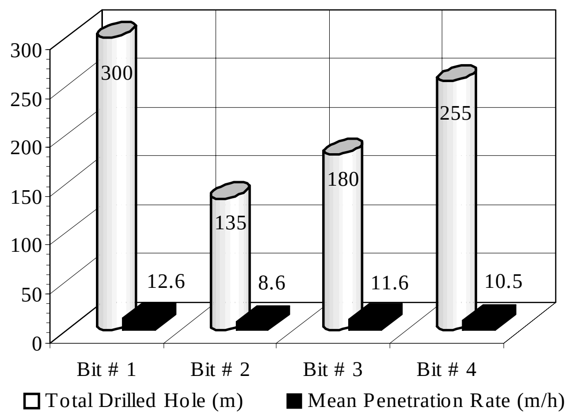

Figure-7 The performance of the bit at KBI Copper mine

Step 5: Bit life as well as penetration rate play a major role in cost effectiveness. For simplifying, if the purchase costs are assumed constant for all bits then bit # 1 can be selected as the most cost-effective bit having the highest penetration rate with 12.6 m/h and the total drilled hole of 300 m. The optimum operational parameters can be taken as previously obtained in the test carried out on HDR.

4 CONCLUSIONS

Drilling of blasthole is an important step of operation in open pit mining operations for both cost and technical reasons. The improvement of the roller bit selection and operation requires thorough examination of bits recommended from the different manufacturers. This can be carried out on HDR as the preliminary selected roller-cone bits are tested on actual samples to determine the optimum operating conditions and the penetration rate. By combining the results obtained from the tests works carried out on HDR with the life test of bits carried out at field, the optimum bit selection and operation can be determined.

At the case of KBI Murgul Copper Mine, bit # 1 gives the highest performance among the four selected bits. The optimum operating parameters which are the bit weight and rotational speed are 13 ton and 60 rpm respectively.

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