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CONTENTS

ROLE OF ROCK MASS CHARACTERISTIC AND ROCK TOUGHNESS ON PREDICTING CUTTING PERFORMANCE OF RAISE BORING MACHINE

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ABSTRACT

Vertical shafts at the underground Pongkor gold mine were developed using a raise boring of Robbins 73RM-DC. Assessment of the raise boring cutting performance was carried out in the Ciurug Raise Boring II, at three levels, such as 40 m, 70 m and 100 m. Core rock samples for laboratory tests were obtained from these three levels to determine the physical and mechanical properties. Relationship between cutting production against toughness index or specific cutting energy and also its relationship with RMR are discussed and established.

INTRODUCTION

Development at the underground Pongkor gold mine was based on total ore production of 370,000 ton ore /annum, and this was concentrated at the Ciurug vein. Bearing in mind a number of aspects such as, geology, geological structure, rock mechanics, hydrogeology and economics, it was decided to mine the ore by means overhead cut & fill method and using a combination of load – haul – dump and jumbo drill. Vertical shafts at a number of positions including Ciurug intake (CURB II) were developed for the purpose of ore and waste transportations, bringing down the filling materials to stopes and mine ventilation. The vertical shafts were excavated by a raise boring of Robbins 73RM-DC with the following features:

- Machine drive power 112 kW
- Two drive speeds; 0 – 70 rpm & 0 – 30 rpm
- Reaming rate 84 - 102 mm/minute
- Cutting head 12 button roller cutters

As rock mass strength properties differ to that of intact rock, assessment of the cutting performance of the raise boring against the properties of during the development of the vertical shaft at the Ciurug Raise Boring II (CURB II) is discussed and presented in this paper. The rock properties related in this assessment are RMR (Bieniawski, 1973), and Specific Cutting Energy or Rock Toughness (Farmer, 1986).

PONGKOR GOLD MINE

Rock Engineering Data

The research was carried out at the Underground Pongkor Gold Mining Business Unit of PT Antam Tbk., and it is located in Kampung Sorongan, West Java, about 150 km from Jakarta. The altitude of the mine area is in the range of 400 m – 700 m ASL, and surrounded by a mountainous region.

The gold veins were formed within the Miocene volcanic rocks and dominated by tuff andesitic, tuff lapilli and volcanic breccia. The ore reserve is distributed within three main veins, namely Ciguha vein, Kubang Cicau vein and Ciurug vein. This paper is concerning the Ciurug vein as the assessment of the raise boring cutting performance was carried out at the Ciurug Raise Boring II, particularly at three levels, such as 40 m, 70 m and 100 m, whereas the machine foundation was at 683 m ASL. Core rock samples for laboratory tests were obtained from these three levels.

The laboratory tests were performed to determine the physical and mechanical properties of the core rocks samples. The average values of density (γ), UCS (σ_c), Young's Modulus and RQD are given in Table 1.

Table 1. Average values of the physical and mechanical properties of intact rock samples obtained from levels 40, 70 and 100 m of the vertical shaft CURB II.

Section	**Level 40 m**	**Level 70 m**	**Level 100 m**
Rock type	relatively compact, breccia volcanic, weathered, slightly smooth when wet	compact, breccia volcanic, no significant weathering identified	compact, andesitic, fine fragmented, dark grey
Density (gr/cc)	2.24	2.17	2.44
UCSi (MPa)	15.31	25.93	47.61
Ei (GPa)	3.84	5.59	11.82
RQD (%)	80	95	100

Observation of the Raise Boring Performance

Observation of the Raise Boring Performance was focused on the deviation of the pilot drilling hole, cutter load, and special emphasis was put on cutting performance. It is also important to note that during the assessment stability of the shaft wall below the cutting head and cutting tools are assumed to remain in good condition. The cutting productions (Q) at levels 40 m, 70 m and 100 m are 8.24 m^3/hr, 6.11 m^3/hr and 4.11 m^3/hr respectively.

ROCK CUTTING ENERGY

Rock failure in rock breaking that is based on brittle fracture obviously undergoes a process of elastic behavior giving fracture strain energy. The fracture strain energy or W_f can be represented approximately by the product of stress and strain at fracture and it is a measure of the work done in fracturing the rock as given in equation [1]:

$$W_f = \frac{1}{2}\frac{\sigma^2}{E} \quad [1]$$

The concept of strain energy characterization can be applied most usefully in the case of rock excavation, - specifically, rock drilling machine and rock cutting machine, such as, road header, tunnel boring machine, shearer, and surface miner - and their ability to cut a particular type of rock.

The energy required to remove a unit volume of rock is defined as Specific Energy (SE) which was proposed by Teale (1965). This is a quick measures to enable drillability of rock be assessed and is measured in MJ/m^3 or, can also be expressed in MPa or MN/m^2. This could also be represented as the specific production rate measured in kW/m^3 which can be determined either experimentally or in the field.

Thus, the strain energy available to fracture the rock will be equal to $\{\sigma \times (\varepsilon_v)\}$/unit volume of rock or (σ^2/E) in linear terms. This can be related to the **energy input** into the rock face from the cutting machine which can be expressed as the Specific Cutting Energy (P ≡ MW or MJ/s) per unit volume of rock excavated (production Q ≡ m^3/hr). The overall argument - provided the mechanical efficiency (Eff) remains constant - is that the volume cutting rate is directly proportionate to the energy input and inversely proportionate to the so called **rock fracture toughness** or **toughness index** (Farmer, 1986). The toughness index is given in equation [2].

$$\text{Specific Cutting Energy} = \text{Toughness Index} = \frac{P\ \text{Eff}}{Q} = \frac{\sigma_c{}^2}{E} \qquad [2]$$

ROCK MASS STRENGTH CHARACTERIZATION

Obviously intact rock strength is much higher than that of rock mass, and this is due to the presence of discontinuities within the rock mass. This phenomenon is referred to as scale effect, and having considered this, the assessment of cutting production of the Raise Boring should appropriately be based on the rock mass strength properties.

A number of empirical equations for the scale effect on σ_c of brittle rock are available elsewhere. However, considering the similarity of mining environments, such as underground gold mines, Equation [3], in dimensionless form (Kramadibrata & Jones, 1993), which is derived from typical rocks in underground gold mines and expressing the scale effect of σ_{ci} (σ_{ci50}) will be applied for predicting σ_{cm} of the rock mass. Thus, the size-effect on σ_c in dimensionless form, based on the test results, can be given as follows:

$$\frac{\sigma_c}{\sigma_{c50}} = \left(\frac{50}{D}\right)^{0.34} \qquad [3]$$

Kramadibrata & Jones (1993) found that the power-law equation leads to the conclusion that there is a critical size beyond which the size-effect would be negligible in which the critical diameter of the rock sample for the uniaxial compressive strength test being 100 mm.

The rock mass charaterization is represented by the Rock Mass Rating (RMR) of Bieniawski (1973), whereas the Joint spacing is calculated using the equation from Priest & Hudson (1976) as given in equation [4]. The RMR values of the levels 40 m, 70 m, and 100 m in which the cutting assessment was performed are given in Table 2. This table suggests that as the level gets deeper the RMR increases, which is in agreement with their σ_c values.

$$RQD = 100e^{-0.1\lambda}(0.1\lambda + 1) \quad [4]$$

λ = frequency discontinuity per meter

Having obtained the rating for each parameter of the RMR (see Table 2) the rock mass modulus can subsequently be determined using the equations proposed by Mehtora, et all., (1991).

$$Em= 10^{(RMR-30)/50} \quad [5]$$

ROCK CUTTING PERFORMANCE ANALYSIS

By using the Tougness Index equation [2] and the scale-effect equation [3] the relationships between cutting production against RMR and also its relationship to the modulus ratio are established. Figures 1 and 2 depict the relationship between cutting production against toughness index or specific cutting energy and also its relationship with RMR are established, and their relationships are very strong as indicated by the R^2 values being one. It can therefore be said that cutting production is very much dependent upon rock mass characterization and the toughness index as proposed by Farmer (1986) or specific cutting energy can be used as a tool to predict cuttability.

Table 2. Determination of RMR ([-] rating)

Depth-m	**Level 40 m**	**Level 70 m**	**Level 100 m**
UCSi (MPa)	15.31 [2]	25.93 [4]	47.61 [4]
RQD (%)	80 [17]	95 [20]	100 [20]
Joint condition	[10]	[10]	[10]
Joint spacing (m)	0.12 [8]	0.28 [10]	20 [20]
Water condition	Wet [7]	Wet [7]	Wet [7]
RMR	**44**	**51**	**61**

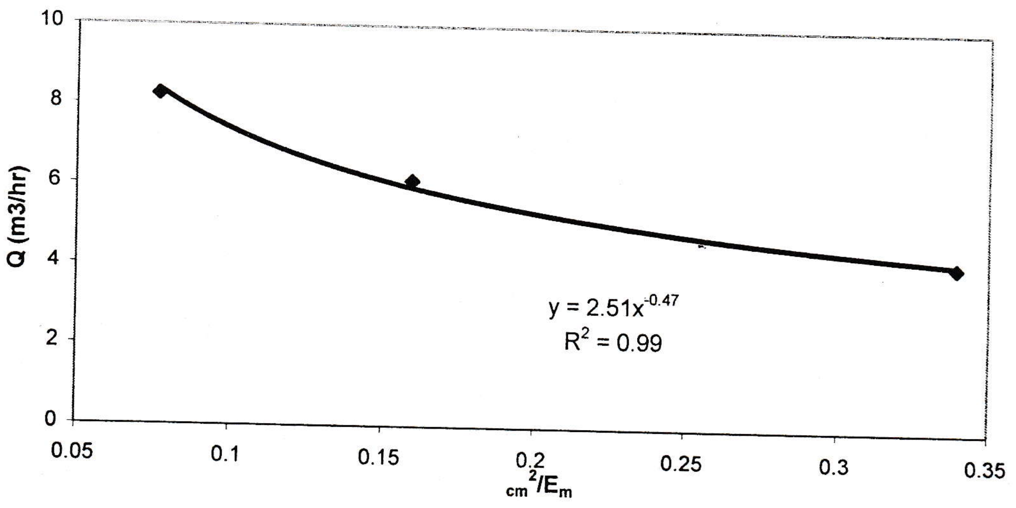

Figure 1. Relationship between cutting production against toughness index or specific cutting energy.

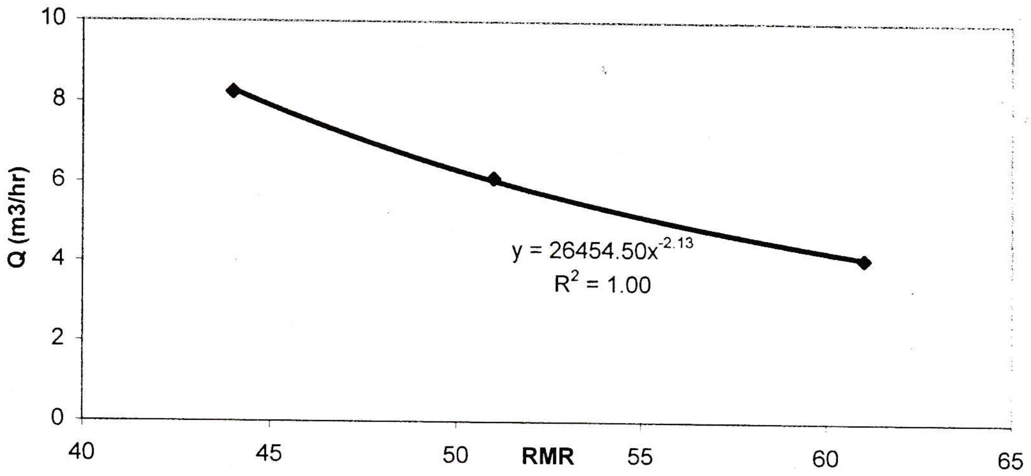

Figure 2. Relationship between cutting production and RMR

CLOSING REMARKS

- Specific cutting energy and toughness index can obviously be used as a tool to predict cutting production of cutting machine such as raise boring machine, which is in agreement with that of Farmer (1986).
- As it has been widely accepted that RMR is a very versatile tool that represents rock mass characteristic to predict cuttability of rock mass as the cutting performance of the raise boring machine is very much dependent on RMR.
- Dimensionless equation for the scale-effect on UCS can be used to well estimate the rock mass strength.
- Determination of rock mass modulus using equation proposed by Mehtora et al (1991) is appropriately accepted.

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