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A new rock cuttability index for predicting key performance indicators of surface miners

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ABSTRACT

The key performance indicators of surface miners, namely production, diesel and pick consumption were considered for the overall operational and economic evaluation of surface miner deployment in Indian mines. The study was conducted in three coal and three limestone mines located in different parts of India. Seven models of surface miner of various makes were studied. The performance of surface miners can be judged better by utilizing the combination of intact rock and rock mass parameters, available machine specifications and operating conditions. Therefore, performance predictive models were developed by considering all these relevant parameters to estimate production, diesel and pick consumption per 1000 t using the rock cuttability index of surface miner. These developed statistical models were validated for different surface miners under varied geotechnical conditions. The study also covers the development of a rock cuttability index nomogram for quick estimation of production. The rock cuttability index values provide a better possibility to determine the machine performance as each parameter can be imitated.

1. Introduction

India is the third largest coal producing country in the world after China and USA. Opencast mining, being more popular in India, is contributing about 90.6% coal production with remaining production coming from underground mining [1]. In Coal India Limited (CIL), surface miners contributed to about 103 million tonne of coal production in the year 2010–2011, which was 26% of the total production [2]. The global scenario indicates that surface miners are being applied maximum in limestone deposit [3]. Surface miners are contributing in large scale in Indian limestone mines too. This trend was spurred mainly by the rising demand for coal and limestone to meet the needs of thermal power generation (produced by coal firing) and construction industries apart from the increasing emphasis on blast free mining for excavating minerals close to human settlements. For producing coal and limestone in different mining projects application of surface miner is rapidly increasing due to the ease in application, capability for continuous and versatile selective mining, bulk production capability, reliability, cost-effectiveness and also for producing sized product at a faster rate. Out of current global population of nearly 300 surface miners in productive use around the world, some 105 operating machines are in India [4].

The key performance indicators (KPI) for predicting the performance of surface miner are production, diesel and pick consumption. The influence of intact rock, rock mass and machine parameters on these performance indicators of surface miners was studied in a few Indian coal and limestone mines and a rock cuttability index was developed which can be used for not only predicting production performance but also the diesel and pick consumption, the two most vital indicators governing the total economics of the operation.

2. Developed models

Jones and Kramadibrata [5] established a relationship between the productivity of continuous surface miners and uniaxial compressive strength of rocks. It was observed that the production decreases in lognormal form with increase in uniaxial compressive strength of rock (Fig. 1). Kramadibrata and Shimada [6] have shown a functional relationship between Voest Alpine Rock Cuttability Index (*RCI*) and various intact rock, rock mass and

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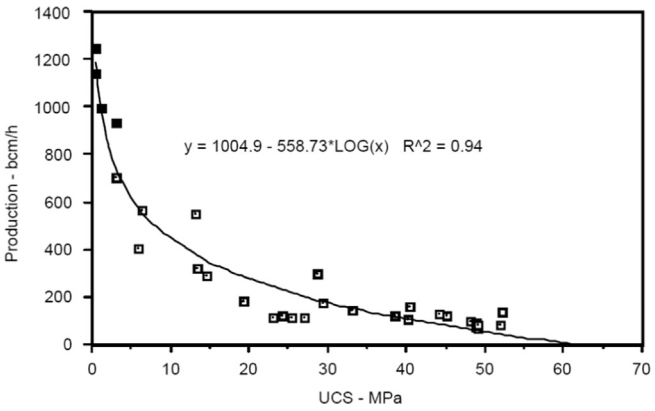

Fig. 1. Relationship between production of surface miners and UCS of rock.

machine parameters as given:

$$RCI = \{N/(L*\sigma_C)\}\alpha f\{(\gamma*\delta/\sigma_C),(\sigma_t/\sigma_C),(d/\delta),(Ey/\sigma_C),(F/\delta*\sigma_C)\} \quad (1)$$

where N is the rated machine power (kW), L is the production rate (m^3/h), σ_C is the uniaxial compressive strength of rock sample (MPa), γ is the specific weight (kN/m^3), δ is the discontinuity spacing (m), Ey is the Young's modulus (MPa), F is Schimazek's abrasivity factor (N/mm) and σ_t is the tensile strength of rock sample (MPa).

Murthy et al. [7] developed an index, *CISM* (Cuttability Index of Surface Miner) considering the various parameters relating to the intact rock, rock mass and machine design and operating parameters. The *CISM* can be determined from:

$$CISM = MF/(RMF \times IRF) \quad (2)$$

where *RMF* (Rock Mass Factor) is the field P-wave velocity (km/s),

$$IRF(\text{Intact Rock Factor}) = LV_P \times S \quad (3)$$

where LV_P is the laboratory *P*-wave velocity in the rock (km/s), and S is the silica content (%),

$$MF(\text{Machine Factor}) = EP \times CS \times CA \quad (4)$$

where *EP* is the total engine power (kW), *CS* is the cutting speed (m/s), *CA* is the total cutting area engaged in cutting rock at any point of time, and

$$\text{CA} = pDW/6 \quad (5)$$

where D is the drum diameter (m) and W is the drum width (m).

In this model, it was assumed that at a given time only 1/6th of the circumferential length of drum gets engaged in cutting of the rock. The equation established for machine performance prediction is:

$$NTPH = b_0(CISM)^{b1} \quad (6)$$

where *NTPH* is the normalized production (t/h/m) and b_0 and b_1 are constants.

Dey and Ghose [8] developed a nomogram to fathom the suitability of a surface miner for a given rock mass taking into account a few key influencing parameters, namely, point load strength index, volumetric joint count, rock abrasiveness and direction of machine operation with respect to joint orientation. The cutting performance of a surface miner (L) may be estimated from cuttability index (*CI*), the rated capacity of the machine (M_c) and a factor for specific cutting condition (k) that varies from 0.5 to 1.0 as follows:

$$L = [1 - CI/100)]k\, M_c \quad (7)$$

where L is the production or cutting performance (bm^3/h), M_c is the rated capacity of machine (bm^3/h),

$$CI = I_s + J_v + A_w + J_s + M \quad (8)$$

is the cuttability index, k is a factor for consideration of influence of specific cutting condition and is a function of pick lacing, pick shape *etc.* and varies from 0.5–1.0. The parameters I_s, J_v, A_w, J_s and M are the ratings corresponding to point load index (I_{S50}), volumetric joint count, abrasivity, direction of cut with respect to major joint orientation and machine power respectively. The cuttability index was derived to have the first hand idea about the "GO—NO GO" criterion on applicability of surface miner. 'k' value considered in the model also varies widely from 0.5 to 1.0 leaving scope for research.

Origliasso et al. [9] considered uniaxial compressive strength, rock abrasivity and machine power as key influencing parameters for production estimation by surface miner and the same is expressed as:

$$PR = (2P_w - 600)\exp\{-0.024\,[UCS + 10(CAI - 0.5)]\} \quad (9)$$

where *PR* is the production rate (m^3/h), P_w is the machine power (kW), *UCS* is the uniaxial compressive strength (MPa), and *CAI* is the Cerchar abrasivity index. Improved reliability of estimated *PR* was observed with this relation and the error was found to be within 25%.

The performance of surface miners can be better judged by utilizing a combination of intact rock and rock mass parameters, available machine power and operating conditions. All these parameters were not covered together in the earlier models. Second, none of the models developed earlier have the flexibility in predicting all the three KPI, namely, production, diesel and pick consumption. This calls for a research targeted to these aspects.

3. Field investigation sites

Field studies were conducted in three coal mines located in different coalfields spread across India, *i.e.*, Sonepur Bazari opencast mine of Eastern Coalfields Limited (ECL), West Bengal, Lingaraj opencast project of Mahanadi Coalfields Limited (MCL), Orissa and Gevra opencast project of South Eastern Coalfields Limited (SECL), Chhattisgarh. The study was also carried out in three limestone mines, namely, Dalavoi Works of India Cements Ltd. and Alathiyur Works of Madras Cements Ltd. located in Tamil Nadu and Jadua limestone mine of Sanghi Industries Ltd., Gujarat. The major rock types excavated were limestone with marl and clay, nummulitic limestone, fossiliferous limestone, clay, coal, carbonaceous shale and coal bands. A number of models of surface miners, mainly Wirtgen, L&T and Bitelli make, were deployed in these mines.

4. Methodology

4.1. Identification of critical parameters

Fourteen distinct intact rock, rock mass and machine parameters were identified from the literature review for the assessment of cutting performance of mechanical excavators in general. Further, the critical parameters influencing the performance of surface miners in terms of production, diesel and pick consumption were arrived at through literature review, artificial neural network and correlation coefficients analysis. The common parameters identified by artificial neural network analysis and correlation coefficients analysis were compiled and categorized as critical variables while others as semi-critical as given in Table 1.