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Building information model for drilling and blasting for tropically weathered rock

Drilling and blasting are the major part unit in operations of mining or civil engineering projects. In spite of the best efforts to introduce mechanization in the mines, blasting continues to dominate the production. Therefore to cut down the cost of production optimal fragmentation from properly designed blasting pattern has to be achieved. Proper adoption of drilling and blasting can contribute significantly towards profitability and therefore optimization of these parameters is essential. This optimized parameter will be effective if a robust information model can be prepared based on the relevant practical data of the specific deposits. Initial rock mass characteristics data collection if collected during exploration stage is useful for selection of drilling machine and prediction of penetration rate – Key Performance Indicator (KPI). Further block model developed with geo-mechanical parameters will be useful during operation stage of mine. Geo-mechanical parameters are also important for design of slope in mine planning till final closure stage. Penetration rate, fragmentation, fly rock, ground vibration, air-overpressure (AOp) and back break are KPI for drilling and blasting. Explosives properties and selection of initiation system have impact on blast performance. There are various computational techniques such as artificial neural network (ANN) where various drilling and blasting (KPI) can be predicted accurately for year-wise budgeting and during operation stage of mine. Tropically weathered rock is classified as fresh, slightly weathered, moderately weathered, highly weathered and completely weathered.

Keywords: *Computational techniques, ground vibration, air over pressure, fragmentation, penetration rate, tropically weathered rock.*

Introduction

Rock breaking by drilling and blasting is the first phase of the production cycle in most of the mining operations. Optimization of this operation is very important as the fragmentation obtained thereby affects the cost of the entire gamut of interrelated mining activities, such as drilling, blasting, loading, hauling, crushing and to some extent grinding. Optimization of rock breaking by drilling and blasting is sometimes understood to mean minimum cost in the implementation of these two individual operations. However, a minimum cost for breaking rock may not be in the best interest of the overall mining system. A little more money spent in the rock-breaking operation can be recovered later from the system and the aim of the coordinator of the mining work should be to achieve a minimum combined cost of drilling, blasting, loading, hauling, crushing and grinding. Only a “balance sheet” of total cost of the full gamut of mining operations vis-à-vis production achieved can establish whether the very first phase - rock breaking - was “optimum” financially; leaving aside factors of human safety. An optimum blast is also associated with the most efficient utilization of blasting energy in the rock-breaking process, reducing blasting cost through less explosive consumption and less wastage of explosive energy in blasting, less throw of materials, and reduction of blast vibration resulting in greater degrees of safety and stability to the nearby structures.

Various researchers have reported that drill ability index depends upon various rock mass characteristics such as uniaxial compressive strength (UCS), tensile strength, Schmidt hammer rebound number, impact strength, P-wave velocity, elastic modulus, rock density, texture and grain size, Mohr’s hardness, joint spacing, joint filling (aperture) and joint dipping [1-3]. Penetration rate for percussive drill depends upon compressed air pressure, thrust and compressive strength of rock [4]. Drilling rate of rotary blast hole drill is classified as slow, slow-medium, medium, medium-fast, and fast which have correlation to blasting [2].

Fragmentation, fly rock, ground vibration, air-overpressure (AOp) and backbreak are key performance indicators for blasting. Explosives properties and selection of initiation system have impact on blast performance. Table 1 shows various factors which affect blast performance. Rock characteristics are not controllable. Operational parameters are controllable.

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TABLE 1: FACTORS AFFECTING BLAST PERFORMANCE

Reference	Blasting parameter	Influencing factors on blasting	
		Rock characteristics	Operational Parameters
[5-6]	Burden	UCS, density, cohesive strength, RQD	Hole diameter, explosive energy
[7-9]	Fragmenta-tion	Block size, type of discontinuities- joints, bedding planes	Burden, spacing, burden to spacing ratio, powder factor
[10-12]	Back break	RMR,	Burden, spacing, stemming length, powder factor
[13-16]	Flyrock	Weakness planes- geological structures, fractures, discontinuities, faults, voids	Hole diameter, less burden, excessive explosive energy
[17-22]	Ground vibration	Massive, degree of weathering, fractures	Maximum charge per delay, distance, type of initiation system
[23-27]	AOp	RQD, fractures, discontinuities	Maximum charge per delay, distance, type of initiation system
[28-29]	Shock-wave	Rock joints openings, numbers and incident angle	Type of explosives

Purpose of building information model for drilling and blasting

There are various aspects which are interrelated to drilling and blasting. Following objectives can be achieved while building information model for drilling and blasting

- Centralized data capturing, monitoring, visualization and meticulous planning.
- Integration of exploration data, deposit modelling, resource evaluation followed by the actual mine production planning and control.
- Power to explore more options for better planning and hence sound corporate decisions within shorter time span.
- A large amount of data generated at various stages of mining which need to be processed.
- Tasks are often time consuming but repetitive too.

Fig.1 Exploration, mine development and production and mine closure stages

- A large proportion of time is spent on generating results with little time left for implementation and analysis.
- Finally managing risks

Stages from preliminary exploration to mine closure

The mining lifecycle commences with a regional preliminary exploration programme, which may continue intermittently over a period of years, particularly as new exploration technologies are introduced. The whole mining life-cycle can be divided into three main stages, namely exploration, production and rehabilitation followed by mine closure (Fig.1).

The exploration phase commences with regional area selection to define the most prospective terrain based on a large extent of previously available geological, geo-chemical, geo-mechanical and geophysical data, supplemented by reconnaissance investigations and surveys.

EXPLORATION STAGE

During early stage of exploration stage, mineral deposit is identified based on available government data. During preliminary stage of exploration geological mapping is done including identification of rock types, lithology, exposed geological features such as faults, folds. In advance exploration stage, core drilling is carried out. A lot of data is generated starting from geological logs up to sample analysis out of which the specific data required for the purpose of the building the information model for drilling and blasting are: Geological logs, RQD, RMR and UCS.

Various sample tests are carried out on core samples such as dry density, UCS, tensile strength, abrasive index, shear strength. Based on the above strength index parameters, the spacing, burden and diameter of the blasthole is decided for selection of drilling equipment. However, all these data again changed based on the practical mining conditions.

Fig.2 Typical geological cores

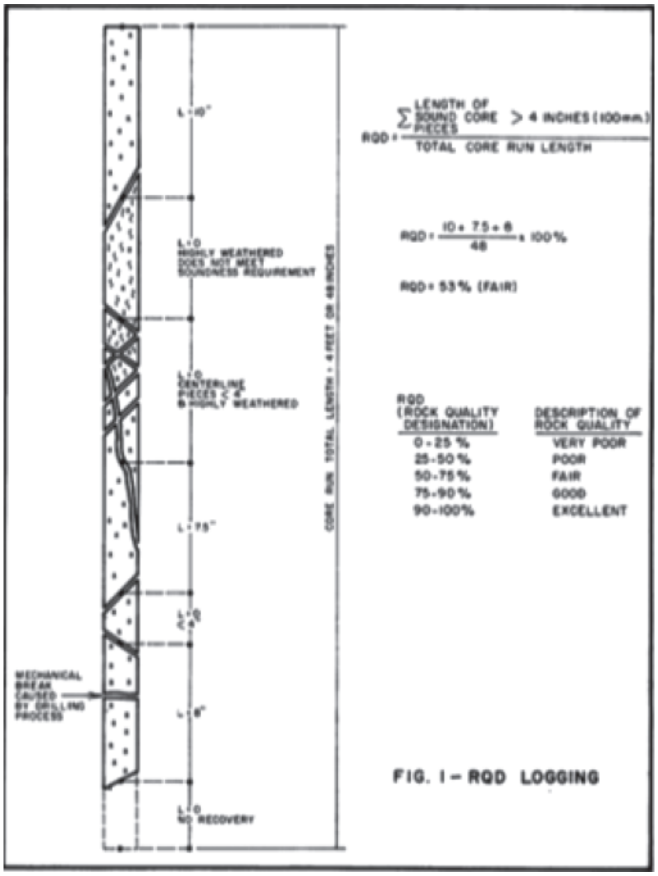

Fig.3 RQD calculation

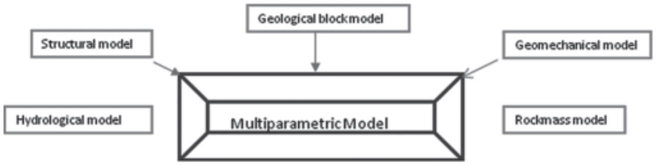

Fig.4 Development of multi parametric model

In tropical region due to humid and higher temperature weathering takes place at faster rate. Rock is classified as fresh, slightly weathered, moderately weathered, highly weathered and completely weathered.

The development of 3D multi-parametric model (Fig.4) simplifies resource information prior to advancement of mining face. Using this model, prediction of grade and tonnage, rock mass quality, geo-mechanical and geo-hydrological parameters. Blast can be designed from the rock mass quality predictions. This information can be used as input to overall resource evaluation and mine planning, production optimization, slope design and costing. This permit the full range of mining activities and thus lowering costs and improving efficiencies through application and development of this multi-parametric model [30].

All these data to be incorporated into the resource model of the deposit will be interpolated to the completed extent of the deposit based on the additional available information. This multi-parametric model will be used for the production planning as well as the drill and blast planning (Fig.5).

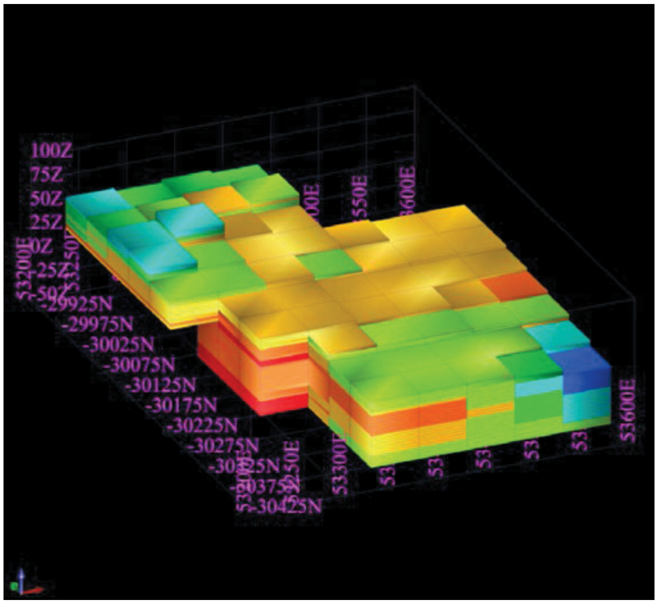

Fig.5 Block model based on exploration data – geotechnical multi-parametric model

Mine development stage

During this development stage of mine, as the fresh rock types are exposed further additional data being captured in addition to the existing exploration data like the joint condition, their patterns, orientation, bank density etc. At present, in India the cost of drilling is around in the range Rs.120-150 per meter drilled which is quite significant amount. However, this cost depends upon the type of drill rig we have deployed like top hammer or DTH which is further directly linked into occurrence of the rock type.

Drill and blast design parameters and their patterns are always dynamic which changes based on the face conditions, rock types and sensitiveness of the grade control exercises of the deposit. Normally all the historical blasthole data and their patterns are stored in a blast data base which is being referred time to time for further improvement. Information on geological features such as faults, folds, discontinuities are collected as mine face is exposed and stored in the database.

Mine production stage

During this actual production stage the drilling and blasting parameters are optimized based on the historical data and the ongoing blasting data. The predesigned data of spacing, burden and blast pattern data being changed further to improve the fragmentation while minimizing the cost of drilling and blasting. There are many methodologies available to optimize the blast pattern, blast fragmentation and control on the blast vibration. In this regard, a detailed study should be undertaken on type of explosive, type of detonator, use of electronic detonator, charge per delay etc. Information on bedding planes, joints, karst is updated in the data base to update model.

The optimization of mining process can be achieved in different ways and methods. These are;

- Optimization of drilling productivity
- Optimization in casting of overburden
- Optimization of explosives and blast design
- Optimization in transportation etc.
- Safety aspects

MINE CLOSURE STAGE

Mining is very much crucial during this stage of mining as most of the deposit is depleted except the periphery area which is across the lease boundary. These areas are normally very sensitive due to the presence of the local communities and many other factors. In this regard, blasting in these areas are wither undertaken by controlled blasting techniques or through alternative blasting practices like use of rock breakers, terminators etc.

Development of a blast optimization model

Selection of proper explosive in any blasting round is an important aspect of optimum blast design. Basic parameters include VOD of explosive (m/s), density (g/cc), characteristic impedance, energy output (cal/gm), and explosive type (ANFO, slurry, emulsion etc.). However, all these parameters cannot be taken for optimizing the blasting method successfully. Some of the parameters are taken for minimizing the blasting cost. These cost reduction and optimum blast design parameter will give an economical result. The parameters are:

i. Drill hole diameter,
ii. Powder factor (desired),
iii. Cost of explosive,
iv. Numbers of holes required to blast.

Drilling and blasting cost in any project can be as high as 25% of the total production cost.

Inputs required for information model

Fig.4 shows various models which can be developed from parametric model as per application requirement which is shown in Table 2

GEOLOGY

Rock density, tensile and compressive strength of rock, Young's modules of rocks, and poisson's ratio. Strike and dip value, joint structure and frequency.

TECHNOLOGY

Explosive technology – bulk, emulsion, type of initiation systems are different. Manufacture of explosives provide technical data sheet that needs to be stored and updated.

TABLE 2: PARAMETERS REQUIRED FOR DEVELOPMENT OF PARAMETRIC MODEL

Model type	Parameters required for developing model
Resource	Rock types, assay/grade value, survey data, mine boundary
Geology	Lithology, mineralogy, texture, grain size, porosity
Structural	Bedding, faults, folds, karsts, discontinuities
Rock mass model	Rock mass rating, RQD, effects of ground water
Geo-mechanical	UCS, shear strength, tensile strength
Groundwater	Groundwater levels, flow regimes, pore pressures, hydrological units

DRILLING EQUIPMENT

Feed thrust, impact frequency, piston strike, impact pressure, rotation rate, type of drill rig, type of bit. Drills new models are brought into market every decade and thus better model selection for improving efficiency is essential. Hence, all technical details to be updated along with performance trial results in each type of strata for future planning.

SITE FACTORS

Dimensions of the face, diameter of hole ratio of spacing and burden, length of hole, inclination of hole, number of rows, wet or dry holes, drilling sequence.

COST FACTOR

Cost of drilling equipment and depreciation cost, number of operators, wages and efficiency factor, the unit cost of drill rods, blasthole bit and consumables, the cost of power and lubrication oil.

Optimization of explosive and blast design

We know mainly drilling and blasting cost is more significant part of the overall operating cost, i.e. explosive cost may vary from 4-12% or the total operating cost. So this cost can be controlled by;

- Optimum use of booster cartridges and cast boosters.
- Optimum use of detonating fuse.
- Saving of explosives by using air decks.
- By eliminating the desensitization of explosive column on the hole.

INFLUENCE OF ROCK PARAMETERS ON BLASTING

- Rock strength,
- Density,
- Blast ability index,
- Porosity,
- Effect of geological disturbances, etc,

PROBLEMS ASSOCIATED WITH BLASTING

(i) Fragmentation: The influencing factors are:

Design parameters -

(1) Drilling pattern
(2) Hole diameter
(3) Sub-grade drilling
(4) Steaming column
(5) Initiation system
(6) Delay timing

Explosive parameters: density, VOD, shock and gas energy released.

Rock parameters

(1) Strength,
(2) Stiffness,
(3) Compressive, shear wave velocity.
(ii) Blast induced vibration
(iii) Noise/air over-pressure
(iv) Flyrocks: It can be controlled by giving proper attention to blast design layout, drilling and loading of explosive.

Computational techniques for prediction of drilling and blasting parameters

Various researchers have developed computational techniques for prediction of blast KPI such as fragmentation, flyrock, ground vibration, AOp and burden [31-38]. Some of these computational techniques include artificial neural network (ANN), artificial bee colony (ABC), fuzzy inference system (FIS), adaptive neuro-fuzzy inference system (ANFIS), gentique algorithm (GA), imperialist competitive algorithm (ICA), particle swarm optimization (PSO) and support vector machine (SVM). The prediction with these computational techniques have found to be more accurate as compared to conventional empirical formulae for a particular condition and for a given mine. Steps for evolving these computational techniques for target KPI to obtain prediction model are:

1. Developing computational algorithm
2. Inputs are selected based on experience/parameters by other researchers
3. Collecting sufficient number of datasets for input parameters, measure actual KPI value
4. Running developed model with trial and error for adjusting weights in ANN
5. Selecting data sets for training model
6. Running developed model with testing data sets
7. Comparing results predicted by developed model and actual measured KPI value
8. Comparing results with other models or empirical equations
9. Utilize established model for predicting KPI

Legal and safety

1. Manufacturer of explosives provide safety data sheet for each product for handling, storage, usage, shelf life etc. The information should be maintained and updated periodically. The information should be available to blaster in local language at mines.
2. There are various authorities DGMS, department of explosives etc where various laws and rules are to be maintained and updated periodically.
3. All personnel connected with explosives, blasting are to be trained for competency training periodically.

Conclusions

For the development of building information model for drilling and blasting, information can be collected as under:

1. During exploration stage of any deposit various information on geo-mechanical, geo-hydrological, structural, RQD, RMR, information can be collected.
2. Through core samples and field samples can be tested for DD, UCS, tensile strength, shear strength for development of geo-mechanical model.
3. Multi-parameter model can be developed while developing block model for resource estimate at the end of exploration stage.
4. Information on geological features such as faults, folds, discontinuities is collected as mine face is exposed and stored in the database. Degree of weathering – fresh, slightly weathered, moderately weathered, highly weathered and completely weathered rock.
5. Information on bedding planes, joints, karst is updated in the data base to update model during production stage
6. Technical information on drills, explosives product wise to be maintained and updated periodically
7. Individual drilling and blasting record of each block can be maintained in 3D format.
8. Development of latest computational techniques is useful tool for predicting drilling and blasting KPI-penetration rate, fragmentation, backbreak, ground vibration, AOp
9. Prediction of various of KPI is useful for cost estimate during budget every year based on yearly production and development plan
10. Blast fragmentation has direct impact on loading, transport and crushing cost which can be optimized. Degree of weathering has direct impact on fragmentation.

To conclude finally building information model for drilling and blasting is useful for overall mining operation throughout the life of mine.

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