

Relationship between Excavation-Geometry and Blast-Geometry with reference to Indian Coal Mines

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ABSTRACT: Blasting is the cheapest and the fastest method of rock breaking and is extensively used for winning minerals. Blasting operations causes excessive noise and vibration which affects the nearby communities. Excessive levels of structural vibration caused by ground vibration from blasting can result in damage to structures. The objective of this research was to investigate the most appropriate blast holediameterswith reference to the prevailing bench heights for coal mines and other excavation jobs based on the correlation. To achieve this objective, field observations and data collection were carried out at different coal mines in Telangana, India. Based on the analysis of the data, reconsideration of hole diameter for blasting operations is suggested. A new model for estimating hole diameter for blasting operations is developed based on multiple regression methods. The measured variables that are used as independent ones (regressors) and included in the model development are hole depth (H), burden (B), and spacing (S). The hole depth and spacing were found to be statistically significant and were included in the final model. Though the burdenwas included in the final model, its effect was statistical less significance.This research could help mining, civil and blasting professionals to accurately design blasting operations and develop effective strategies to mitigate various hazards associated with blasting.

KEYWORDS: Drilling and Blasting, Diameter of Drilling, Bench Height

I. INTRODUCTION

Mineral resources are the backbone of industry and industry needs metal and non-metals as raw material. Mineral resources are extracted by both the open cast mining and underground mining method. In both, the case extraction of the mineral is done by loosening the rock or coal. Surface mining is the most popular method of ore excavation worldwide. Drilling and blasting operation is the first element of the ore extraction process. Blasting is the most energy efficient stage in the comminution system and has an energy efficiency of 20 to 35% as compared to the efficiency of 15% and 2% by crushing and grinding respectively [1]. There exists a strong relationship between blast properties and the efficiency of crushing and grinding [2]. The primary purpose of blasting is rock fragmentation and displacement of the broken rock. The blasting process and usage of explosives is a potential source of numerous human and environmental hazards. Studies by Singh and Singh [3] show that fragmentation accounts for only 20-30% of the total amount of explosive energy used while the rest of the energy is wasted away in the form of ground vibrations, flyrock and air-overpressure. Nicholls (1981) [4] indicates blasting vibrations may cause significant damage to nearby buildings or various structures. A study by Raina et al. (2004) [5] suggests the level of human response to blast vibrations and air-overpressure.

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The size of the blast hole is the first consideration of any blast design. The blast hole diameter, along with the type of rock being used and the type of rock being blasted, will determine the burden. Practically, blast hole diameters for surface mining range from 2 to 17 inch. As a general rule, large blast hole diameter yield low drilling and blasting costs due to cheaper drill cost per unit volume and cheaper blasting agents can be used in a larger diameter. However, larger diameter blast holes result in large burden and spacing and collar distance and hence, they tend to give coarser fragmentation. Drilling costs for the large blast holes will be low, a low-cost blasting agent will be used, and the cost of the detonators will be minimal. However, in a difficult blasting situation, the broken material will be non-uniform in size and blocky, resulting in higher loading, hauling, and crushing costs. It may also result in more secondary breakage and insufficient breakage at the toe. Higher diameters of drilling with the wider pattern, though cost-effective, can't be used all the times as higher diameters result in higher loading densities, higher charge per delay and result in higher fly rock, bigger sizes and higher vibrations.

Smaller holes cost more to drill per unit volume, powder for small-diameter blast holes is usually more expensive, and the cost of detonators will be higher. However, the fragmentation will be finer and uniform, resulting in lower loading, hauling, and crushing costs. Secondary blasting and toe problems will be minimised.

Size of equipment, subsequent processing required for the blasted material, and economics will determine the type of fragmentation needed, hence the size of the blast hole to be used. The geometry of excavation to a great extent influences the blasting geometry to be adopted. The blasting geometry includes factors such as the diameter, burden, spacing and the depth of drilling. The literature survey reveals that numerous studies [6-14] have been conducted to establish the relationship between blast hole diameter and prevailing bench height. However, practically in the field once the blast hole diameter has been fixed based on planned bench height, we rarely get the actual bench height. For this purpose, practically hole depth is the actual bench height for the excavation. This research gap provides the impetus for research more on the relationship between blast hole diameter and bench height.

Based on the research gap identified, the study has the objective to investigate the most appropriate blast hole diameters with reference to the prevailing bench heights for coal mines based on the correlation.

The objective is determined by developing a multiple regression model between blast hole diameter and hole depth, burden and spacing. The model is developed based on the data collected on various bench geometry parameters from different dimensional stone quarries and other excavation jobs. The mines or excavation setups selected have similar geological conditions, similar capacity of excavation machinery but use different diameters of blast hole drilling.

II. METHODOLOGY AND DATA ANALYSIS

The blasting details were collected from different coal mines in Telangana, India. The bench parameters i.e bench angle, width, overall slope angle, and bench height varied with the type of material excavated (coal or overburden) and also whether the excavation is carried out by department machinery or contractual machinery. The standard hole diameter varied from 150 mm to 250 mm. The hole depth varied from 5 m for coal benches to 27 m for dragline benches.

2.1 Multiple Regression Model

Based on the analysis of the data, reconsideration of hole diameter for blasting operations is suggested. A new model for estimating hole diameter for blasting operations is developed based on multiple regression methods. The measured variables that are used as independent ones (regressors) and included in the model development are hole depth (H), burden (B), and spacing (S).

The first step that should be undertaken in model building is the correlation test between the independent variables. The correlation coefficient measures the linear relationship between variables and has the value range from minus one to one. The value of plus one shows the perfect positive correlation, while the value of minus one shows the perfect negative correlation. Minitab software was used to get the correlation among variables. Next, one of the most important problems in regression analysis involves selecting the set of independent (regressor) variables to be used in the model.

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Finally, the best subset analysis and stepwise regression analysis were used for the determination of significant independent variables for the development of the model. The selection of the “best” subset of the independent variables involves examining available variables to obtain the regression model. Therefore, to make a model easy to use, one’s goal is to choose a few regressor variables as possible. For k regressors x_1, x_2, \dots, x_k and a single response variable y there are 2^k total equations that should be analyzed. For evaluating and comparing those different possible regression models, there are several criteria that can be used:

- a) R_{adj}^2 - The adjusted coefficient of determination R_{adj}^2 is one of the most commonly used criteria. As previously explained, the model maximizing this parameter also minimizes the mean square error. Thus, it is considered to be a suitable candidate for the best regression model.
- b) C_p - Another criterion that is used for evaluation of regression models is C_p statistic. It is defined as the total mean square error for the regression model. Therefore, the best regression model should have a minimum C_p statistic.

Thus, the best subset analysis was performed on all regressors that are available, and parameters R_{adj}^2 and C_p were used for evaluation of the most suitable model, which will be presented later in this paper.

Besides the all possible regressor selection method, the stepwise regression technique was performed. The stepwise regression method uses iterations to make a series of regression models by adding or removing variables at every step [15-16]. As previously mentioned, the criterion for addition or removal of variables is usually a partial F-test. The process of the stepwise selection method begins with making one variable model, with the regressor that has the highest correlation with the response variable Y . Interms of statistics used for this analysis; this regressor will have the highest value of partial F-statistic. Generally, at every step, the set of remaining regressors is examined, and the one with the largest partial F-statistic is inserted into the model.

A different approach for selecting the best subset of variables is particularly useful to check if the same models result. However, it is suggested that if there are not many candidate regressor variables, the recommended selection technique will be the best subset selection [15]. Also, this technique is not affected by dependencies between regressor variables.

To check if multicollinearity exists, the variance inflation factors (VIF) are calculated for the variables in the model. Multicollinearity represents dependency among the regressor variables, which has a high impact on the coefficients of the regression as well as the appropriateness of the derived model. It is expressed with the Variance Inflation Factor(VIF), which has the following equation [15]:

$$VIF = \frac{1}{1-R_j^2} \quad (1.1)$$

where:

R_j^2 is the coefficient of multiple determination that is the result of regressing x_j on the other k_j regressors.

The value of multicollinearity should not be more than 5 or 6 [15]. However, with VIF greater than 10, there is an indication for presence of multicollinearity [17].

Table 1 shows the results of the best subset regression for hole diameter. The three variable model consists of log hole depth (H), log burden (B) and log spacing (S). The full model containing all the variables has R^2 (adj) = 87.4 which is the highest among all models. The next best model is two model containing log hole depth (H), and log spacing (S). Both the full model and two variable model have low C_p . Thus, the backward stepwise regression analysis is conducted to find the preferred model.

Table 1.Results of the best subset regression for Hole Diameter

Variables	R^2	R^2 (adj)	R^2 (pred)	C_p	Log H	Log B	Log S
1	86.0	85.8	85.0	11.8	X		
1	73.0	72.7	71.9	92.5			X
2	87.1	86.8	85.8	7.0	X		X
2	86.4	86.1	85.1	11.2	X	X	
3	87.9	87.4	86.2	4.0	X	X	X

Results of the multiple regression model of blast hole diameter are shown in Table 2 and Table 3. It can be seen from Table 2 that hypothesis test of the individual regression coefficients (with t statistic) yields p values less than 0.05 for log hole depth (H), log burden (B) and log spacing (S) which indicates that all these variables are statistically significant in the model. The maximum value of VIF for the model is 5.74 and indicates that multicollinearity is not an issue in this case. The coefficient of determination R^2 shows that 87.9% of the variation of the Hole Diameter is explained with the variables in the model.

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The analysis of variance table for the blast hole diameter is shown in Table 3. Analysis of variance indicates that F statistics are very large, and the MSE is small, which further means that the regression line explains the most of the variability of the response variable. Comparison of SSE with PRESS statistics is a way of informal judging of the sensitivity of the model fit. The value of the PRESS statistic (Table 2) is close to the value for sum squares of error (error adj. SS in Table 3), which indicates that overfitting is not the issue in this model. Moreover, the predicted R^2 is reasonably close to the regular R^2 .

Table 2. Results of the multiple regression model for Hole Diameter

Term	Coef	SE Coef	T-value	P-value	VIF
Constant	1.7418	0.0393	44.29	0.000	
Log H	0.2882	0.0442	6.53	0.000	5.74
Log B	0.1465	0.0655	2.24	0.028	1.96
Log S	0.2034	0.0672	3.03	0.003	4.15
Summary of Model	$R^2 = 87.92\%$	$R^2(\text{adj}) = 87.43\%$	$R^2(\text{pred}) = 86.17\%$	Press = 0.116354	=

Table 3 Analysis of variance table for Hole Diameter

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	3	0.7394	0.2464	181.90	0.000
Log H	1	0.0577	0.0577	42.58	0.000
Log B	1	0.0067	0.0067	5.00	0.028
Log S	1	0.0124	0.0124	9.16	0.003
Error	75	0.1016	0.0013		
Total	78	0.84			

The regression equation has the following form:

$$\text{Log D} = 1.7418 + 0.2882 \text{Log H} + 0.1465 \text{Log B} + 0.2034 \text{Log S} \quad (1.2)$$

Removing log from both sides, the mathematical formulation of the model is represented by Equation 1.3.

$$D = 55.18 \times H^{0.2882} \times B^{0.1465} \times S^{0.2034} \quad (1.3)$$

For validation of the model, data splitting was carried out. The data was divided into two separate samples in a random order. One of the samples was used to building the model, and the other sample was used for validation of the model. The MSPR was calculated when the regressed coefficients were used on the validation data set. The MSPR is 0.0029 which is very close to MSE value of 0.0013 (Table 2). Thus, the selected model has a good predictive ability for the validation data set.

III. CONCLUSIONS

The research emphasises on adoption of the appropriate diameter of blasthole on blast geometry of excavation geometry, which allows full exploitation of the mineral throw and benefits of blasting while improving the ability to limit the mineral damage, dilution, and loss.

The primary focus in developing a new model was to formulate a new blast hole diameter equation for blasting operations at various coal mines considering the use of on-site blasting geometry data such as the blast hole diameter, burden, spacing and the depth of drilling. Based on the new model developed, it can be concluded that:

- i) The bench height or hole depth has a significant effect on the hole diameter at coal mines. Optimum blast hole diameter increases with the height. In general, an increase in blast hole diameter decreases in drilling costs

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- ii) Spacing also plays a major role in hole diameter. Proper spacing of the holes is essential as improper spacing produces undesired fragmentation. Too much of the spacing between holes may produce boulders from the middle portion. The spacing to burden ratio (S:B) is what determines the quality of fragmentation.
- iii) Burden also has a positive effect on hole diameter, though their effects were statistically less significant. The smaller burden is required when the distance between discontinuities is large. Too little a burden results in fly rock and excessive fines and too much of burden produces back break, boulders and toe.

IV. LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

The analysis of blast hole diameter for blasting operations at different coal mines in this research were based only on several data sets that were available for analysis. A collection of more data would enhance the accuracy of the evaluation and give better insight into the role of different parameters on the blast hole diameter. The new data also may change the coefficients as well as increase the number of parameters in the model. Also, with more data, mining professionals could more accurately design blasting operations at mines and develop effective strategies to mitigate various hazards associated with blasting.

REFERENCES

1. Eloranta, J. *The efficiency of blasting versus crushing and grinding*. in *Proceedings of the 23rd Conference of Explosives and Blasting Technique*. Las Vegas, Nevada. February. 1997.
2. Beyglou, A.H., *Improvement of blast-induced fragmentation and crusher efficiency by means of optimized drilling and blasting in Aitik*. 2012.
3. Singh, B., ed. *Investigation of blasting pattern and geo technical properties of the surrounding rock mass on the ground vibration, fragmentation, fly rock etc*. 1991. p.7-87.
4. Nicholls, H.R., C.F. Johnson, and W.I. Duvall, *Blasting vibrations and their effects on structures*. 1971: US Government Printers.
5. Raina A. K., Haldar A., Chakraborty A. K., *Human response to blast-induced vibration and air-overpressure: an Indian scenario*, Bulletin of Engineering Geology and the Environment, Vol. 63, Issue 3, 2004, p. 209-214
6. Adhikari, G., et al., *Role of blast design parameters on ground vibration and correlation of vibration level to blasting damage to surface structures*. Indian National Institute of Rock Mechanics (September 2005), 2005.
7. Ash, R.L., *The design of blasting rounds*, in *Surface mining*. 1968, AIME, New York. p. 373-397
8. Bhandari, S., *Engineering rock blasting operations*. A. A. Balkema. 388, 1997: p. 388.
9. Gregory, C.E., *Explosives for Engineers*, University of Queensland Press, Queensland, Australia (1966)
10. Hagan, T.N., 1983, *The influence of controllable blast parameters on fragmentation and mining costs*, Proc. 1st Int. Symp. on Rock Fragmentation by Blasting, Lulea, Sweden, 31-51.
11. Hustrulid, W.A., *Blasting principles for open pit mining: general design concepts*. 1999: Balkema Publications.
12. Jimeno L.C & Jimeno L.E. *Drilling & Blasting of Rocks*. New York, 2006, pp.191- 196,328
13. Konya, C.J. and E.J. Walter, *Surface blast design*. 1990: Prentice-Hall.
14. Langefors, U. and B. Kihlström, *The modern technique of rock blasting*. 1978: John Wiley & Sons.
15. Montgomery, D.C. and Runger, G.C., 2003, "Applied Statistics and Probability for Engineers," Third Edition, John Wiley and Sons Inc., New York, USA.
16. Moore D.S. and McCabe George P., 2006, "Introduction to the practice of statistics," Fifth Edition, W. H. Freeman and Company, New York, USA.
17. Statisticssolution, 2019, Available at: <https://www.statisticssolutions.com/multicollinearity/>