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Estimation of Optimal Blasting Geometry Using Multivariate Modeling to Reduce Boulder Potential and Improve Mining Production

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ABSTRACT

One of the most critical stages in mining operations is rock encroachment. A commonly used method of laying rocks is blasting which aims to cleave rocks according to the size of the planned fragmentation. The effectiveness of a blasting activity is a benchmark for the success of loading and transportation activities which greatly affects the achievement of mining production targets. This study aims to estimate the optimum blasting geometry to minimize the percentage of the number of boulders so that loading activities become more effective and production targets are achieved. The research case study was conducted on 8 blasting blocks in the South Osela Pit located at PT J Resources Bolaang Mongondow, North Sulawesi, Indonesia. The research data consists of detonation fragmentation, digging time, cycle time, digging rate, and ore mining productivity. The research method was carried out by multivariate modeling and estimation of blasting geometry. The results of multivariate modeling show that to achieve the production target of 700 bcm / hour, the percentage of boulders < 4%, digging time 8 seconds, cycle time 14 seconds, and digging rate 800 bcm / hour. The results of the blasting geometry estimation show that to get the percentage of the number of boulders < 4 % then the optimum blasting geometry is a burden of 3.8 meters; spacebar 3.2 meters; stemming 2.2 meters; blast hole depth 5.8 meters, and powder factor 0.42 Kg/bcm.

INDEX TERMS ***Blasting Geometry Estimation, Multivariate Modeling***

I. INTRODUCTION

Rock encroachment is one of the most important stages in mining operations. Rock harvesting can be done in various ways depending on the characteristics of the rock to be harvested. According to Ghokale (2009: 36) "The commonly used methods of rock hatching more than four centuries ago were drilling and blasting". Blasting activities aim to release or remove material from the parent rock so that the size of the resulting fragmentation can facilitate subsequent mining activities (Bhandari, 1997: 2-3). The size of fragmentation will affect the efficiency of material loading activities and processing processes in primary crushing (Hustrulid, 1999: 25-27).

PT J Resources Bolaang Mongondow (PT JRBM) is a company engaged in the gold mining industry with an open-pit mining system and open-pit mining methods. The majority of gold harvesting activities are dominated by drilling and blasting activities because the material to be harvested has a compressive strength of rocks ranging from 5-32 MPa. According to Kramadibrata (1997) "Blasting activities are carried out for materials with a compressive strength of > 25 MPa".

In planning a blasting activity, several factors need to be considered, one of which is the geometric pattern used (Bhandari, 1997: 5). The geometric pattern of blasting will affect the resulting degree of fragmentation. The ore fragmentation target to be achieved at PT JRBM is 80% measuring < 10 cm, 20% measuring 10-50 cm, and 0% measuring 50 cm.

activities that can have a positive influence on loading and transport activities in production activities (Hustrulid, 1999: 11-12). This study examines the optimization of blasting geometry to achieve fragmentation targets to increase druggability in meeting ore productivity targets.

The research method uses statistical analysis that results in an approach to the relationship between blasting activities and diggability for the achievement of productivity targets. From a statistical approach, it can be estimated the ideal conditions of blasting activities to support increased diggability in meeting productivity targets. Through this value, an optimum blasting geometry design is carried out to meet the fragmentation target so that productivity is also achieved.

The study aims to model the ideal conditions of blasting and loading activities to achieve the planned productivity targets. The research data consists of detonation fragmentation, digging time, cycle time, digging rate, and ore mining productivity. The research method was carried out with multivariate modeling and trial and error.

II. RESEARCH LOCATION

The research location is in Pit South Osela PT J Resources Bolaang Mongondow North Sulawesi Indonesia. A map of data collection at the study site can be seen in Figure 1. The data observed at the study site were blasting activity data (blast hole depth, stemming, powder factor, and blast fragmentation) and loading activities of blasting materials by loading and digging devices (digging time and cycle time)

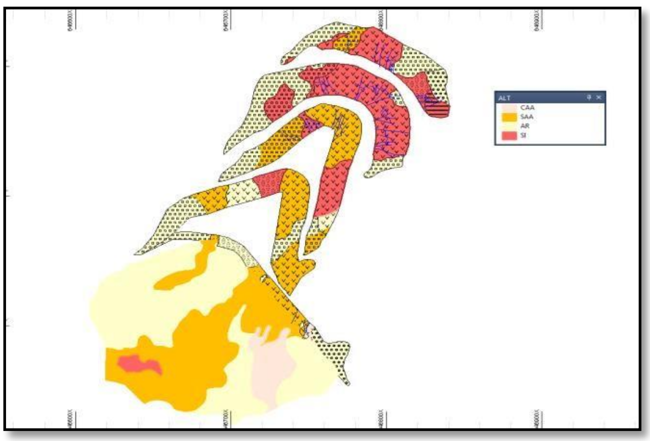

Figure 1. Sampling Location Map

Research data observed in the study area can be seen in Tables 1 and 2

TABLE 1
OBSERVATIONAL DATA ON BLASTING AND FRAGMENTATION ACTIVITIES OF EXPLOSIVE MATERIALS

Blasting Block	Collapse Hole Depth (%)	Collapse Stemming (%)	Boulder fragmentation (%)
SOS_695A	15.79	10.00	5.7
SOS_695C	8.19	14.04	7.3
SOS_695E	11.95	10.45	6.7
SOS_700A	10.58	13.47	10.8
SOS_700D	3.36	1.88	7.1
SOS_705E	7.9	9.09	7.5
SOS_710H	7.07	5.09	7.2
Average	9.26	9.15	7.46

TABLE 2
EXPLOSIVE MATERIAL LOADING DATA

Blasting Block	Digging Time (s)	Cycle Time (s)
SOS_695A	8	20
SOS_695C	8	20
SOS_695E	7	16
SOS_700A	6	16
SOS_700D	8	19
SOS_705E	7	17
SOS_710H	8	18
Average	7	18

Blasting data collection is taken at the beginning of the shift on each blasting block, then continued with the collection of loading data for loading and unloading devices in the blasting block that has been previously observed. So from Table 1, it can be seen that the average size of boulder-sized detonation fragmentation (> 50 cm) is 7.46%, with a digging time and cycle time of 7 seconds and 18 seconds. Blast fragmentation and loading capacity in the South Osela Pit can be seen in Figures 2 and 3.

Figure 2. Fragmentation of SOS_695A Block Blasting

In Figure 2, we see sticks (40 and 50 cm) which are used as a scale reference to determine the fragmentation of blasts that are boulder-sized. Boulder fragmentation blasting is characterized by a material size larger than the scale.

Figure 3. Loading Activities of SOS_695A Block Blasting Materials

III. METHODE

3.1 Blasting Activities

Blasting activities aim to destroy or dismantle rocks from the parent rock, to meet production targets, and move crushed rocks into piles of material (muck piles) that are ready to be loaded into a means of transport. One of the indicators for determining the success of a blasting activity is the degree of fragmentation of the resulting rock. The size of the resulting rock fragmentation will be determined by the needs of subsequent mining operations.

3.1.1. Blasting Geometry

The calculation of the blast geometry according to C.J. Konya (1991) not only considers explosive factors, rock properties, and the diameter of the explosive pit but also pays attention to the correction factor to the position of the rock layer, the state of the geological structure, as well as the correction to the number of explosive holes detonated. The most important factor to correct according to Konya (1990) is the problem of determining the magnitude of the burden value.

a. Burden (B)

The burden is the perpendicular distance between the explosive pit to the nearest free plane and is the direction the displacement of the rock will occur.

$B_2 = Kd \times Ks \times Kr \times B_1$ ....(1)

Information:

B1 = Initial burden (m)
B2 = Corrected burden (m)

Kd = Correction factor based on the geological structure of the rock

Ks = Correction factor based on layer orientation

Kr = Correction factor based on the number of blasting lines, i.e. Kr = 1 if there are one or two lines and Kr = 0.9 if there are three or more lines.

b. Space (S)

Spacing is the closest distance between two adjacent explosive holes within a row.

To obtain spaces, the following formulation is used:

1) Simultaneously Each Row of Explosive Holes

(a) Low Benches

$H < 4B,\ S = (H + 2B) / 3$ ....(2)

(b) High Benches

$H = 4B,\ S = 2B$ ....(3)

2) Streak In Each Row Of Explosive Holes

(a) Low Benches

$H < 4B,\ S = (H + 7B) / 8$ ....(4)

(b) High Benches

$H = 4B,\ S = 1{,}4B$ ....(5)

c. Stemming (T)

Stemming is the place of the covering material inside the explosive pit, which is located above the blast fill column. The function of stemming is to balance the pressure and confine the gases resulting from the explosion so that it can suppress the rock with maximum energy.

$T = 0{,}7 \times B$ ....(6)

d. Subdrilling

Subdrilling is the additional depth to the drill holes under the floor of the level made with the intention that the rock can be exposed to the extent of the floor.

$J = 0{,}3 \times B$ ....(7)

e. Depth of Explosive Pits

The determination of the depth of the explosive pit is usually adjusted to the level of production (capacity of the loading digging tool) and geotechnical considerations. In principle, the depth of the explosive hole is the total number between the height of the level and the magnitude of the sub drilling which can be written as follows:

$H = L + J$ .... (8)

e. Powder Factor

Powder Factor is a large number of explosives used to detonate one bcm of rock material.

$$PF = \frac{Jumlah\ Bahan\ Peledak}{B \times S \times H} \quad ....(9)$$

3.1.2 Blast Fragmentation

Rock fragmentation is the rate of fragmentation of material of a certain size as a result of the blasting process. The blasted material that is the size of a chunk is called a boulder, where the size of the boulder depends on the needs and plans of the implementer of the activity.

3.2. Loading Activities

3.2.1. Digging Time

Digging time is the time used by the loading digging tool to harrow the material to be moved. Digging time is part of the cycle time which can be one of the references for determining the productivity of the loading and digging tool.

3.2.2 Cycle Time

Cycle time is the time it takes for a loading tool to move material in one cycle (Rochman Hadi, 1990).

$$CT = T_1 + T_2 + T_3 + T_4 \text{ ....(10)}$$

Information:
CT = Circulation time of the dig-load tool, seconds
T1 = Time to dig material, seconds
T2 = Playtime with the bucket filled, seconds
T3 = Load shed time, seconds
T4 = Playtime with an empty bucket, seconds

3.2.3 Digging Rate

The digging rate is the amount of material that can be dug by a loading digging tool in one hour. The size of the digging rate of the loading and digging tool is determined by the condition of the blasting material. The condition of the blasting material will affect the digging resistance experienced by the bucket teeth when digging the material. Boulder-sized fragmentation has a larger digging resistance, and vice versa.

Digging Rate = BC x BFF x CT ....(11)

Information:
BC = Bucket Capacity (m3)
BFF = Bucket Fill Factor
CT = Cycle Time (Hours)

3.2.4 Productivity of Loading Digging Tools

Productivity is the magnitude of the production target that can be achieved within an hour (Rochman Hadi,1990).

Productivity = Digging Rate x UA x PA. ....(12)
Information: UA = Use of Avaibility (%)
PA = Physical Avaibility (%)

3.3 Multivariate Modeling

Multivariate modeling is performed to measure the intensity of the relationship between many variables and make predictions of approximate values of x and y (Hastono, 2006). The multivariate equations model is as follows in general:

Y = b0 + b1. X1 + b2.X2 + ……. + bk.Xk .... (13)

Information:
i = 1.2, ..., n
k = free variables, i.e. X1, ... , Xk.
b0 = Constant (intersect)

From the equation obtained, it is known the interpretation of the relationship between dependent and independent variables through the magnitude of the value of the coefficient of determination (R2). The greater the value of R2, the stronger the relationship between these variables (Hastono, 2006: 131)

TABLE 3
INTERPRETATION OF THE VALUE OF THE COEFFCIENT OF DERMINATION (R2)

R^2	Interpretation
0,00 – 0,25	Weak Relationships
0,26 – 0,50	Medium Relationship
0,51 – 0,75	Strong Relationship
0,76 – 1,00	Very Strong Relationship

IV. RESULT AND DISCUSSION

A. RESULT

4.1 Digging Rate

The calculation of the digging rate on the blasting block in the West Durian Pit can be seen in Table 4.

TABLE 4
DIGGING RATE ON BLASTING BLOKS

Blasting Block	Bucket Capacity (m3)	Bucket Fill Factor	Digging Rate (bcm/jam)
SOS_695A	4.5	0.7	567
SOS_695C	4.5	0.7	567
SOS_695E	4.5	0.7	709
SOS_700A	4.5	0.7	709
SOS_700D	4.5	0.7	597
SOS_705E	4.5	0.7	667
SOS_710H	4.5	0.7	630
Average	4.5	0.7	635

In Table 4, it can be seen that in the calculation of the digging rate, the bucket capacity value used is 4.5 m3 because the load digging tool observed is the Hitachi ZX870LC-5G and the bucket fill factor used is 0.7 assuming digging activities with a moderate type of work so that from the calculation, the average digging rate value of 635 bcm / hour is obtained.

4.2 Productivity of Loading And Digging Tools

The calculation of the productivity value of the loading digging tool on the blasting block can be seen in Table 5. From table 5, it can be seen that the average value of the productivity of loading and digging equipment that can be achieved in blasting blocks is 556 bcm / hour from the planned productivity target of 700 bcm / hour.

TABLE 5
PRODUCTIVITY OF LOADING DIGGING TOOLS ON BLASTING BLOCK

Blasting Block	Productivity (bcm/hour)
SOS_695A	548
SOS_695C	607
SOS_695E	564
SOS_700A	610
SOS_700D	536
SOS_705E	558
SOS_710H	550
Average	560

4.3 Multivariate Modeling of the Relationship of Blasting and Loading Activities to the Productivity of Loading And Digging Tools

Statistical analysis was carried out to determine the magnitude of the relationship between blasting and loading activities to productivity targets. The data used is boulder-sized fragmentation, digging time, cycle time, digging rate, and the productivity of loading and unloading tools on blasting blocks.

From the multivariate modeling carried out, an R2 value of 0.973 was obtained, which means that the equation has a very strong relationship. In another sense, productivity can be explained by 97.30% of the parameters of fragmentation, digging time, cycle time, and digging rate. While the other 2.70% was influenced by other factors.

The equation obtained through multivariate modeling is as follows:

Y= 2,28X1-2,079 X2+86,492 X3+2,879X4– 2831,29

Information:
X1 = Fragmentasi Berukuran Boulder (%)
X2 = Digging Time (s)
X3 = Cycle Time (s)
X4 = Digging Rate (bcm/hour)

B. DISCUSSION

4.4. Multivariate Model Trial and Error Test

The productivity target to be achieved at PT J Resources Bolaang Mongondow Sulawesi Utara is 700 bcm / hour. To get the target, an estimate is carried out using the equations that have been obtained from multivariate modeling on 6 combinations of data. The combination of data includes boulder-sized fragmentation percentage data (3-8 %), digging time (6-11 seconds), cycle time (14-19 seconds), and digging rate (600-850 bcm / hour). This data range is compiled based on the distribution of data from observations made on blasting blocks.

The productivity calculation was carried out by trial and error in the pairs of data combinations above, each of which consisted of 215 data pairs resulting in 1,290 productivity data. From these data, an optimum point is obtained that shows the ideal conditions in the combination of data as shown in Table 5.

This optimum point was obtained at a productivity value close to the value of 807 bcm / hour in the Pit South Osela. The productivity value is assumed from the production value that has been accumulated with the error percentage of the multivariate equation above.

TABLE 6
MULTIVARIATE MODEL TRIAL AND ERROR TEST

Variable	KOMBINATION					
	1	2	3	4	5	6
Fragmentation (%)	3	4	5	6	7	8
Digging Time (s)	11	11	11	11	11	11
Cycle Time (s)	14	14	14	14	14	14
Digging Rate (bcm/jam)	800	800	800	800	800	800
Productivity (bcm/hour)	822	825	828	831	834	808

Table 6 shows that a good combination to accomplish the production target of 700 bcm / h in the West Durian Pit is as follows:

a. The total percentage of boulders ranges from 3% to 5%.
b. Digging time 7 seconds to 8 seconds
c. Cycle time 14 seconds to 15 seconds
d. Digging rate 750 bcm/h to 850 bcm/hour.

4.5. Blasting Geometry Optimization

The calculation of the geometry of blasting was carried out with the theory of C.J. Konya (1991) so that geometric parameter were obtained as in Table 7.

TABLE 7
OPTIMIZATION OF BLASTING GEOMETRY WITH THE THEORY OF C.J. KONYA (1991)

No	Parameters	Unit	Blasting Geometry	
			JRBM	C.J. Konya
1	Burden	m	3	3.1
2	Space	m	4	3.4
3	Stemming	m	2.2	2.2
4	Subdrilling	m	0.2	0.9
5	Hole Depth	m	5.2	5.9
6	Fill Column	m	3	3.8

	Length			
7	Powder Factor	Kg/bcm	0.38	0.51
8	Boulder fragmentation	%	7.46	4.93
9	Productivity	bcm/hour	536	582

From Table 7, it can be seen that with the revision of the blasting geometry according to C.J. Konya, the percentage of boulder-sized fragmentation decreased by 2.53 %. If a geometric revision is carried out based on the theory of C.J. Konya, geometric changes are obtained in the following parameters, namely:

a. Burden increased by 0.1 m
b. Spacing was reduced by 0.6 m
c. Subdrilling and depth of explosive pits increased by 0.7 meters
d. The length of the fill column has increased by 0.8 meters
e. The powder Factor increased by 0.13 Kg / bcm

V. CONCLUSIONS

From the data processing and analysis carried out, it can be concluded:

a. The analysis of blasting geometry with C.J. Konya's theory shows a smaller percentage of boulder-sized blast fragmentation results
b. With the optimization of the blasting geometry, productivity has increased by 46 bcm / hour

VI. ACKNOWLEDGMENTS

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