Evaluation Of Blasting Geometry To Fragmentation Of Rock And Blasting Cost On Pit Lisat Pt. Teguh Sinarabadi District West Kutai Province East Kalimantan, Indonesia.

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Abstract: The rock that has been erupted or called fragmentation was an important part of a blasting result, because the fragmentation of the rock is a direct impact of the explosion that will affect the next stage. Based on the company standard the success rate of the blasting activity is the percentage rate of boulder which is below 15%. To produce good fragmentation many things that affect blasting geometry is one of the things that can be controlled. To know the level of fragmentation of blasting results can be used calculation method with kuz-ram model and direct technique with image analysis method. The cost calculation also needs to be calculated to determine whether the blasting activity is economical or not. From eight explosions, boulder fragmentation was predicted by using kuz-ram model: 19,72%, 16,56%, 14,35%, 16,35%, 14,09%, 14,94%, 15,27 %, 16.90%. While the calculation of rock fragmentation level is actually used image analysis method using splitdekstop 2.0 software, and obtained the level of boulder fragmentation are: 20,77%, 19,58%, 15,90%, 17,35%, 15,80%, 16 , 92%, 16.60%, 17.56%. From each blasting activity is calculated how total blasting cost incurred, and obtained the total cost incurred are: 0.256 $ / BCM, 0.281 $ / BCM, 309 $ / BCM, 0.284 $ / BCM, 0.322 $ / BCM, 0.300 $ / BCM , 0.282 $ / BCM, 0.274 $ / BCM. Subsequently, a new blast geometry was proposed based on the R.L Ash equation (1963), C. J.Konya (1972), Anderson (1952), and Austin Powder. From the explosive cost calculation sought the equation of the relationship between the total cost of blasting and the powder factor (PF) is used to estimate the blasting cost incurred in accordance with the new usability geometry.

Keywords: Blasting Cost, Correlation, Fragmentation, Image Analysis, Kuz-ram Model, Powder Factor (PF).

1. INTRODUCTION

PT. Teguh Sinarabadi is a coal mining company that uses the blasting method to unload interburden material. Blasting material will be removed, or the so-called fragmentation is an important part of a blasting product because the results will affect further activities.The purpose of drilling and optimal work, namely blasting that produces fragmentation according to needs with the lowest overall costs for drilling, blasting, loading, transportation and subsequent processing. So an analysis is carried out for rock fragmentation resulting from blasting activities to determine what factors affect the blasting results with the planning that has been carried out and

The calculation of costs incurred.

The application of actual geometry in the field will directly affect the results of blasting activities, especially rock fragmentation, the size of the rock fragmentation will directly affect the productivity of the excavator. The use of explosives and blasting equipment depends on the application of the blasting geometry, so the costs incurred for blasting will also vary. So it is necessary to evaluate to find out how effective and efficient the application of blasting geometry has been.

METHODOLOGY

Data collection is carried out directly in the field to find out the actual geometry applied in the field. Blasting geometry, explosive stuffing, and size distribution of blasting fragments were observed at 8 observation locations in blocks 27-32

Method of collecting data

Data collection was carried out in two ways, namely observing and collecting data in the field. Field conditions and descriptions of blasting activity were observed directly in the field. While data collection in the field was obtained from primary data (primary) and literatures related to existing problems (secondary data). The main data consists of the contents of the explosives, the geometry of the explosion, the use of blasting equipment and equipment, the salary of the crewblasting, digging time and digging rate of digging tools, photos of blasting results as well as data on material types and specific gravity. Meanwhile, the supporting data (secondary) used includes blasting methods, types of explosives, prices for blasting equipment and equipment.

Data Processing Methods

The relationship between the effect of explosive filling on the results of fragmentation from actual data in the field was analyzed using the second order polynomial regression equation approach. As for the fragmentation distribution analysis, two methods were used. actually. Furthermore, looking for the relationship between the digging time of the blasting material with the average size of its fragmentation and distribution to determine the effect of fragmentation on the digging time and digging rate of the digging tool. The calculation of blasting costs is based on the use of explosives, drilling costs, use of blasting equipment, and blasting crew salaries. From the calculation of blasting costs, the relationship between costs incurred and the use of explosives is sought and the distribution of the resulting fragmentation. This equation is then used to determine the estimated costs incurred when using the new proposed geometry. The determination of the proposed geometry used the equation R.L Ash, C.J Konya, Anderson and Austin Powder.

ANALYSIS

Actual Blasting Geometry

From field observations, the actual blasting geometry was obtained (Table 1). In the planning, the blasting geometric parameters used were burden of 9 m, spacing of 10 m, depth of 11 m, stemming of 6.5 m, and column charge of 4.5 m. However, in actual application there are deviations due to the accuracy of the drilling which is not precise, causing geometric differences in plan and actual. The location of the blasting is uneven and narrow causes the drill tool to not work optimally, consequently it will affect the accuracy of drilling. So that it will affect the drilling pattern. The actual blasting geometry can be seen in table 1. At the blasting location IB D B30-31 there was an increase in PF, the actual PF used was 0.26 kg / BCM, this was due to the geometry detonation more tightly. This increase was carried out because it was expected that the resulting blasting fragmentation was in accordance with the desired standard, so that the production target was achieved. In addition, the location of the blasting is narrow, so the drill tool cannot work optimally, so there are several holes close together.

Table 1. *Actual blasting geometry*

Blasting Date	Location	Blasting Geometry (m)					Loading Density Aktual (kg/m)
		Burden	Spasi	Depth	Stemming	PC	
8/8/2017	IB 13L B28-29	8.8	10.0	6.8	3.8	3.0	36.91
9/8/2017	IB 12 B28	8.5	9.7	7.2	3.9	3.3	38.71
10/8/2017	IB 8 B30	8.3	9.8	4.9	2.8	2.2	37.88
12/8/2017	IB 5 B27	8.8	9.5	8.0	4.2	3.9	39.39
18/08/2017	IB D B30-31	7.5	9.9	8.6	4.4	4.1	39.53
21/08/2017	IB 8 B27	7.8	9.9	7.5	4.1	3.5	38.31
22/08/2017	IB 5 B32-33	8.7	9.6	9.0	4.6	4.4	39.05
25/08/2017	IB 13 B28	8.6	9.9	6.2	5.5	2.9	38.11

Actual Blasting Powder Factor

Table 2*. Actual Powder Blasting Factor*

Blasting date	Location	Kg/bcm (P. F)
8/8/2017	IB 13L B28-29	0.18
9/8/2017	IB 12 B28	0.22
10/8/2017	IB 8 B30	0.22
12/8/2017	IB 5 B27	0.23
18/08/2017	IB D B30-31	0.26
21/08/2017	IB 8 B27	0.23

The difference in powder factor in each blasting activity is influenced by the blasting geometry that is applied directly in the field. Spacing, burden and depth of blast holes. From the data above, it can be seen that the highest powder factor was on 18/8/2017, namely the blasting at Pit Lisat Seam D B30-31, while the lowest powder factor was at the blasting on 8/8/2017 at 28 Pit Lisat location. IB 13L Block 28-29.

Fragmentation Analysis Using the Kuz-Ram Model.

From the observations that have been made regarding the geometry of the explosion, the physical and mechanical properties of the rock, the weight of the rock, the geological conditions, and the properties of the explosives. It can be determined the resulting fragmentation average and size distribution using the Kuz-Ram model. Where this model is used to determine theoretically or predict the results of fragmentation that will be generated based on the above parameters.

The following is the theoretical fragmentation distribution data that will be generated from each explosion.

Table 3.
Distribution of rock fragmentation in the kuz-ram model.

Date	< 20 cm	20 - 40 cm	40 - 100 cm	> 100 cm	X (cm)
8 Agustus	29.50%	13.03%	36.71%	19.72%	41.84
9 Agustus	28.43%	14.77%	37.23%	16.56%	37.78
10 Agustus	43.52%	12.43%	28.14%	14.35%	34.99
12 Agustus	26.31%	20.76%	35.59%	16.35%	37.51
18 Agustus	39.36%	13.35%	31.50%	14.09%	34.66
21 Agustus	28.95%	16.78%	37.36%	14.94%	35.73
22 Agustus	25.49%	17.91%	40.02%	15.27%	36.11
25 Agustus	41.52%	13.19%	27.73%	16.90%	38.21

Fragmentation Analysis Using Image Analysis Techniques.

The fragmentation results from blasting in the field can be determined directly using image analysis techniques with the help of software. This method is used to evaluate the results by taking the input data in the form of a fragmentation digital photo that has a comparison in it. Furthermore, the results of the digital photo will be analyzed using software on a computer. From the observations, the results of the analysis using split desktop 2.0 software obtained the average fragmentation produced and the size distribution as follows:

Table 4.
Distribution of rock fragmentation by image analysis technique.

Date	< 20 cm	20 - 40 cm	40 - 100 cm	> 100 cm	X (cm)
8 Agustus	29.50%	13.03%	36.71%	20.77%	43.58
9 Agustus	28.43%	14.77%	37.23%	19.58%	40.46
10 Agustus	43.52%	12.43%	28.14%	15.90%	38.44
12 Agustus	26.31%	20.76%	35.59%	17.35%	38.86
18 Agustus	39.36%	13.35%	31.50%	15.80%	35.78
21 Agustus	28.95%	16.78%	37.36%	16.92%	35.83
22 Agustus	25.49%	17.91%	40.02%	16.60%	39.30
25 Agustus	41.52%	13.19%	27.73%	17.56%	41.21

Comparison of Theoretical and Actual Fragmentation Results.

The results of blasting rock fragmentation can be evaluated by comparing the theoretical and actual calculation of the distribution of fragmentationThis is done to control the fragmentation of the blasting product. There are some differences between measured and predicted fragmentation, as would be expected, given the nature of the explosives, geological circumstances and rock variability. Because the bigger the scale of the operation and the bigger it is holes and increasingly varied rocks and geological conditions (Konya, 1991. From the results of observations and calculations made, the error rate of evaluation of the theoretical and actual results is less than 10%. The comparison between the two is as follows:

Table 5.
Comparison of rock fragmentation distribution by Kuz-ran model and image analysis technique.

Tanggal	theoretical			Actual			S.Dev *Boulder*
	< 20 cm	20 - 100 cm	> 100 cm	< 20 cm	20 - 100 cm	> 100 cm	
8 Agustus	27.72%	52.55%	19.72%	29.50%	49.74	20.77%	0.52%
9 Agustus	30.21%	53.23%	16.56%	28.43%	52.00	19.58%	1.51%
10 Agustus	32.18%	53.47%	14.35%	43.52%	40.57	15.90%	0.78%
12 Agustus	30.38%	53.26%	16.35%	26.31%	56.35	17.35%	0.50%
18 Agustus	32.43%	53.48%	14.09%	39.36%	44.85	15.80%	0.85%
21 Agustus	31.63%	53.43%	14.94%	28.95%	54.13	16.92%	0.99%
22 Agustus	31.33%	53.40%	15.27%	25.49%	57.92	16.60%	0.66%
25 Agustus	29.92%	53.18%	16.90%	41.52%	40.92	17.56%	0.33%

Calculation of Digging Time and Digging Rate of Blasting Material.

The actual fragmentation results will affect the digging time of the dig-and-load tool, the greater the size of the rock fragmentation, the longer it will take for the digging tool to stick the bucket teeth until it is filled so that it will affect the cycle time of the tool, and the effectiveness of the tool work will be smaller, but vice versa the resulting fragmentation results, the digging time of the digging tool will be faster, thus accelerating the cycle time and increasing the work effectiveness of the tool. From the results of the blasting, the digging time data for the digging tool was taken, for this case the digging tool used was Liebherr 9350. The following is the digging time data for the digging tool for each material result from the blasting activity:

Table 6.
Average fragmentation, digging time, digging rate.

Location	Dig and Load Tool	Average Fragmentation (cm)	Digging Time(S)	Digging Rate (BCM/hour)
IB 13L B28-29	Exc-Liberr 9350 (2392)	43.58	15.11	1180.29
IB 12 B28	Exc-Liberr 9350 (1639)	40.46	14.66	1432.61
IB 8 B30	Exc-Liberr 9350 (2392)	38.44	14.34	1468.56
IB 5 B27	Exc-Liberr 9350 (2393)	38.86	14.58	1459.79
IB D B30-31	Exc-Liberr 9350 (7022)	35.78	13.68	1541.29
IB 8 B27	Excr-Liberr 9350 (2393)	35.83	14.28	1473.22
IB 5 B32-33	Exc-Liberr 9350 (2392)	39.30	14.55	1450.47
IB 13 B28	Exc-Liberr 9350 (2393)	41.21	14.98	1358.80

To make it easier, the results of the digging time of each blasting location are presented in graphical form, as follows:

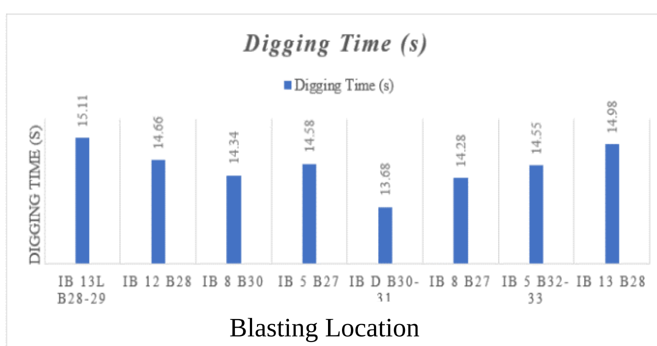

Figure 1*.Graph of digging time of the digging tool for each blasting activity material.*

The graph above shows the comparison of the digging time of each blasting location, it can be seen that the digging time of the digging tool is the smallest in the blasting material at the IB D Block 30-31 location with a time of 13.68 seconds. This time is the standard time for the Liebherr 9350 digger to carry out excavations. Meanwhile, the highest average digging time is in the blasted material at the 13L block 28-29 seam location. Digging time of the digging tool greatly affects the material it is extracted, in this case it depends on the fragmentation of the blasting product. Where the smaller the fragmentation resulting from blasting, the digging time will be smaller and the bucket fill factor will increase, thus accelerating the cycle time of the digging tool and accelerating the filling of material to the conveyance. The relationship between rock fragmentation as a result of blasting with the digging time of the Liebherr 9350 digger can be seen from the following graph:

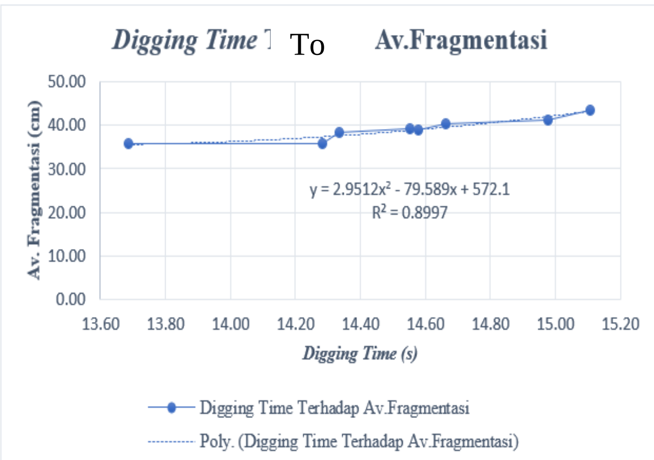

***Figure 2**. Graph of the relationship between digging time of the digging tool for each blasting activity material with the average fragmentation.*

From the graph above it can be seen that the smaller the resulting fragmentation, the smaller the digging time of the digging tool. load. It can be seen that the determination value (R2) of the equation is 0.89 which means that fragmentation and digging time have a strong correlation between one another. Where the size of the fragmentation greatly affects the digging time of the digging tool.

Fragmentation Relationship with Drilling and Blasting Costs.

The results of the calculation of drilling and blasting costs for each blasting activity are as follows:

Table 7.
Boulder percentage, total blasting costs.

Blasting Date	Location	Boulder Percentage (%)	COST ($ /BCM)
8/8/2017	IB 13L B28-29	19.17%	$ 0.256
9/8/2017	IB 12 B28	15.97%	$ 0.281
10/8/2017	IB 8 B30	16.60%	$ 0.309
12/8/2017	IB 5 B27	17.44%	$ 0.284
18/08/2017	IB D B30-31	17.77%	$ 0.322
21/08/2017	IB 8 B27	17.87%	$ 0.300
22/08/2017	IB 5 B32-33	16.23%	$ 0.282
25/08/2017	IB 13 B28	17.50%	$ 0.274

From the calculation of drilling and blasting costs, it was found that the blasting with the highest cost was at the location of Seam D Block 30-31 with a total cost of 0.322 $ / BCM and the lowest cost was at the blasting location at Seam 13L Block 28-29 with a total cost of 0.256 $ / BCM.

For simplicity, the following graph compares the total drilling and blasting costs at each location

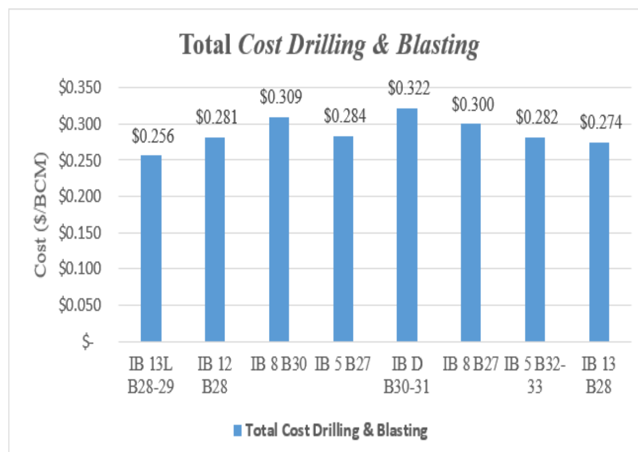

***Figure 3**. Graph of total drilling and blasting costs for each blasting activity.*

From the data on the distribution of the blasting fragmentation results and the total cost of drilling and blasting, a second order polynomial equation can be determined which can then be used to predict the drilling and blasting cost model that will be issued with the desired fragmentation distribution. The equation can be seen in Figure 3.The value of determination (R2). namely 0.75 indicating that the boulder distribution has a strong correlation with the total drilling and blasting costs. Where to produce a small amount of boulder, it is necessary to spend more money, because this depends on the use of explosives.

The following is a comparison graph between the distribution of fragmentation with a size> 100 cm:

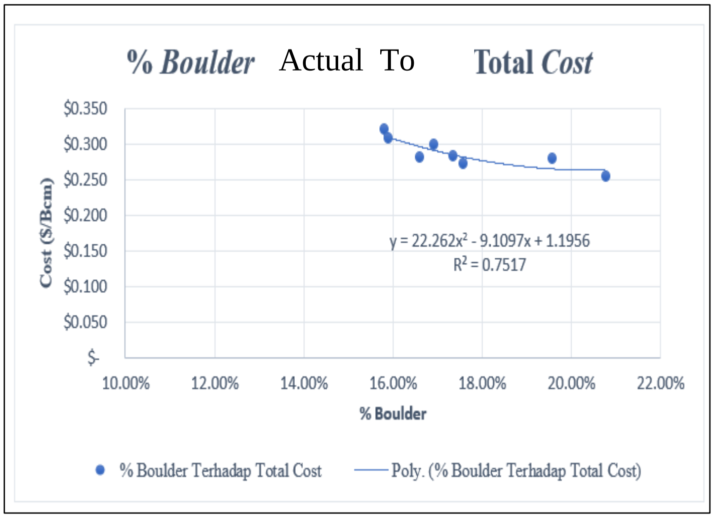

***Figure 4**. Graph of the equation between the percent of actual boulder and the total cost of blasting.*

Powder Factor Against Drilling and Blasting Costs.

Powder factor is a parameter to determine whether or not a blasting activity is economical. Therefore, it is necessary to know the optimum powder factor, with good fragmentation results but with the most effective total drilling and blasting costs possible. From 8 blasting times, the powder susceptibility factor and total costs for drilling and blasting are obtained as follows:

Table 8.
Powder Factor, Total drilling and blasting costs.

Location	PF (kg/BCM)	Total Cost ($/BCM)
IB 13L B28-29	0.18	$ 0.256
IB 12 B28	0.22	$ 0.281
IB 8 B30	0.22	$ 0.309
IB 5 B27	0.23	$ 0.284
IB D B30-31	0.26	$ 0.322
IB 8 B27	0.23	$ 0.300
IB 5 B32-33	0.21	$ 0.282
IB 13 B28	0.21	$ 0.274

For more details, the data is presented in the form of a comparison chart between powder factor and The total cost for drilling and blasting, then from the comparison graph the polynomial equation of order 2 is calculated. The equation is obtained in Figure 5. With a determination value (R2) of 0.76 shows a good correlation between powder factor and total blasting costs incurred. Furthermore, the equation between PF and costs incurred is used to estimate the total cost of blasting that will be incurred using the proposed geometry with a certain powder factor value.

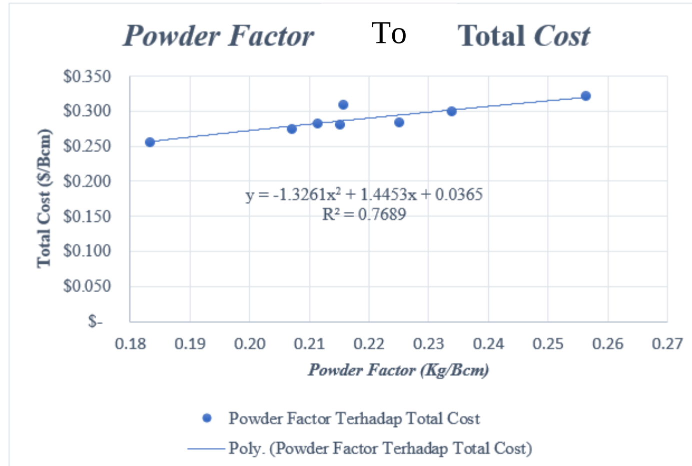

***Figure 5**. Graph of equations between PF and total blasting costs.*

Blasting Evaluation.

The blasting geometry greatly influences the fragmentation of the blasting activity. Burden size and spacing that actually differ from the plan will certainly affect the fragmentation results. The difference in spacing and burden size between actual and plan often occurs during the blasting process. In addition to the blasting geometry, the explosives used, and the blasting pattern, the physical and mechanical properties of the rock and the geological structure conditions in the area to be detonated must also be considered. Determination of the blasting geometry starting from the burden, spacing, length of the column, stemming, level height, sub-drilling, and depth of the blast hole must pay attention to the rock mass characteristics and local geological conditions in order to obtain the expected fragmentation. The current burden size and spacing of 9 m and 10 m in the study location are not considered good because the propagation of the detonation wave generated from the blast hole until the energy returns in the form of tensile energy becomes long and makes the association between waves not optimal. The presence of free space in blasting activities will also affect the results. Because the function of the free field is to conduct energy in the blast hole. Stemming measures also play an important role in maintaining the distribution of explosive energy in balance between areas filled with explosives and areas that are not filled with explosives. If the stemming is too short, at the time of blasting the hole will be dismantled too quickly because it is not compressed properly, the gas produced by the explosives that exploded in the blast hole will come out and the pressure will decrease (loose energy) so that it is not strong enough to make fractures and break rock. As a result of this loose energy, the resulting fragmentation is large. In the research area, drill cutting material was used as stemming to lock the blasting gas in the blast hole. This drill cutting material is good enough to be used as stemming at the blasting location in dry holes, but in wet holes this material is less effective because the drill cutting material has low moisture against water. However, it would be better if the stemming material size is 10% -15% of the diameter of the blast hole. The drilling and blasting costs incurred also depend on the explosives released. So that the blasting geometry is something that needs attention so that the use of explosives is as effective as possible in blasting activities.

Factors Affecting the Fragmentation of Blasted Rocks
After making observations, there are several factors that affect the fragmentation of the results of blasting activities, namely:

- Actual blasting geometry, application of blasting geometry greatly affects the rock size resulting from blasting activities. Spacing, burden, drill hole depth, stemming will have an immediate effect.
- The nature of the rock mass, the nature of the different rock masses at the blasting location will affect the fragmentation results, this results in uneven fragmentation of the blasted rock.
- Geological structure, this is one thing that cannot be controlled. One of the factors that must be considered in planning a blasting operation is the geological structure. There is a discontinuity in the rock properties affect the propagation of energy waves in rocks. If the energy propagates through the layering field, some of the waves will be reflected and some will be refracted and forwarded, because some waves are reflected, the strength of the detonation energy will decrease.
- The use of explosives (powder factor), the greater the use of explosives or the PF value used, the smaller the size of the resulting fragmentation and vice versa, the smaller the PF value the greater the size of the fragmentation. The use of PF is adjusted to the properties of the rock mass to be blasted
- There is a free face. Forward movement of blasted material can occur easily if it has sufficient free space. The movement of rock masses is necessary to allow crack propagation to occur. This increased movement will aid in crack propagation and improve fragmentation.
- Drilling and blasting patterns, there are two types of drilling patterns, namely the staggered pattern (zigzag) and the pattern (parallel). In its application, the zigzag pattern is better than the parallel pattern because the fragmentation results will be more uniform than the parallel pattern, but for application in the field it will be more difficult to handle.

Proposed Geometry
After calculating and analyzing the data as above, it is concluded that it is necessary to redesign or create a new blasting geometry plan. In this case the authors use 4 equations to determine the proposed blasting geometry, wherein the three new blasting geometries are then simulated the resulting fragmentation results and an estimate of the total drilling and blasting costs per BCM. The geometric calculations used are the equation R.L Ash (1963), C.J Konya (1972), Anderson (1952) and the equation from Austin Powder (2002). From these four geometries, a technical and economic simulation is performed to determine the optimal blasting geometry. For the calculation of each geometry, see the appendix

The following is the geometry based on the equation R.L Ash, C.J Konya, Anderson, and Austin Powder:

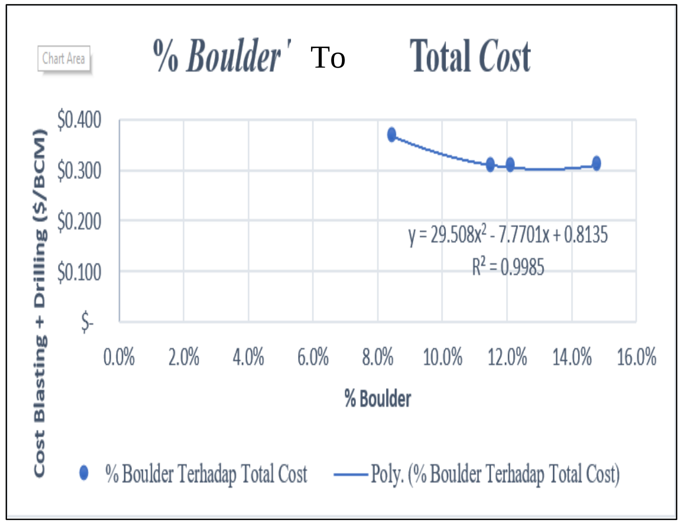

***Figure 6**. Graph of the relationship between percent of boulder and total blasting costs From the 4 equations above, it is considered*

From the 4 equations below, it is considered that the Austin Powder equation is the most optimal which produces boulder fragmentation below 15%, namely 12.13% at a cost of approximately 0.307 $ / BCM and it is expected that the digging time and digging rate of the Liebherr 9350 digging tool are more optimal.

Table 9.
The proposed geometry and fragmentation estimation and costs incurred.

Equation	Geometry(m)					PF	Est.Av, Fragmentation (cm)	Est. Boulder %	Est.Cost ($/BCM)
	Space	Burden	Depth	Stemming	Column Charge				
R.I.Ash	9.5	8.5	9	4.5	4,5	0,24	36,27	14,18%	$ 0,310
CJ.Konya	9,5	6,8	9	6	4	0,30	28,06	10,51%	$0,361
Anderson	7	5,5	9	6,9	2,1	0,24	32,05	11,50%	$0,309
Austin Powder	7	6	9	6,6	2,4	0,24	32,85	12,13%	$0,307

CONCLUSION AND SUGGESTIONS .

From the results of observations and calculations made, it can be concluded that:

1. In its application, the blasting geometry parameters used are 10 m spacing and 9 m burden with various hole depths ranging from 3 - 11 m.
2. Of the 8 blasting activities, after analysis using the Kuz-Ram model the results of rock fragmentation produced in each blasting area the average was around 34.66 - 41.84 cm, with a boulder presentation of> 100 cm in the range of 13 , 54% - 19.09%.
3. The results of the blasting fragmentation are calculated using image analysis techniques through the input of digital photos of the blasting results, this is done to control the actual fragmentation of the blasting activity. The average rock fragmentation analysis was 35.78 - 43.58 cm, with a boulder percentage ranging from 15.80% - 20.77%.
4. The factor that affects the results of rock fragmentation is the not yet optimal blasting geometry, so it is necessary to improve the blasting geometry in order to obtain optimal fragmentation results which are expected to accelerate the digging time of digging. increase the bucket fill factor, and increase the digging rate.
5. Based on calculations using 4 equations, namely R.L Ash, C.J Konya, Anderson, and Austin powder. Obtained the optimal blasting geometry is the Austin Powder equation with 7 m spacing, 6 m burden, 9 m depth, 6.6 m stemming, 2.4 m column charge with powder factor 0.24 kg / BCM. With this geometry it is estimated that the boulder fragmentation of 12.3% with a total drilling and blasting cost of 0.305 $ / BCM is expected to increase the digging rate of the digging tool to 1716 BCM / hour.

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