Monte Carlo Simulation to Predict Rock Fragmentation Results from Blasting Activity at Quarry PT. Semen Padang

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Abstract. One aspect and factor that is very important in the blasting stage is rock fragmentation, which has a direct impact on drilling costs, blasting costs and operational economics, both loading, transportation and crushing. As time progresses, new technological advances for the application of blasting have developed. This technology is to computerize blast design and predict the results of the explosion, which is rock fragmentation. Many factors influence rock fragmentation, such as the nature of the rock mass, geological location conditions, explosion and fracture parameters present in place, so it is difficult to predict completely. However, empirical models to predict the size distribution of rock fragmentation have been developed. In this study, Monte Carlo simulation as a rock fragmentation simulator based on the Kuz-Ram fragmentation model has been developed to predict fragmentation size distribution. The results obtained from this Monte Carlo simulation can be said to be quite good when compared with the actual data fragmentation obtained from field conditions.

Keywords: Rock Fragmentation, Monte Carlo Simulation

1 Introduction

As time goes on, the industrial world continues to evolve rapidly, forcing companies to continue looking for new innovations to be able to grow in a better direction and stay competitive. One of the factors for a company to survive amidst industrial development is good production. Companies must carry out good management of production. Where production is a series of activities to create/add/produce something/objects aimed at satisfying other people/consumers. This production process is very important because production is a reference for achieving or not achieving the targets or goals of a company.

PT. Semen Padang is a State-Owned Enterprise (BUMN) company that focuses on cement production in the mining sector using limestone as raw material. PT factory. Semen Padang is in Indarung, Padang City, West Sumatra, while PT. Semen Padang carries out mining at the Bukit Karang Putih location, Indarung, Padang City, West Sumatra. One of the mining activities carried out by PT. Semen Padang is a blasting process, which aims to separate rock from its parent rock or break up the rock so as to make subsequent mining processes easier such as loading, hauling, crushing and so on. The result of this blasting process is rock fragmentation. PT. Semen Padang has a blasting rock fragmentation target measuring 80 cm with a percentage of 80%. This is because if a large amount of debris larger than 80 cm is created then it will take longer to move on to the next process, which is loading explosive materials, such as boulders that need to be broken up mechanically break the stone, or even multiple times. when the blasting process is performed. The second time for boulders that are larger than 80 cm, so they will require higher costs. Rock fragmentation resulting from blasting at PT. Semen Padang can be said to have not achieved its target, where rock fragmentation measuring more than 80 cm still exceeds the percentage of 20%.

The aim of this research is to analyze rock fragmentation resulting from blasting at PT. Semen Padang using Monte Carlo simulation based on the Kuz-Ram method.

2 Methodology

The method applied in this research is through literature study (library study) and using quantitative methods. The data used comes from primary data obtained from the research location and secondary data found from journals related to the application of the Internet of Things (IoT) in the Monte Carlo simulation analysis process for rock fragmentation resulting from blasting.

3 Theoretical Review

3.1 Kuz-Ram Fragmentation Model

The Kuz–Ram model is an empirical fragmentation model based on the Kuznetsov and Rosin–Rammler equations as well as an algorithm developed by Cunningham, which obtains uniformity coefficients in the Rosin–Rammler equation from detonation parameters (Cunningham, 1983, 1987; Lizotte, 1990). The Kuz-Ram model predicts fragmentation due to blasting in terms of the percentage of mass that passes through a certain mesh size.

- Fragmentation of smaller sizes is produced by several factors such as higher blast energy, weaker rock types and smaller blast hole diameters.
- More regular fragmentation size results from uniform distribution of explosives in the rock mass, lower charge, and greater space-to-charge ratio.

Problem areas in a particular predictive blasting model are typically:

- Define relevant properties of rock mass.
- Select appropriate performance index of explosive materials.
- Determination of actual fragmentation of explosives.

This activity aims to overcome the problem of variability and uncertainty in rock mass properties through the use of Monte Carlo simulation. Because the state of the rock mass changes with each blasting operation, the fragmentation is also different.

2.1.1 Kuznetsov Equation

The Kuz–Ram model is an empirical fragmentation model (Cunningham, 1983, 1987; Lizotte, 1990) based on the Kuznetsov and Rosin–Rammler equations as well as an algorithm developed by Cunningham, which obtains uniformity coefficients in the Rosin–Rammler equation from the detonation parameters. This model estimates fragmentation due to blasting in terms of the percentage of mass that passes through a certain mesh size.

$$X_m = A\left(\frac{V_0}{Q_T}\right)^{0,8} {Q_T}^{1/6}, \quad (1)$$

where:

X_m : average fragmentation size (cm),
A : rock factor,
V_0 : rock volume (m^3),
Q_T : mass (kg) of TNT containing energy equivalent to the explosive in each blast hole.

Kuznetsov (1973) constructed a semi-empirical equation based on field studies and review of previously published data relating the average fragment size to the mass of the explosive, the blast volume explosion and rock resistant. The Kuznetsov equation, given below, involves an average measure of fragmentation and the explosive energy exerted per unit rock volume (i.e. powder coefficient) as a function of rock type.

$$Q_T = Q_e \frac{S_{ANFO}}{115}, \quad (2)$$

where:

Q_e : mass of explosives used (kg),
S_{ANFO} : the relative weight strength of the explosive relative to the ANFO.

This equation can also be expressed in terms of powder factor or specific charge K (kg of explosives/m^3 of rock).

$$\frac{V_0}{Q_e} = \frac{1}{K}, \quad (3)$$

Equation (2) and (3) can be rewritten to calculate the fragmentation size as X_m, as follows:

$$X_m = A\left(K^{-0,8}\right){Q_e}^{1/6}\left(\frac{115}{S_{ANFO}}\right)^{19/30}, \quad (4)$$

Cunningham (1983, 1987) and Lilly (1986) provided a methodology for evaluating rock factor A based on the geomechanical properties of the rock mass to be exploded, usually in the range 8–12.

2.1.2 Rosin-Rammler Equation

The Rosin–Rammler equation is used to characterize the partial size distribution of a material for use in various applications (Rosin and Rammler, 1933).

$$R = e^{-\left(\frac{X}{X_c}\right)}, \quad (5)$$

where:

R : mass fraction larger than size X,
X : rock fragmentation diameter (cm),
X_C : a characteristic measure of rock fragmentation (cm),
n : Rosin–Rammler exponent,
e : natural logarithm based, 2,7183.

The characteristic size of rock fragmentation, X_C, is approximately the 36.8% size retention point in the size distribution function. The Rosin–Rammler exponent, n, is known as the uniformity coefficient. A wide variety of size distributions can be modeled with the Rosin-Rammler equation simply by changing the value of n to fit the curve. Cunningham (1987) notes that the uniformity coefficient n typically varies between 0.8 and 1.5.

Since the Kuznetsov formula gives a size X_m through which 50% of the material can pass, substitute X = X_m and R = 0.5 into equation (6).

$$X_c = \frac{X_m}{(0,693)^{1/n}}, \quad (6)$$

Given that the Kuznetsov equation takes into account the explosion strength and rock mass characteristics, and that the average size is related to the characteristic size of the Rosin–Rammler distribution, the only unknown is the uniformity coefficient. Cunningham determined the applicable coefficient of uniformity through several investigations, taking into account the impact of factors such as: blasting geometry, blasthole diameter, burden, spacing, hole length and drilling accuracy. The exponent n for the Rosin–Rammler equation is estimated as follows:

$$n = \left(2{,}2 - 14\frac{B}{D}\right)\left[\frac{1+\frac{S}{B}}{2}\right]^{0{,}5}\left(1-\frac{W}{B}\right)\left(\frac{L}{H}\right), \quad (7)$$

where:
B : *burden* (m),
S : *spacing* (m),
D : blast hole diameter (mm),
W : standard deviation of drilling accuracy (m),
L : total fill length (m),
H : height (m).

Uniform fragmentation is usually desired; so a high value of n is preferred. Cunningham's (1987) experience indicates that the normal range of n for reasonably competent blasting fragmentation in soil is from 0.75 to 1.5, with the average being about 1.0. More competent rocks have higher values.

The modified Kuznetsov equation (4), the Rosin–Rammler equation (5) and the estimated Rosin–Rammler exponent form the basis of the Kuz-Ram formulation for explosive fragmentation prediction models. The Kuz-Ram model can be implemented in various ways depending on the design goals. If it is possible to vary the blast design to achieve a constant average fragmentation size (X_m), or the powder factor (K) can be kept constant, it is possible to predict the resulting size distribution.

3.2 Monte Carlo Simulation and Fragmentation Prediction

First created by Metropolis and Ulam (1949), Monte Carlo-based simulation methods have acquired the status of complete numerical methods capable of solving complex problems. Monte Carlo simulation can generally be described as a simulation method where the simulation results are based on a model where the input values are randomly selected from a representative statistical distribution function that describes the input. The simulation is repeated n times and the results now describe a statistical distribution (Sobol et al., 1994; Fishman, 1996). The Monte Carlo simulation method is used in situations where there is uncertainty in the input data and the uncertainty in the calculated results accurately reflects the uncertainty in the input data.

It is generally known that natural materials such as rocks tend to exhibit a variety of properties. Rock strength, fracture spacing and orientation within a rock mass can and does vary. Drilling itself can introduce variability with deviations in spacing, burden, and drill hole alignment. The end result of these variations is the resulting fragmentation measure which is predicted by the Kuz–Ram model to also show variability.

This observation is especially important if blasting is intended to achieve a specific goal other than breaking up the rock mass. For example, the width of a conveyor system is usually measured using the size of the fragment to be moved. If oversized rocks are encountered more frequently than expected, the conveyor system will not perform as expected. Another example involves hopper size for a crusher. If the material being blasted is larger than expected, the crusher size will be small, if the material is finer than expected, the use of the crusher will be less than optimal.

Monte Carlo-based simulations using the Kuz–Ram model can provide insight into all these issues and help to create appropriate blast designs to meet the required objectives.

3.3 Blastability Index and Rock Factor

Table 1. Rock Mass Properties

Parameter	Weighting
1. *Rock Mass Description* (RMD)	
a. *Powder/Friable*	10
b. *Blocky*	20
c. *Total Massive*	50
2. *Joint Plane Spacing* (JPS)	
a. *Close* (Spasi <0.1m)	10
b. *Intermediate* (Spasi 0.1-1m)	20
c. *Wide* (Spasi >1m)	50
3. *Joint Plane Orientation* (JPO)	
a. *Horizontal*	10
b. *Dip out of Face*	20
c. *Strike Normal to Face*	30
d. *Dip Into Face*	40
4. *Spesific Gravity Influence* (SGI)	SGI=25 x (SG-50)
5. *Hardness* (H) Mohs Scale	1-10

Source: Jimeno et al., 1995

The relationship between these five parameters and the Blastability Index (BI) can be seen in the following equation:

$$BI = 0{,}5 \times (RMD + JPS + JPO + SGI + H)$$

According to Lily (1986), the equation that provides the relationship between rock factors and the explosive ability of a rock is as follows:

$$RF = 0{,}12 \times BI$$

3.4 Blasting Principles in Pits and Quarries

Blasting design must consider the following parameters (Ash, 1968; Jimeno et al., 1995; Hustrulid, 1999):

- Blasthole diameter *D* (m)
- Bench height *H* (m)
- *Burden B* (m)
- *Spacing S* (m)
- *Subdrilling J* (m)
- *Stemming T* (m)
- Blasthole pattern (*staggered* or *rectangular*)
- Blasthole deviation and alignment
- Rock mass properties and discontinuities
- Explosive properties

The most critical and important dimension in blasting is the burden (B) because it represents the rock mass that will be fragmented by the explosive column. The actual value will depend on a combination of variables including rock characteristics, explosives used, etc. A practical guide used to estimate burden is the K_B ratio (K_B is burden/diameter). In general, when K_B=30 (values range 20–40), the blaster/blaster can usually expect satisfactory results for average field conditions.

The distance between adjacent blast holes, measured perpendicular to the burden, is defined as spacing (S). The ideal energy balance between explosives is usually achieved when the spacing dimensions are almost equal to twice the burden (K_S=2) when charging begins simultaneously.

For most conditions, the required subdrilling (J) must be 0.3 times the burden dimension that produces K_J or the subdrilling to burden ratio (Ash, 1963).

Stemming (T) is the part of the blast hole that has been filled with drilling ash or gravel material which is compacted on top of the explosive material so that it can limit and contain the gas produced by the explosion, thereby increasing the fragmentation process. In general, a K_T (stemming/burden ratio) of 0.7 is a fairly good value.

It has been found that fragmentation is strongly influenced by local geological conditions. The strike direction and dip direction of joint joints and their frequency in the rock mass are very important, because the stress waves generated by the explosion of explosives will be reflected towards surface fractures. Rock mass discontinuities perpendicular to the blast hole axis have little influence on fragmentation. However, if the hole is parallel to the borehole axis, energy will be wasted due to excessive crushing in the area near the borehole, while little energy is distributed around the blast hole. The direction of the blast in relation to the structural conditions is of great importance in practice.

4 Research Results and Discussion

4.1 Blasting Geometry Di PT. Semen Padang

Table 2. Actual Blasting Geometry

No	Date	Blasthole	D Hole (inch)	B (m)	S (m)	T (m)	H (m)	Subdrilling (m)	PC (m)	PF (kg/ton)
1	30-01-23	33	5	5	5	4	9.23	1	5.23	0.344
2	31-01-23	50	5	5	5	4	7.93	1	3.93	0.301
3	13-02-23	50	5	5	5	4	9.79	1	5.79	0.359
4	14-02-23	40	5	5	5	4	7.6	1	3.6	0.288
5	16-02-23	50	5	5	5	4	8.24	1	4.24	0.313
6	17-02-23	46	5	5	5	4	9.72	1	5.72	0.358
7	20-02-23	55	5	5	5	4	7.8	1	3.8	0.296
8	22-02-23	50	5	5	5	4	9.83	1	5.83	0.360
9	23-02-23	40	5	5	5	4	9.38	1	5.38	0.348

4.2 Rock Mass Properties

Rock Mass Weighting at PT. Semen Padang, according to Lilly (1986), is obtained from the sum of the values of the five parameters, namely rock mass description, joint spacing, joint plane orientation, influence of specific gravity, and hardness. It can be seen in (Table 1).

Based on the values of the rock parameters above, the Blastability Index (BI) and Rock Factor (RF) can be determined as follows:

Blastability Index (BI):

= 0.5 (RMD + JPS + JPO + SGI + H)

= 0.5 (50 + 20 + 40 + 16.25 + 3)

= 64.625

Rock Factor (RF):

= 0.12 x BI

= 0.12 x 64.625 = 7,755

4.3 Fragmentation Analysis Using the Kuz-Ram Method

The rock from the blasting process carried out by the company is expected to produce good fragmentation, namely less than 80 cm. Fragmentation can be said to be good if the percentage value of the fragmentation size is ≤1/3 of the bucket size used. However, on the other hand, if the resulting rock fragmentation is larger than 1/3 of the bucket size, then the fragmentation is said to be boulder, namely >80 cm. The company targets a fragmentation size of <80 cm to have a pass percentage of at least 80%.

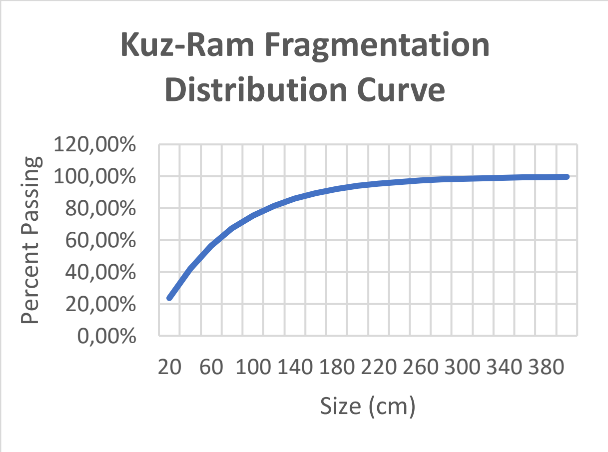
To analyze the size of rock fragmentation resulting from blasting using the Kuz-Ram method, the Kuz-Ram and Rosin-Rammler equations are used, so the results are as follows:

Table 3. Kuz-Ram Method Analysis

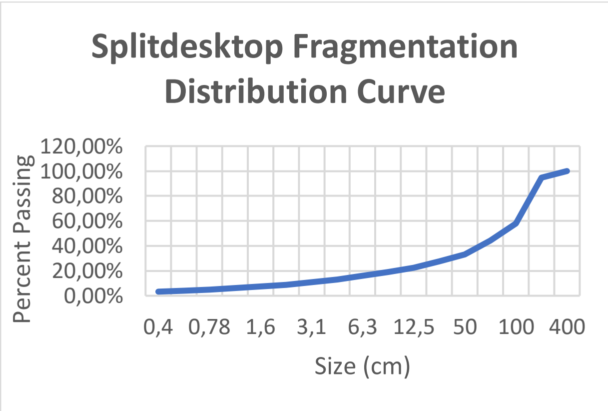
No	Date	Average Size of Fragmentation (cm)	Rosin Rammler Index (n)	Size Characteristic Values *Xc* (m)	Retained Percentage (R80)
1	30-01-23	49,32	1,06	69,71	31,40%
2	31-01-23	52,26	0,95	76,88	35,40%
3	13-02-23	48,50	1,10	67,69	30,07%
4	14-02-23	53,39	0,91	79,89	36,74%
5	16-02-23	51,40	0,98	74,73	34,33%
6	17-02-23	48,58	1,10	67,80	30,13%
7	20-02-23	52,71	0,93	78,19	36,00%
8	22-02-23	48,44	1,10	67,60	30,01%
9	23-02-23	49,07	1,07	69,13	31,06%
Rata-Rata		50,41	1,02	72,40	32,79%

Table 4. Results of Rock Fragmentation Measures Kuz-Ram Method

Size (cm)	20	40	60	80	100
30-01-23	23,37%	42,59%	57,39%	68,60%	76,91%
31-01-23	24,29%	41,58%	54,62%	64,60%	72,30%
13-02-23	23,01%	42,92%	58,35%	69,93%	78,48%
14-02-23	24,69%	41,31%	53,73%	63,26%	70,68%
16-02-23	24,03%	41,48%	55,35%	65,67%	73,56%
17-02-23	22,98%	40,86%	58,28%	69,87%	78,42%
20-02-23	24,53%	41,50%	54,24%	64,00%	71,55%
22-02-23	23,04%	42,96%	58,40%	69,99%	78,53%
23-02-23	23,30%	42,70%	57,65%	68,94%	77,34%



Picture 1. Rock Fragmentation Distribution Curve Using the Kuz-Ram Method



Picture 2. Rock Fragmentation Distribution Curve Using the Splitdesktop Method

4.4 Fragmentation Analysis Using Monte Carlo Simulation

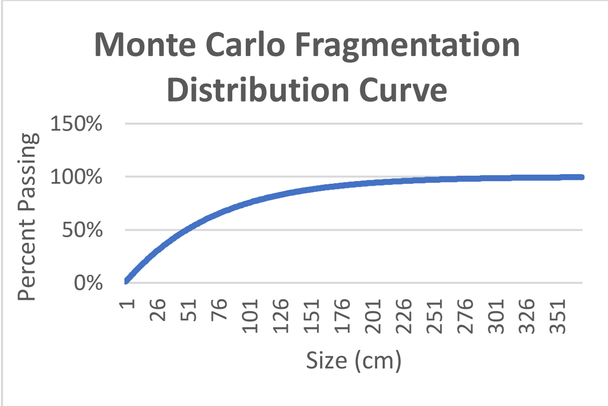
In this study, the simulation of rock fragmentation resulting from blasting uses Monte Carlo simulation based on parameters or the Kuz-Ram model, so that it will be able to predict the entire size distribution of rock fragmentation resulting from blasting.

Monte Carlo simulation analysis based on Kuz-Ram parameter data obtained from the PT. Semen Padang. Nine data were taken on different days. Then, based on this data, the Kuz-Ram method analysis will be carried out as has been done previously.

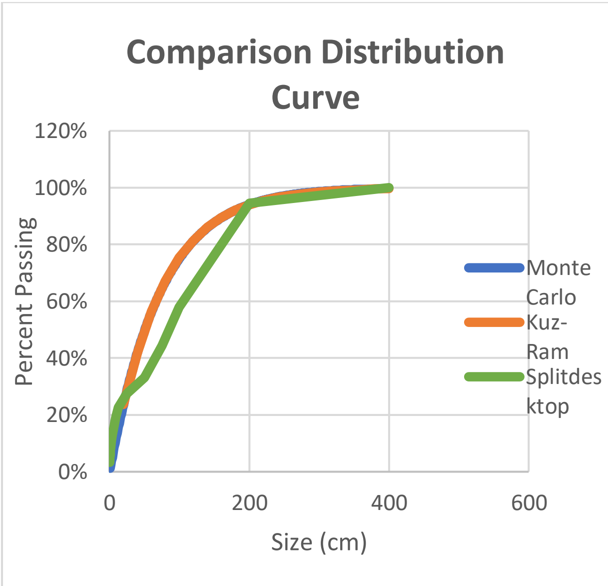
Monte Carlo simulations were carried out based on the Kuz-Ram equation to calculate the percentage distribution of rock fragmentation;

$$Rx = e^{-(\frac{x}{Xc})^n} x100\%$$

with a formula that has been set in Microsoft Excel, the X value is set starting from 0 until the percentage distribution of rock fragmentation produced is 100%. The size characteristic value (Xc) is obtained based on the average of the nine Kuz-Ram method data produced. This results in a rock fragmentation distribution curve resulting from blasting as follows:



Picture 3. Rock Fragmentation Distribution Curve Using Monte Carlo Simulation



Picture 4. Comparison Curve of Cumulative Distribution of Rock Fragmentation Results from Blasting

5 Conclusion

1. By using Splitdesktop analysis it was found that the average fragmentation of rocks that passed the 80 cm size was 47.31%, while using the Kuz-Ram method the average fragmentation of rocks that passed the 80 cm size was 67.21%. Meanwhile, using the Monte Carlo simulation method, the fragmentation of rocks that pass the 80 cm size is 66.85%. The comparative value of rock fragmentation resulting from blasting using the Kuz-Ram method with Splitdesktop analysis is 1:0.89.
2. The blastability index parameters are as follows:
   a. The RMD (Rock Mass Description) value in the research area was obtained with a weight of 50 with a totally massive rock description.
   b. The JPS (Joint Plane Spacing) value is obtained with a weight of 20, with information about the distance between joints ranging from 0.1 – 1 m).
   c. The JPO (Joint Plane Orientation) value is obtained with a weight of 40.

d. The SG (Specific Gravity Index) value was obtained with a weight of 16.25. By calculating the specific gravity of limestone, it is 2.65 gr/cm3.
e. The Hardness value with the help of the Mohs scale is obtained with a weight of 3 which is the limestone group.

With these blastability index parameters, the blastability index value itself is 64.625. With a blastibility index value of 64.625, the rock factor value is 7.755.

3. The fragmentation that passes the 80 cm size in the Kuz-Ram method is 67.21%, in the Splitdesktop analysis it is 47.3% while in the Monte Carlo method it is 67%.

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