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Original Article

Rock Engineering Systems (Res) Method As A Fragmentation Prediction Of Rock Blasting At Quarry Bukit Karang Putih Pt Semen Padang West Sumatera

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Abstract *- Blasting activities will result in certain fragmentations, where fragmentation is one of the parameters of the success of blasting activities. Over time there have been many innovations in predicting the fragmentation of rocks that will form. Rock Engineering Systems (RES) is a model prediction of blasted rock fragmentation that is currently being developed. This study used 11 effective parameters that affect rock fragmentation. Data that has been collected as many as 30 blasting data conducted at PT. Semen Padang, West Sumatra. In this study, the authors also used the Kuzram method, cunningham modification 2005, as well as the statistical model of multiple linear regression as a comparison prediction model. To evaluate the method used, the authors analyzed the correlation coefficients (R^2) and Root Mean Square Error (RMSE) between the actual fragmentation of the results of Image Analysis Software against the prediction model used. The results showed that among kuzram prediction models, Cunningham Modification 2005, Multiple Linear Regression, and RES showed that the RES model produced a very strong correlation coefficient of 0.96 and a low RMSE value of 6. Compared to the Kuzram method, the weak correlation coefficient is 0.40 with a high RMSE value of 18. Cunningham method obtained a medium correlation coefficient of 0.55 with a high RMSE value of 83, and then a double linear regression model obtained a strong correlation coefficient value of 0.80 with a value of RMSE 8. Therefore, this Rock Engineering Systems (RES) model can be used to predict rock fragmentation in PT Semen Padang.*

Keywords - *PT. Semen Padang, Rock Engineering Systems, Kuzram, Cunningham, Multiple Linear Regression.*

I. INTRODUCTION

Blasting activities are one of the activities in mining to release rocks from the source rock. In addition to the effectiveness of work, blasting is considered more economical when compared to using mechanical equipment. Blasting is a follow-up to drilling activities, the purpose of which is to release rocks from their source rocks into smaller fragments, making it easier to dig, load, transport, and process the material (Suwandhi, 2004).

A blasting process will produce rock that breaks down into fragmentation. Fragmentation of rocks that have different rock sizes is one of the factors to determine the success of a blast. Because blasting activities have a very significant impact on subsequent processes such as loading (Kulatilake et al.:, 2010), fragmentation of blasted rock can be said to be good if the distribution of the blasted material is evenly distributed and no boulder size is found. Usually, fragmentation is said to be boulder if the material is larger than 75% of the excavator bucket dimensions. Thus the efficiency of excavation carried out by the excavator will decrease; in addition to that, the loading of boulder material onto the dump truck vessel must be handled carefully. If the results of fragmentation are found in many boulders, it can affect the digging time and feed rate of the crusher so that production will be less than optimal.

One common model that is often used to predict rock fragmentation is the Kuznetsov model or Kuz Ram, which uses calculations by connecting between the average size of fragments with explosive fillings, then developed again by Cunningham based on Kuz Ram and Rossin Ramler distribution with the addition of delay time parameters, then developed using statistical models, however, According to F. Faramarzi et al. in 2013 that the model has not simultaneously considered all the relevant parameters in a model to predict the fragmentation of blasting results.

Rock Engineering Systems is a basic model capable of calculating all parameters related to rock fragmentation. In addition, RES can also be used in various things such as evaluation of the stability of underground mine excavation, hazard and risk of falling rocks, characterization of rock mass for natural slope instability, development of rock mass blastibility assessment system, hazard assessment in geotechnical for tunnels and calculation of hazard assessment in tunnel collapses.

PT. Semen Padang has a target of blasting or fragmentation that is an average of 60 cm and less than 20% measuring ≥100 cm. The results of several detonation times with the same blasting geometry each blasting activity showed that there is still a fragmentation of rocks that are not uniform and have a size of more than 60 cm to 200 cm.

This study will apply the RES model to evaluate the risk of fragmentation or unwanted fragmentation by the company and predict the results of rock fragmentation connecting several complete parameters of this model conducted at PT Semen Padang. Also, comparing with the prediction results from Kuz Ram, Cunningham (2005) and multiple linear regression statistical models in order to obtain a new accurate prediction model that can be applied at PT Semen Padang to obtain the actual fragmentation according to the company's target and evaluate the risk of poor fragmentation at the Bukit Karang Putih limestone mine of PT Semen Padang.

This study aims to determine the basic model of Rock Engineering Systems in predicting the size rock fragmentation X80 (80% average fragmentation size) at PT Semen Padang, as well as knowing the comparison of the prediction results of the Rock Engineering Systems (RES) model with actual data from field measurements and empirical calculations of Kuz-Ram, Cunningham Modification (2005) and the Statistical Model of Multiple Linear Regression.

The research site is located at PT. Semen Padang in Bukit Karang Putih is located around Indarung, Lubuk Kilangan Subdistrict, Padang, West Sumatra Province, Indonesia ±15 Km to the East of Padang City. The research site can be reached from the city of Padang by paved road by four-wheeled vehicle to the location of the mine operations office.

II. RESEARCH METHODS

The type of this research is to examine the benefits of scientific theories that have been carried out by previous researchers and to find out the empirical relationship and analysis of certain fields. This type of research is a type of evaluation research in terms of methods that aim to find, calculate, analyze, and provide solutions in the form of evaluations in order to achieve things that should be or are in accordance with applicable standards. The author makes observations from the theory and actual conditions or real conditions in the field that have been obtained from primary data by paying attention and observing the object of research directly in the field and secondary data sourced from companies. So, the data will be combined to get a better approach to the problem.

The method used in this study is a problem approach in the form of taking materials, both in the form of theoretical basis and object data that are observed directly in the field so that it is carried out in several stages, which include the pre-field stage, the field stage, and the post-field stage.

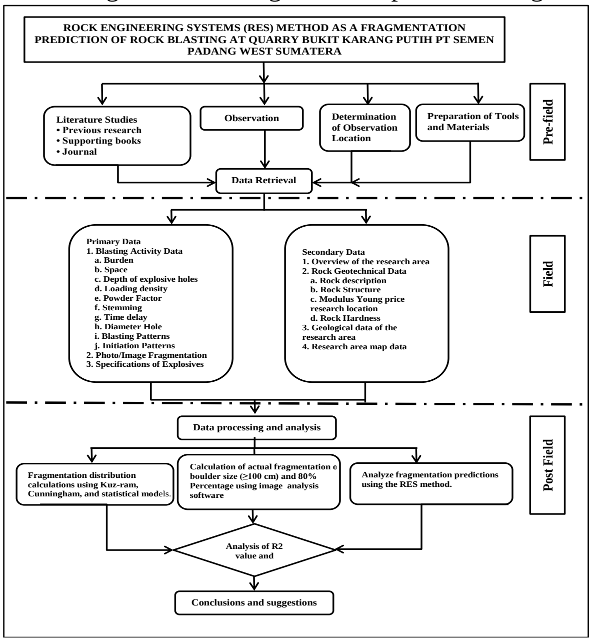
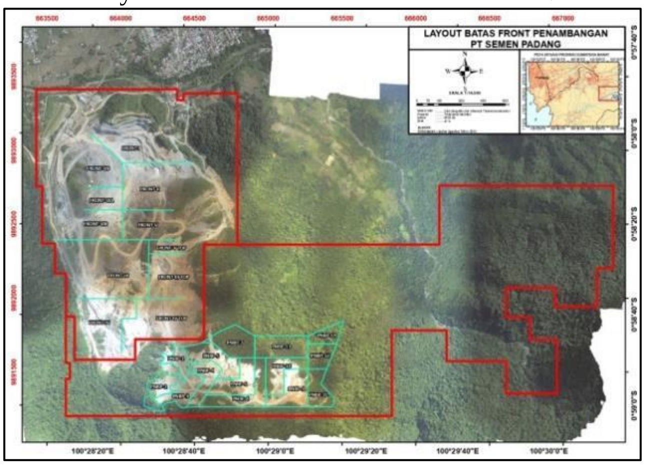


Fig 1. Research Flowchart

III. RESULT AND DISCUSSION

A. Blasting Activity Area Condition Of PT Semen Padang

The research site was conducted on open-pit mining Areas 242 and 15.15 PT. Semen Padang, where at this location the research is limestone that has its own rock characteristics. The geological condition of this area is a very steep hill with a natural slope angle of up to 45˚. Bukit Karang Putih is generally occupied by limestone with breakthrough igneous rocks (basalt, andesite, granite). The limestone layer is located on top of volcanic sedimentary rocks with a thickness of 100m -350m.



Source: Department of Mine Development Planning and Evaluation (PPET) PT. Semen Padang.

Fig 2. Map of PT Semen Padang Mining Area

B. Blasting Geometry

Current geometric blasting plans, especially at PNBP and PLB locations, generally use the same geometry. However, under actual conditions, there are some deviations that occur in the geometry of blasting against the plan. So it will produce a blasting geometry with a different value than the plan or plan. The average blast geometry used in blasting at PNBP and PLB locations can be seen in table 1 above. The data in table 1 is obtained from observations made during several detonations, which are then calculated on average.

Table 1. Blasting Geometry

No	Geometry		Min	Max	Mean
1	Total hole		40	100	62
2	Hole Diameter (inch)		4	4	4
3	Burden (m)		2.8	4.70	4.13
4	Spacing (m)		3.0	5.60	4.99
5	Hole Depth(m)	Plan	10	10	10
		Act	10.1	11.25	10.45
		Dev	0.1	1.25	0.45
6	Primarry Charge (PC) (m)	Plan	7	7	7
		Act	7.07	7.88	7.31
		Dev	0.70	0.88	0.31
7	Stemming (m)	Plan	3	3	3
		Act	3.03	3.38	3.13
		Dev	0.03	0.38	0.13
8	Explosive Charge (kg)	Kg/m	9.72	9.72	9.72
		Act	2749.91	6929.22	4446.23
9	Volume Actual (m^3)		3514.8	26315.3	14138.65
10	PF Actual (kg/m^3)		0.26	0.78	0.36

C. Rock Fragmentation Prediction Using Kuzram Method

In the calculation of the Kuzram prediction, first, calculate the rock factor (A). The rock factor value (A) is obtained from the data input in accordance with the data input in the Kuz Ram method. In table 2, it can be seen the results of rock factor values derived from company data. Next, calculate the distribution of the Kuzram method predictions with the following equations. To determine the percentage of passing the sieve, the author uses the Rossin Ramler distribution.

$$Xm = A \times \left(\frac{Vo}{Q}\right)^{0.8} \times Q^{0.1667} \times \left(\frac{E}{115}\right)^{-0.63} \quad (1)$$

$$Xc = \frac{Xm}{0.693^{\frac{1}{3}}} \quad (2)$$

$$n = \left\lfloor 2.2 - \left(\frac{14B}{d}\right)\right\rfloor \times \left\lfloor 1 - \left(\frac{W}{B}\right)\right\rfloor \times \left\lfloor 1 - \left(\frac{1+\frac{S}{B}}{2}\right)\right\rfloor \times \left(\frac{PC}{H}\right) \quad (3)$$

$$R = e^{-\left(\frac{x}{Xc}\right)^{n}} \quad (4)$$

Where Xm = Average Size of Rock Fragmentation (cm), A = Rock Factor, Vo = Volume of Rock Uncovered (m3), Q = Weight of Explosives Each Hole (kg), E = RWS Explosives (DABEX 73 = 77), R=Percentage of Rock Size (%), Xc= Size Characteristics (cm) , X= Rock Size (cm), n= Uniformity Index, e= Exponential Constant (2.71828), B= Burden, S= Spacing, D= Diameter of the blast hole, W= Standard deviation (0.3), PC= Fill column, H= Height of the ladder (m).

Table 3, showing that based on the average results, there is still fragmentation of rocks measuring ≥ 60 cm by 45.54% and boulder ≥ 100 cm, which is 29.96%. While the largest ≥ 60 cm of rock fragmentation was on January 22, 2021, at 50.148%, and the largest boulder percentage was on January 20, 2021, at 36.92%.

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Table 2. Rock Factor Kuzram Method Of PT Semen Padang

Parameter	Rating	Rating PT. Semen Padang
Rock Mass Description (RMD)		
Powdery/friable	10	**50**
Blocky	20	
Totally massive	50	
Joint Plan Spacing (JPS)		
Close (< 0.1 m)	10	**20**
Intermediet (0.1 – 1.0)	20	
Wide (>0.1 m)	50	
Joint Plane Orientation (JPO)		
Horizontal	10	**40**
Dip out of face	20	
Strike normal to face	30	
Dip into face	40	
Specific Gravity Influence (SGI)	$25 \times density - 50$	**9.25**
Hardness (H)	1 to 10	**3.76**
Blastibility Index (BI)	$0.5 \times (RMD + JPS + JPO + SGI + H)$	**66.25**
Rock Factor (A)	$0.12 \times BI$	**7.95**

D. Rock Fragmentation Prediction Using Modification Of Cunningham 2005 Method

In calculating Cunningham's prediction, first, calculate the rock factor (A). The rock factor value (A) is obtained from the data input in accordance with the data input in the Cunningham method. In table 4, it can be seen the results of rock factor values derived from company data. Next, perform the calculation of the prediction distribution of the Cunningham method with the following equations. To determine the percentage of passing the sieve, the author uses the Rossin Ramler distribution.

$$Xm = A \times At \times K^{-0.8} \times Q^{1/6} \times \left(\frac{115}{RWS}\right)^{19/20} \times c\,(A) \quad (5)$$

$$\mathrm{At} = 0.9 + 0.1\left(\frac{\mathrm{T}}{\mathrm{Tmax}} - 1\right) \quad (6)$$

$$\mathrm{Tmax} = \left(\frac{15.6}{\mathrm{cx}}\mathrm{B}\right) \quad (7)$$

$$n = ns \times \sqrt{2 - 30\frac{B}{De}} \times \frac{\sqrt{1+\frac{S}{B}}}{2} \times \left(1 - \frac{W}{B}\right) \times \left(\frac{PC}{H}\right)^{0.3} \times c\,(n) \quad (8)$$

$$ns = 0.206 + \left(1 - \frac{Rs}{4}\right)^{0.8} \quad (9)$$

$$Rs = 6 \times \frac{\alpha t}{Tx} \quad (10)$$

$$\alpha t = \sqrt{2\alpha 1^2 + \alpha 2^2} \quad (11)$$

$$c(n) = \left(\frac{A}{6}\right)^{0.3} \quad (12)$$

$$Xc = \frac{Xm}{0.693^{1/n}} \quad (13)$$

$$R = e^{-\left(\frac{x}{Xc}\right)^{n}} \quad (14)$$

Where Xm= Average Size of Rock Fragmentation (cm), A= Rock Factor, At= timing factor, K= Powder Factor (PF), Q= Amount of explosives per hole, RWS= Relative Weight Strength of explosives, c(A)= Rock correction factor, T= Range of delay used, Cx= VOD of Explosives (km/s), B= Burden, ns= Scatter Ratio, S = Space, De= Diameter of explosives (mm), W= Standard deviation from drilling accuracy (m), PC= Primary Charge (m), H= hole depth (m), C (n)= Correction factor, α1=

Standard deviation to in hole delay, α2 = Standard deviation to surface delay, Tx = Delay, Rs= Scatter ratio, R= Percentage of rock size (%).

The calculation of the percentage of the size below shows if using a different delay in blasting activities will also affect the percentage of the size. Figure 4 shows broadly, the smaller the delay used, the percentage of size will be small. In table 4, it can be seen that the percentage of size will be larger when using a larger delay. It occurs at a ≥ size of 60 cm and the size of the boulder. Thus, in the calculation of the prediction of fragmentation cunningham method can be concluded delay of 17 ms will produce a percentage of the size of fragmentation smaller than other delays.

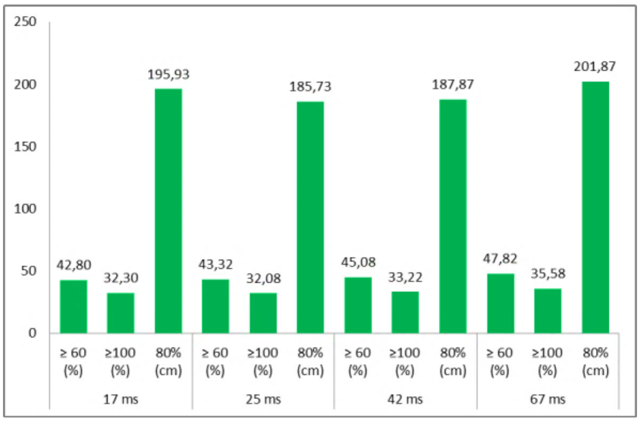

Fig 4. Fragmentation Graph Based on Surface Delay

Table 3. Kuzram prediction fragmentation results

No	Date	Xm (cm)	Xc (cm)	Fragmentation (%)		80% (≤... cm)
				≥ 60 cm	≥ 100 cm	
1	04/01/2021	25.58	55.5	35.43	26.68	150.35
2	05/01/2021	26.21	58.16	36.26	27.72	165.35
3	06/01/2021	56.89	97.27	48.74	36.09	195
4	07/01/2021	37.58	69.43	39.99	28.84	150.35
5	08/01/2021	45.15	79.76	43.5	31.44	165
6	09/01/2021	58.27	98.86	49.3	36.49	195.25
7	10/01/2021	27.81	57.91	36.13	26.87	150.35
8	11/01/2021	53.04	91.2	47.08	34.5	182.55
9	12/01/2021	57.56	97.92	49.01	36.25	195.45
10	13/01/2021	54.96	94.1	47.92	35.26	190
11	14/01/2021	54.84	93.41	47.84	35.06	190
12	15/01/2021	50.05	86.73	45.75	33.3	180
13	16/01/2021	57.87	97.99	49.13	36.27	195.45
14	17/01/2021	40.8	69.89	40.61	27.9	140
15	18/01/2021	58.13	98.61	49.24	36.43	195.45
16	19/01/2021	58.21	98.76	49.28	36.47	195.45
17	20/01/2021	59.27	100.52	49.71	36.92	195.45
18	21/01/2021	55.49	94.74	48.14	35.42	190.25
19	22/01/2021	61.21	103.85	50.48	37.75	210
20	27/01/2021	52.59	71.04	44.31	21.94	105
21	01/02/2021	58.15	79.9	48.75	27.37	120
22	02/02/2021	57.56	78.6	48.3	26.51	118
23	03/02/2021	55.99	75.63	47.04	24.51	111
24	09/02/2021	57.67	79.75	48.45	27.48	120
25	15/02/2021	54.35	73.65	45.8	23.54	110
26	16/02/2021	45.2	61.64	37.96	16.99	92
27	20/02/2021	53.77	72.98	45.36	23.23	108
28	23/02/2021	53.2	72.78	45.03	23.45	108
29	25/02/2021	53.63	72.79	45.25	23.12	109.45
30	26/02/2021	54.72	75.21	46.27	24.94	115
Mean		51.19	81.95	45.54	29.96	154.94

E. Actual Blast Fragmentation

Measurement of actual fragmentation is done by means of image analysis (Photographic); this method uses software (Software) to perform fragmentation analysis. Fragmentation of the actual blasting results was obtained by taking photos in the field and analyzed with split desktop software. For comparison, a helmet measuring 28 cm was used. And in the end, the software will analyze the percentage of rock size in the photo. In this research, we will use split desktop demo 2.0 software.

In figure 5(b) is seen the results of the analysis conducted by split desktop demo software 2, which shows the size of the ≤ 100 cm by 46.22%, and the percentage held or the size of the ≥ 100 cm, which is 100 % - 46.22 % = 53.78 %. Meanwhile, the size of the X80 or percentage of 80 shows 1523.67 mm or 152.367 cm. That means the percentage of ≤ size 152.367cm by 80% and the percentage held or the size of the ≥ 152.367 cm, which is 100 % - 80 % = 20%. Then for the percentage of all calculations analysis using the next software can be seen in table 5.

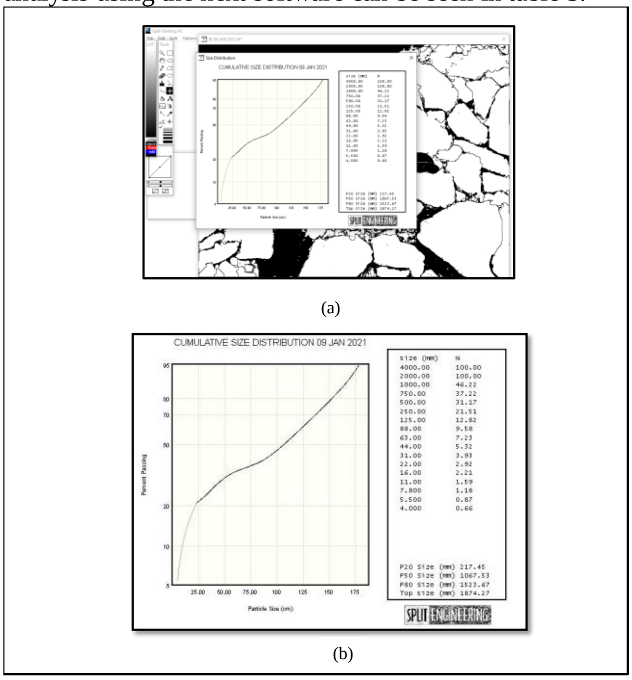

Fig 5. Result Analysis of Fragmentation Software

Table 5. Actual Fragmentation

No	Date	Rock Size 80% (cm)	≥ 100 cm (%)	Top Size (cm)
1	04/01/2021	47.68	0	74.54
2	05/01/2021	51.8	0	67.36
3	06/01/2021	86.29	12.35	135.28
4	07/01/2021	79.59	5.73	109.91
5	08/01/2021	67.96	2.55	105.94
6	09/01/2021	152.36	53.78	187.42
7	10/01/2021	73.78	2.06	103.38
8	11/01/2021	96.77	18.86	171.98
9	12/01/2021	138.48	46.94	187.12
10	13/01/2021	93.83	16.98	163.62
11	14/01/2021	108.31	24.78	150.14
12	15/01/2021	118.39	28.86	176.82
13	16/01/2021	77.2	5.24	112.73
14	17/01/2021	121.46	39.58	162.3
15	18/01/2021	111.22	26.85	148.36
16	19/01/2021	126.21	34.64	196.62
17	20/01/2021	186.09	47.64	275.53
18	21/01/2021	121.81	34.81	162.63
19	22/01/2021	192.77	62.94	245.35
20	27/01/2021	99.28	13.31	118.98
21	01/02/2021	115.22	31.26	151.48
22	02/02/2021	144.62	46.88	204.15
23	03/02/2021	122.94	41.27	163.57
24	09/02/2021	158.59	39.9	252.24
25	15/02/2021	153.61	51.1	192.2
26	16/02/2021	102.07	21.36	163.69
27	20/02/2021	113.54	28.84	168.35
28	23/02/2021	119.52	30.08	188.96
29	25/02/2021	105.58	22.83	165.55
30	26/02/2021	146.55	51.98	184.32
Mean		114.45	28.11	163.02

F. Rock Fragmentation Prediction Using Multiple Linear Regression

Multiple regression was used in this study to predict the size of 80% fragmentation (X80). In this study, the author used IBM SPSS 25 statistics software.

In this study, there are 30 data where the data is the data of 30 explosions. To predict fragmentation using this statistical model, the researcher will divide the data into two parts, namely, 80% for training data and 20% for testing data. At the beginning of the test (training data), the author determines the independent variables into eleven variables including, Burden (B), the maximum amount of explosive charge (kg), Powder Factor (PF), burden ratio spacing (S/B), stemming burden ratio (T/B), stiffness ratio (H/B), delay time, Deviation depth of blast hole, diameter of blast hole (mm), Blastability Index (BI), and Burden diameter ratio (B/D). The dependent variable is the X80 Actual fragmentation. After all training data was collected, analysis was carried out using IBM SPSS 25 statistical software. It turned out that from the eleven variables, there were data that were rejected, including Burden, delay time, Blastabilty Index (BI), and Diameter. The data was rejected because there was a missing correlation or the data had the same value every time it was blasted.

The results of multiple linear regression analysis using SPSS software will produce useful equations to determine the effect of the independent variable on the dependent variable. The equation is taken from the value of the unstandardized coefficients in the coefficients table resulting from linear regression analysis. Valid variables in multiple linear regression multivariate modeling are those with a p-value <0.05. The equations obtained from linear regression analysis using SPSS software are as follows:

$$\boldsymbol{Y = -1310.767 + 0.014X1 - 1.464X2 - 230.165X3 - 1971.331X4 + 1009.90X5 - 1.219X6 + 20.547X7} \quad (15)$$

Dimana :

Y = Actual Fragmentation (X80)
-1310.767 = Constanta
X1 = max of explosive charge (kg)
X2 = Powder Factor (PF) (gr/ton)
X3 = Spacing Burden ratio (S/B)
X4 = Stemmning Burden ratio (T/B)
X5 = Stiffness Ratio (H/B)
X6 = Hole depth deviation(%)
X7 = Burden Diameter ratio (B/D)

based on the above equation, data testing is carried out to get 80% fragmentation (X80), we can see in table 6.

G. Rock Engineering System (RES)

Rock Engineering Systems (RES) proposed by Hudson (1992), Hudson (1992) RES is one of the models that can provide parameter weighting on rock mechanics, the main principle in RES modeling is to use matrix interactions. This matrix interaction principle can provide weighting on any parameter that can affect bound variables, each parameter is placed on a matrix diagonal and has at least 2 parameters that affect the bound variable, and those parameters provide a causal effect.

The first step is to determine effective parameters that are likely to affect a system or an object, which in this case is the percentage of boulder size fragmentation.

Table 4. Cunningham 2005 Modification Prediction Result

Date	Fragmentations Per Delay											
	17 ms			25 ms			42 ms			67 ms		
	≥ 60 (cm)	≥100 (cm)	80% (cm)	≥ 60 (cm)	≥100 (cm)	80% (cm)	≥ 60 (cm)	≥100 (cm)	80% (cm)	≥ 60 (cm)	≥100 (cm)	80% (cm)
04/01/2021	26.86	16.02	81.7	26.77	15.26	80	28.63	16.18	83.5	32.26	18.9	95.5
05/01/2021	26.91	15.79	81.1	26.93	15.11	80	28.99	16.18	83.5	32.75	18.92	95.5
06/01/2021	45.56	35.7	235	46.11	35.56	224	47.71	36.6	225	50.1	38.71	230
07/01/2021	35.99	24.6	125	36.28	24.09	120	38.19	25.22	125	41.41	27.85	135
08/01/2021	40.65	29.96	165	41.04	29.59	155	42.74	30.63	160	45.48	32.97	175
09/01/2021	45.89	35.62	225	46.52	35.53	210	48.24	36.69	215	50.79	38.95	230
10/01/2021	28.85	17.79	90	28.86	17.08	87	30.77	18.09	94	34.27	20.7	105
11/01/2021	43.94	33.32	200	44.5	33.13	190	46.27	34.29	185	48.95	36.65	200
12/01/2021	45.67	35.44	225	46.27	35.33	215	47.98	36.47	210	50.51	38.72	230
13/01/2021	44.72	34.32	210	45.3	34.16	200	47.02	35.3	195	49.62	37.59	215
14/01/2021	44.43	33.33	190	45.09	33.21	180	47.03	34.52	185	49.9	37.08	200
15/01/2021	42.54	31.47	175	43.09	31.24	165	44.97	32.46	170	47.87	34.98	185
16/01/2021	45.67	35.07	215	46.33	34.99	200	48.14	36.22	205	50.81	38.6	215
17/01/2021	45.67	34.72	200	46.41	34.69	190	48.38	36.06	195	51.24	38.64	210
18/01/2021	45.84	35.57	225	46.47	35.48	215	48.19	36.63	210	50.73	38.9	230
19/01/2021	45.87	35.6	225	46.5	35.51	215	48.22	36.67	210	50.77	38.93	230
20/01/2021	46.28	36.29	235	46.89	36.2	224	48.55	37.32	225	50.99	39.49	235
21/01/2021	44.89	34.44	210	45.48	34.3	200	47.23	35.45	200	49.85	37.77	220
22/01/2021	47	37.57	265	47.58	37.49	255	49.11	38.51	245	51.35	40.5	260
27/01/2021	43.63	32.69	185	44.22	32.51	174	46.08	33.74	185	48.9	36.22	200
01/02/2021	45.95	36.05	235	46.53	35.93	224	48.15	37.01	225	50.56	39.14	235
02/02/2021	45.67	35.44	225	46.27	35.33	210	47.98	36.47	215	50.51	38.72	230
03/02/2021	44.94	34.12	205	45.59	34.01	190	47.45	35.26	190	50.22	37.72	210
09/02/2021	45.9	36.31	245	46.43	36.17	224	47.96	37.17	225	50.25	39.19	245
15/02/2021	44.38	33.66	195	44.98	33.51	185	46.8	34.71	195	49.52	37.12	210
16/02/2021	40.67	29.98	165	41.06	29.61	155	42.76	30.66	160	45.51	32.99	175
20/02/2021	44.19	33.52	195	44.77	33.35	185	46.56	34.53	190	49.27	36.92	200
23/02/2021	44.13	33.83	205	44.66	33.63	195	46.33	34.71	200	48.89	36.95	210
25/02/2021	44.13	33.47	200	44.71	33.29	190	46.51	34.47	190	49.21	36.86	200
26/02/2021	47.14	37.17	245	47.82	37.17	235	49.56	38.37	240	52.05	40.62	245
Mean	42.8	32.3	195.93	43.32	32.08	185.73	45.08	33.22	187.9	47.82	35.58	201.9

The selected parameters will have interacted between one parameter and another. These parameters are obtained based on the study of literature that has been studied, the results of observations, and the results of discussions with people whom the author considers to have the ability in this field. Therefore, 11 effective parameters are obtained that are interconnected and affect bound variables. The 11 parameters can be seen in table 7.

Matrix interaction analysis which is the basis in the Rock Engineering Systems model, is a diagonal box containing predetermined parameters and causal influence that occurs between these parameters and will then be given code / coding matrix interaction.

Matrix interaction in the Rock Engineering Systems model will first be made a diagonal box or diagonal box that amounts to as many existing parameters. So, the diagonal box will amount to 11 x 11. The diagonal box for this study can be seen in figure 6. Figure 6 shows the diagonal box that has contained a set of parameters that have been set and the direction of influence that occurs from existing parameters. The yellow box from the top left to the bottom right with the symbols p1, P2, P3, and so on are the names of the parameters in table 7.

Table 6. Multiple Regression Prediction Result

No	Date	VARIABEL DEPENDENT (Y)	VARIABEL INDEPENDENT (X)							MULTIPLE REGRESSION PREDICTION X80 (cm)
		ACTUAL X80 (cm)	Max Instantaneous Charge (kg)	PF (gr/ton)	S/B	T/B	H/B	DEV. H (%)	B/D	
25	15/02/2021	153.61	6266.93	129.02	1.26	0.73	2.44	23.00	41.34	139.59
26	16/02/2021	102.07	3912.15	163.18	1.10	0.78	2.61	45.00	39.37	100.55
27	20/02/2021	113.54	4645.57	131.50	1.24	0.75	2.50	50.00	41.34	112.73
28	23/02/2021	119.52	4698.66	133.58	1.16	0.74	2.47	62.00	42.32	120.73
29	25/02/2021	105.58	4926.69	131.50	1.24	0.74	2.46	34.00	41.34	120.23
30	26/02/2021	146.55	4594.52	111.90	1.14	0.77	2.56	125.00	43.31	131.17

Then, the influence of the upper parameters on the parameters below will be written on the right box of the parameter box. The effect that occurs from the lower parameters on the upper parameters will be written into the left box of the parameter box. Diagonal boxes (coding) above that have been obtained can show the influence of one parameter on other parameters.

Table 7. RES Parameters

Parameter	
Code	**Name**
P1	Burden (B)(m)
P2	Max Instantaneous Charge (kg)
P3	Powder Factor (PF)(g/ton)
P4	Spacing Burden ratio (S/B)
P5	Steeming Burden ratio (T/B)
P6	Stiffness Ratio (H/B)
P7	Delay Time (ms)
P8	Blast Depth Hole Deviation (%)
P9	Blast Hole Diameter (mm)
P10	Blastability Index (BI)
P11	Burden Diameter Ratio (B/D)

The effect can be seen by adding up each row or row and column or column. The sum of rows is called Cause (C) or C ordinate, and the sum of columns is called Effect (E) or E ordinate (Table 8).

P1	2	2	2	2	2	3	0	0	0	0
0	P2	0	0	0	0	1	0	0	0	0
2	0	P3	2	0	0	0	0	0	0	2
0	2	2	P4	0	0	0	0	0	0	0
0	2	1	0	P5	0	0	0	0	0	0
2	2	2	3	2	P6	1	2	2	0	1
0	1	0	0	0	0	P7	0	0	0	0
2	1	1	2	1	0	0	P8	0	0	1
3	3	2	1	1	2	2	3	P9	0	2
3	2	4	2	1	2	3	3	1	P10	3
3	1	2	0	0	2	3	0	0	0	P11

Fig 6. The interaction matrix for the parameters affecting

Table 9, in column C + E which shows how active a parameter is in terms of affecting a system. This can be seen in the highest value generated. As the table shows that the burden parameter is an active parameter in influencing the system with a total of 28.

Table 8. Row and Column Summation

	Column (Effect)											C ordinate
Row (Cause)	P1	2	2	2	2	2	3	0	0	0	0	13
	0	P2	0	0	0	0	1	0	0	0	0	1
	2	0	P3	2	0	0	0	0	0	0	2	6
	0	2	2	P4	0	0	0	0	0	0	0	4
	0	2	1	0	P5	0	0	0	0	0	0	3
	2	2	2	3	2	P6	1	2	2	0	1	17
	0	1	0	0	0	0	P7	0	0	0	0	1
	2	1	1	2	1	0	0	P8	0	0	1	8
	3	3	2	1	1	2	2	3	P9	0	2	19
	3	2	4	2	1	2	3	3	1	P10	3	24
	3	1	2	0	0	2	3	0	0	0	P11	11
E ordinate	15	16	16	12	7	8	13	8	3	0	9	

While the C-E value indicates the dominant parameter in its influence in a system, the results of the reduction that have positive values such as stiffness ratio, hole depth deviation, blast hole diameter, blastibility index (BI), and burden diameter ratio (B/D) indicate that these parameters are more dominant in influencing the size of rock fragmentation. Other parameters that have other negative value reduction results such as burden, the maximum amount of explosive charge (kg), PF, S/B ratio, T/B ratio, and delay time indicate a subordinate parameter value or the system has a larger dominant role in affecting these parameters. The system in question is a way of treating the parameters to get the desired fragmentation. Then plot the values (C, E) or co-ordinates into the Cause-Effect plot as shown in Figure 7.

Table 9. List of C-E co-ordinates

Parameters		C	E	C+E	C-E
Code	Nama				
P1	Burden (B)(m)	13	15	28	-2
P2	Max Instantaneous Charge (kg)	1	16	17	-15
P3	Powder Factor (PF)(g/ton)	6	16	22	-10
P4	Spasi Burden ratio (S/B)	4	12	16	-8
P5	Steeming Burden ratio (T/B)	3	7	10	-4
P6	Stiffness Ratio (H/B)	17	8	25	9
P7	Delay Time (ms)	1	13	14	-12
P8	Blast Depth Hole Deviation (%)	8	8	16	0
P9	Blast Hole Diameter (mm)	19	3	22	16
P10	Blastability Index (BI)	24	0	24	24
P11	B/D Ratio	11	9	20	2
Total		107	107	214	0

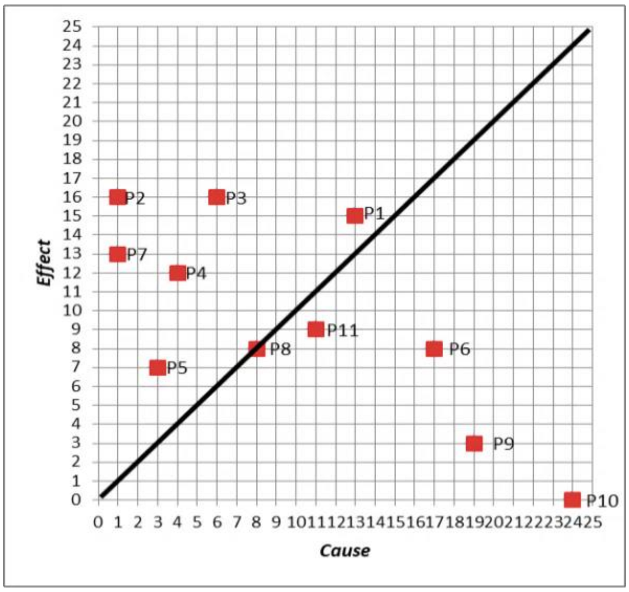

Fig 7. Cause-Effect Plot

The next stage is to calculate the percentage value of the weighting per each of the existing parameters. The calculation of the percentage weighting is carried out using equation 16. In which the input data in the equation is known as in table 4.20. The following is an example of calculating the percentage weighting of parameter 1.

$$a_i = \frac{(C_i+E_i)}{\sum C+\sum E} \times 100 \quad \text{.......(16)}$$

$$a_i = \frac{(13+15)}{107+107} \times 100 = 13.1$$

The equation above shows that the weighting of the percentage of burden parameters has a value of 13.1. The results of the calculation of the percentage weighting permasing of each other parameter can be seen in table 10.

Further determining the value of the Vulnerability Index (VI), wherein 2004 Bernados and Kaliampoks first introduced the principle of the RES model, which is used as a concept of vulnerability index determination methodology (VI). Where the vi value is used to find and determine weak fields at the time of use of tunnel machine boring (TBM). The model was analyzed and developed to predict fragmentation, where it was used to determine fragmentation on the X80 (an 80% fragmentation measure) by Faramarzi, H. Mansouri, and Ebrahimi Farsangi in 2013.

Table 10. The weighting of the principal parameters in rock fragmentation.

Parameters		C	E	C+E	C-E	ai (%)
Code	Name					
P1	Burden (B)(m)	13	15	28	-2	13.1
P2	Max Instantaneous Charge (kg)	1	16	17	-15	7.9
P3	Powder Factor (PF)(g/ton)	6	16	22	-10	10.3
P4	Spasi Burden ratio (S/B)	4	12	16	-8	7.5
P5	Steeming Burden ratio (T/B)	3	7	10	-4	4.7
P6	Stiffness Ratio (H/B)	17	8	25	9	11.7
P7	Delay Time (ms)	1	13	14	-12	6.5
P8	Blast Depth Hole Deviation (%)	8	8	16	0	7.5
P9	Blast Hole Diameter (mm)	19	3	22	16	10.3
P10	Blastability Index (BI)	24	0	24	24	11.2
P11	B/D Ratio	11	9	20	2	9.3
Total		107	107	214	0	100.0

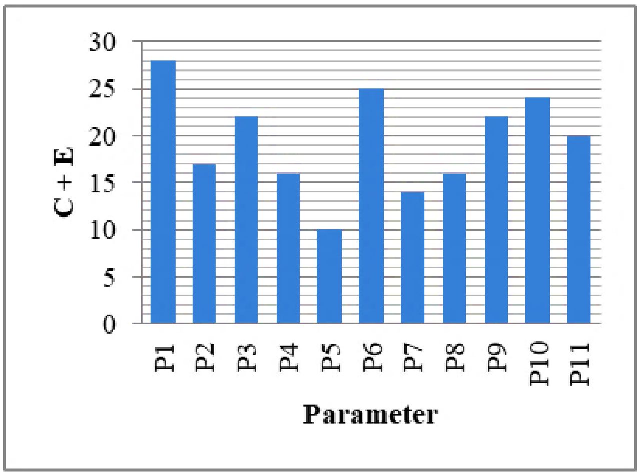

Fig 8. The C+E values for principal parameters of rock fragmentation

To conduct an evaluation using the RES method from 30 data retrievals in this study, Then as much as 24 or 80% of each time the detonation activity will be done to calculate the vulnerability index value or the development of the RES model, while for other detonation that is 6 times the detonation as (measured / testing) or actual measurement using desktop split software which the author compares with other methods of predicting the size of rock fragmentation for X80 (80% fragmentation escapes adulation) that has been determined by Faramarzi, et al. at each time the blasting activity.

Table 11. Proposed Ranges For The Parameters Effective In Fragmentation (Faramarzi et al.,2013)

Parameters		Value and Rating						
Code	Name							
P1	Burden (B)(m)	**Value**	< 3	3 s.d 5	5 s.d 7	7 s.d 9		> 9
		Rating	4	3	2	1		0
P2	Max Instantaneous Charge (kg)	**Value**	< 500	500 - 1000	1000 - 2000	2000 - 3000	3000 - 4500	.> 4500
		Rating	5	4	3	2	1	0
P3	Powder Factor (PF)(g/ton)	**Value**	< 125	125 - 150	150 - 175	175 - 210	210 - 300	> 300
		Rating	0	1	2	3	4	4
P4	Spasi/Burden ratio (S/B)	**Value**	< 1	1 - 2	2 - 3	3 - 4		> 4
		Rating	0	3	2	1		0
P5	Steeming/Burden ratio (T/B)	**Value**	< 0.7	0.7 - 0.9	0.9 - 1.2	1.2 - 1.4		> 1.4
		Rating	0	2	4	3		1
P6	Stiffness Ratio (H/B)	**Value**	< 1	1 - 2	2 - 3	3 - 4		> 4
		Rating	0	1	2	3		4
P7	Delay Time (ms)	**Value**	< 20	20 - 50	50 - 70	70 - 100	100 - 200	> 200
		Rating	0	1	3	4	2	1
P8	Blast Depth Hole Deviation (%)	**Value**	0	0 - 5	5 - 10	10 - 15		> 15
		Rating	4	3	2	1		0
P9	Blast Hole DIameter (mm)	**Value**	< 100	100 - 150	150 - 200	200 - 250	250 - 300	> 300
		Rating	4	3	2	1	0	0
P10	Blastability Index (BI)	**Value**	0 - 20	21 - 40	41 - 60	61 - 80		81 - 100
		Rating	4	3	2	1		0
P11	B/D Ratio	**Value**	< 20		20-40		> 40	
		Rating	2		1		0	

The following will be shown an example of the calculation of value VI in the 26th blast data, dated February 16, 2021.

$$VI = 100 - \sum_{i=1} a_i \frac{Q_i}{Q_{max}} \quad (17)$$

$$VI = 100 - 100\frac{22}{42} = 50$$

Table 12, showing that the value OF VI on the 26th blast, February 16, 2021, is 50. The VI value is obtained from the input of data for the equation (17). While the rating value is taken from the range of values from parameters sourced from Faramarzi et al. and can be seen in table 11. And Q max based on equations (18). The value VI on the other blasts can be seen in table 13.

$$Qmaks = max\,rating\,P1 + max\,rating\,P + \cdots + max\,rating\,Pn \quad (18)$$

The VI value that has been obtained can be the basis for classifying the risk of fragmentation that occurs whenever the detonation activity takes place. This is based on the sources of Bernardos and Kaliampakos in 2004 in Faramarzi, which has been described in table 14. when connected to table 14, the value VI is indicated by table 13, which shows the value VI in each area. The highest VI value in the blasting area was 64.28 on blasts no. 17, 19, and 24. This means that blast area no. 17, 19, and 24 falls into category II with a description of the risk of fragmentation at the medium-high level or the problem of bad fragmentation and will affect the subsequent blasting activity.

As previously mentioned in this study, researchers will use blasting numbers 1 to 24 as the basis for the development of the RES model or training data, while blasting numbers 25 to 30 are used as blasting data for evaluation analysis of fragmentation predictions for the RES prediction method. The following is a comparison between the VI value and the measurement of the actual fragmentation percentage of X80 (percentage 80) at each blasting activity no. 1 to 24 using split desktop software, which can be seen in Figure 9 below.

Figure 9 shows how the value movement compares between value VI and the percentage measurement of 80% in actual conditions by desktop split software. In the picture, it appears that there is a fairly good correlation relationship. This is seen from the changes that occur between the two values that have the same moving average. So, the calculation will be done to predict the size of rock fragmentation with a percentage of 80% at each time the detonation activity using linear equations that occur between the value VI and the measurement X80.

Table 12. Parameters value and VI blast to 26, 16 February 2021

Parameters	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	Total
	(m)	(Kg)	(gr/ton)				(ms)	(%)	(mm)			
Value	4	3912.15	163.18	1.1	0.78	2.61	67	45	101.6	66.25	39.37	
Rating(Qi)	3	1	2	3	2	2	3	0	3	1	1	21
Weighting (ai(%))	13.1	7.9	10.3	7.5	4.7	11.7	6.5	7.5	10.3	11.2	9.3	100
Maximum Rating(Qmax)	4	5	4	3	4	4	4	4	4	4	2	42
VI	50											

Source: Faramarzi, 2013

Table 13. VI for 30 Blasts, PT Semen Padang

No	Date	VI	Actual 80%
1	04/01/2021	33.33	47.68
2	05/01/2021	35.71	51.80
3	06/01/2021	54.75	86.29
4	07/01/2021	45.23	79.59
5	08/01/2021	47.61	67.96
6	09/01/2021	59.52	152.36
7	10/01/2021	33.33	73.78
8	11/01/2021	59.52	96.77
9	12/01/2021	59.52	138.48
10	13/01/2021	54.76	93.83
11	14/01/2021	54.76	108.31
12	15/01/2021	57.14	118.39
13	16/01/2021	57.14	77.20
14	17/01/2021	61.9	121.46
15	18/01/2021	54.76	111.22
16	19/01/2021	59.52	126.21
17	20/01/2021	64.28	186.09
18	21/01/2021	59.52	121.81
19	22/01/2021	64.28	192.77
20	27/01/2021	54.76	99.28
21	01/02/2021	59.52	115.22
22	02/02/2021	59.52	144.62
23	03/02/2021	57.14	122.94
24	09/02/2021	64.28	158.59
25	15/02/2021	57.14	153.61
26	16/02/2021	50	102.07
27	20/02/2021	57.14	113.54
28	23/02/2021	57.14	119.52
29	25/02/2021	54.76	105.58
30	26/02/2021	61.9	146.55
Mean		54.996	114.45067

Table 14. Classification of the vulnerability index

Risk Description	Low-Medium	Medium-High	High-Very High
Category	I	II	III
Vulnerability Index	0-33	33-66	66-100

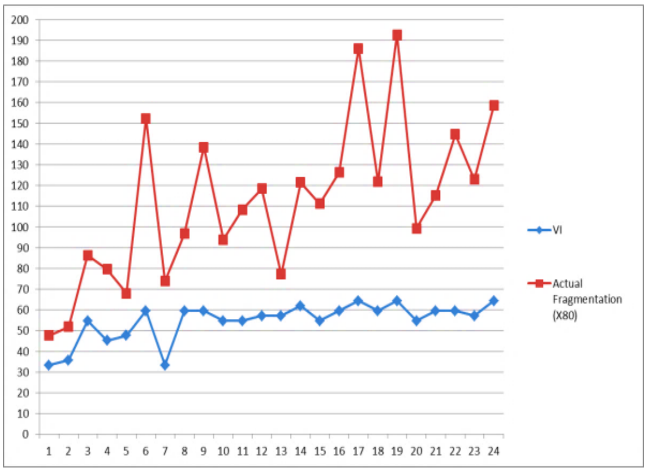

Fig 9. VI and Actual X80 Value

Based on Figure 10, which shows the relationship between the VI value and the X80 measurement, it results in a relationship with the R^2 value in the Strong range, which is 0.65 and has similarities such as equation (19). So, to find the X80 value in the research area for blasting numbers 25 to 30 using equation (19).

$$X80 = 3.3531VI - 71.079 \quad (19)$$

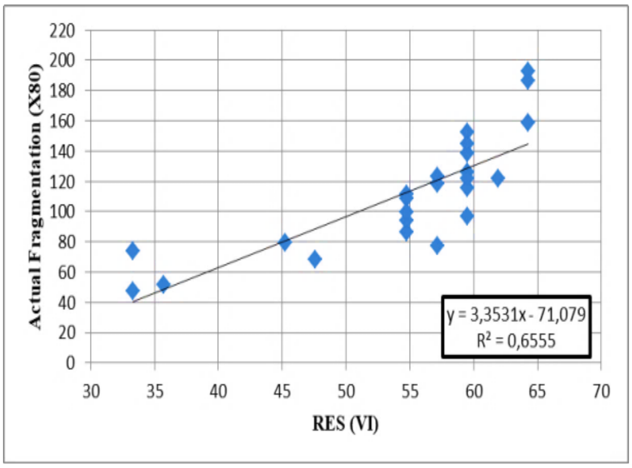

Fig 10. X80-VI predictive model

From the equation, we can get an evaluation of the RES model and then enter the value VI in blasting no. 25 to 30 in the equation (19), following the results of the prediction of fragmentation using the RES Model in Table 15.

Furthermore, an evaluation of the model that has been used in predicting rock fragmentation occurs during each detonation activity. The evaluation that compares between 4 predictive models is the Kuz Ram method, Cunningham 2005, multiple linear regression models, and Rock Engineering Systems (RES) models to actual. Evaluation, as described in the literature review chapter, is by looking at the values of the coefficient of determination (R2) and Root Mean Square Error (RMSE) displayed into linear regression relationships.

Table 15. X80 RES Value

No Blast	VI	Linear Regression	X80(RES)
25	57.14	X80 = 3.3531VI-71.079	146
26	50		96.58
27	57.14		112.54
28	57.14		120
29	54.76		96.58
30	61.9		136.48
Mean			118.03

A fragmentation comparison between the measurements and predictions of the four models can be seen in figure 11. In the image can be seen the difference in the percentage of X80 measurements with the four existing methods. In the image, it is seen that the method that has a difference from actual measurements by the X80 desktop split software is the RES model.

Based on the data that has been obtained, shown in table 16, it will be analyzed into linear regression by comparing the actual X80 fragmentation measurement using desktop split software with the X80 fragmentation measurement per perration of each method.

Table 16. Actual and Prediction Fragmentations

No Blast	VI	X80 (Actual (cm))	Predictions X80: RES (cm)	KUZRAM (cm)	CUNNINGHAM (cm)	MULTIPLE LINEAR REGRESSION (cm)
25	57.14	153.61	146	110	210	139.59
26	50	102.07	96.58	92	175	100.55
27	57.14	113.54	112.54	108	200	112.73
28	57.14	119.52	120	108	210	120.73
29	54.76	105.58	96.58	109.45	200	120.23
30	61.9	146.55	136.48	115	245	131.17
Mean		123	118	107	207	121

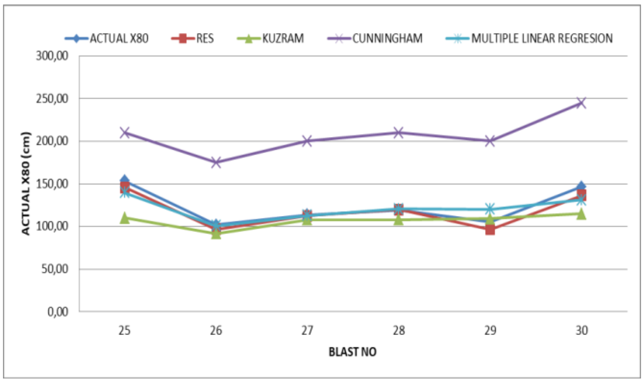

Fig 11. Comparison of Actual Fragmentation with Prediction

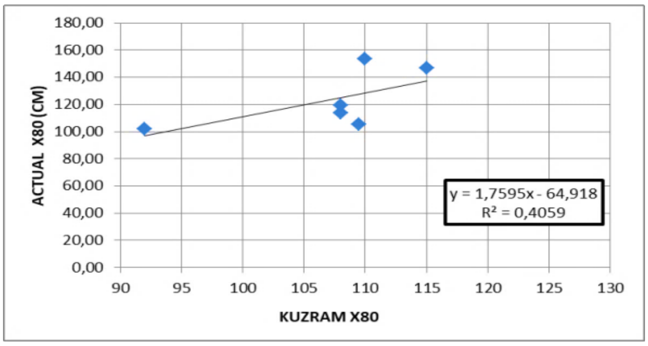

Fig 12. The Measured And Predicted X80, Kuz–Ram Model

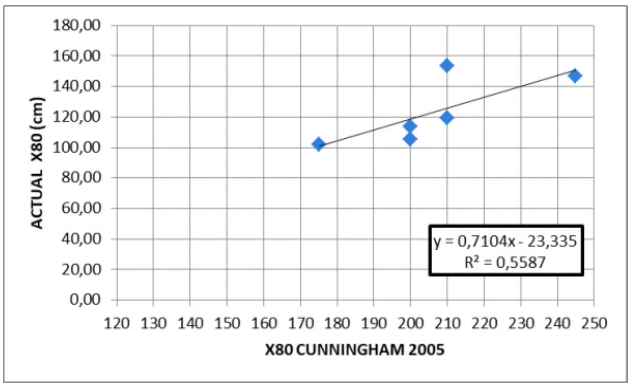

Fig 13. The Measured And Predicted X80, Cunningham Model

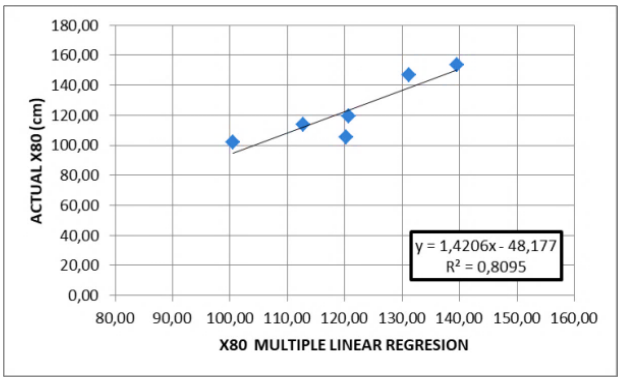

Fig 14. The Measured And Predicted X80, Multiple Linear Regression Model

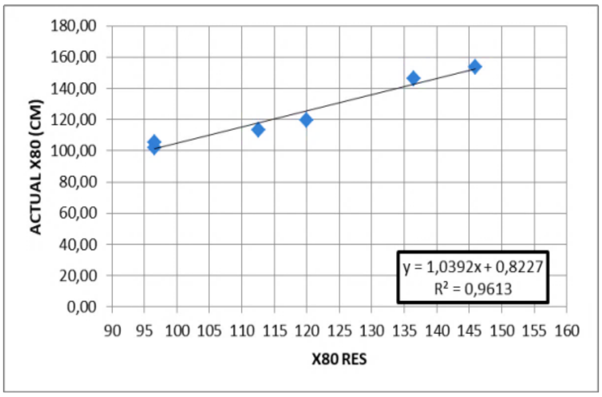

Fig 15. The Measured And Predicted X80, RES Based Model

The regression results show the difference in the R2 value of each method. The results of analytical calculations that have been done in the Blasting area show that the RES prediction model has a very strong correlation coefficient value of 0.96 (figure 15), where the data line is almost perfect. The Kuzram method obtained a weak correlation coefficient value of 0.40 (Figure 12). Cunningham's method obtained a moderate correlation coefficient of 0.55 (Figure 13), then the multiple linear regression model obtained a strong correlation coefficient value of 0.80 (Figure 14). The strongest relationship value is indicated by the RES model, which has a value of 0.96, followed by a double linear regression model of 0.80, then cunningham method (2005) 0.55 and kuz ram method 0.40, which means weak.

Next, calculations will be performed to find the RMSE value of each method used. This calculation uses equations (20).

$$RMSE\ (x) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{imeas} - X_{ipred}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

Where:

x_{imeas}: (i measured) or actual fragmentation measurement by desktop split software.

x_{ipred} : (i prediction) or fragmentation prediction measurement by RES model, Kuz Ram, Cunningham Modification, and multiple linear regression models.

Table 17. X80 Predicted By Various Models For Six Blasts, PT Semen Padang

No Blast	RMSE			
	RES	KUZRAM	CUNNINGHAM	STATISTICA MODELS
25	7.61	43.61	56.39	14.02
26	5.49	10.07	72.93	1.52
27	1.00	5.54	86.46	0.81
28	0.48	11.52	90.48	1.21
29	9.00	3.87	94.42	14.65
30	10.07	31.55	98.45	15.38
Mean	6	18	83	8

The results of the analysis calculations that have been done in the Blasting area show that the RES prediction model has a very strong correlation coefficient value of 0.96 and a low RMSE value of 6 compared to the Kuzram, Cunningham, and Multiple Linear Regression methods. Therefore, this Rock Engineering Systems (RSE) model can be used to predict rock fragmentation in the limestone quaary mine pt. Semen Padang.

IV. CONCLUSION

Analysis of Rock Engineering Systems (RES) model on the fragmentation of blasting activities at PT. Semen Padang can be used to predict the fragmentation of 80% of the syakan in the quarry mine of PT. Semen Padang with model X80 = 3.3531VI – 71.079. The results of the analysis calculations that have been done in the Blasting area show that the RES prediction model has a very strong correlation coefficient value of 0.96 and a low RMSE value of 6; the Kuzram method obtained a weak correlation coefficient of 0.40 with a high RMSE value of 18. Cunningham's method obtained a moderate correlation coefficient of 0.55 with a high RMSE value of 83, and then a multiple linear regression model obtained a strong correlation coefficient value of 0.80 with a value of RMSE 8.

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