JIM: Jurnal Ilmu Multidisiplin
GREENATION PUBLISHER
+62 812 1046 7572 http://greenpub.org greenation.info@gmail.com
E-ISSN : 2829-4580
P-ISSN : 2829-4599
DOI: https://doi.org/10.38035/jim.v4i5

Optimization of Explosive Loads for Controlling Ground Vibrations in Blasting Activities at PT Riung Mitra Lestari, Jobsite Energi Batu Hitam, East Kalimantan

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Abstract: This study aims to optimize the explosive charge to minimize ground vibration generated by blasting operations at PT Riung Mitra Lestari, Energi Batu Hitam Jobsite, East Kalimantan. According to the Indonesian National Standard (SNI 7571:2023), the permissible ground vibration limit is 5 mm/s. However, the company implements a more stringent internal limit of 4 mm/s for all types of structures as a preventive measure to mitigate potential damage and ensure safety and comfort for surrounding communities. Field measurements indicated that vibration levels exceeded the established limits, with values of 21.68 mm/s at the explosive magazine area (250 m from the blast site) and 7.168 mm/s at residential areas (326 m from the blast site). This evaluation employs a scaled distance approach and Peak Vector Sum (PVS) analysis based on the United States Bureau of Mines (USBM) empirical method. A regression model was developed to establish the relationship between scaled distance and PVS, which was subsequently used to predict Peak Particle Velocity (PPV) values derived from the obtained constant and exponent. The regression demonstrated a strong correlation, with a constant (k) of 9410.6, an exponent (e) of −1.999, and a coefficient of determination (R^2) of 0.8646. Based on these findings, the maximum recommended explosive charge to maintain PPV below 4 mm/s is 41.3 kg/hole for residential areas and 25.7 kg/hole for the explosive magazine area, adjusted according to the blasting geometry. The proposed design yields a Scaled Depth of Burial (SDOB) classified as "controlled energy,, which is in accordance with company standards. This study provides a safer and standardized blasting design alternative to minimize the risk caused by vibrations on the surrounding infrastructure.

Keywords: Explosive Charge per Delay, Peak Vector Sum (PVS), Peak Particle Velocity (PPV), Ground Vibration, Mining Blasting.

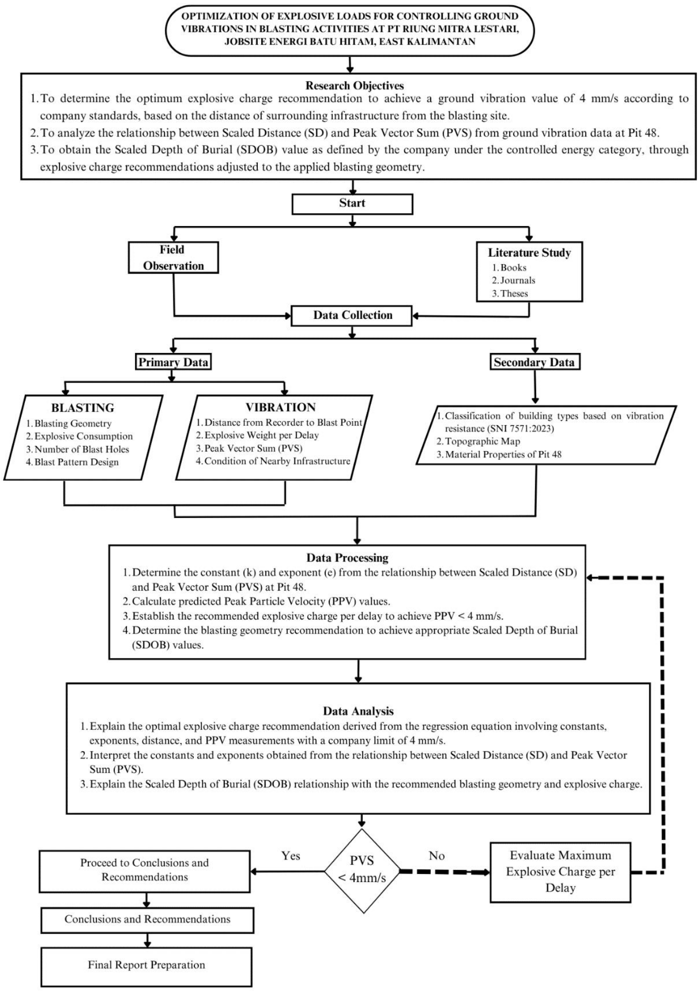
INTRODUCTION

Mining activities have two systems, namely open-pit mines and underground mines. The stages of open-pit mining activities start from land clearing, overburden stripping, and coal extraction (Kinata E, 2017). The activity of taking overburden soil is easier to do by blasting. Blasting gives rocks in large volumes using explosives, making the rock mass easy to dig and transport. One of the effects of blasting activities is ground vibration. Ground vibration occurs in elastic areas because the stress received by the material is less than the materials' strength, so it only causes a change in shape and volume. Because of the material's elastic properties, its shape and volume will return to its original state (Permana, 2019).

PT Riung Mitra Lestari is a coal mining contractor operating at the Energi Batu Hitam jobsite in Kutai Barat, East Kalimantan, employing open-pit mining methods. Overburden removal is performed by blasting to improve production efficiency. However, blasting operations can generate environmental impacts, notably ground vibration, which may compromise the stability of nearby infrastructure and affect the comfort of surrounding communities. According to the Indonesian National Standard (SNI 7571:2023), the maximum allowable particle vibration limit is 5 mm/s; nevertheless, the company enforces a stricter internal threshold of 4 mm/s for all building types.

METHOD

In this study, a theory is used to achieve the expected results, primary and secondary data will be collected and processed, and a method for its collection is also used.



Source: Research Data

Figure 1 Flow Chart of the Final Project

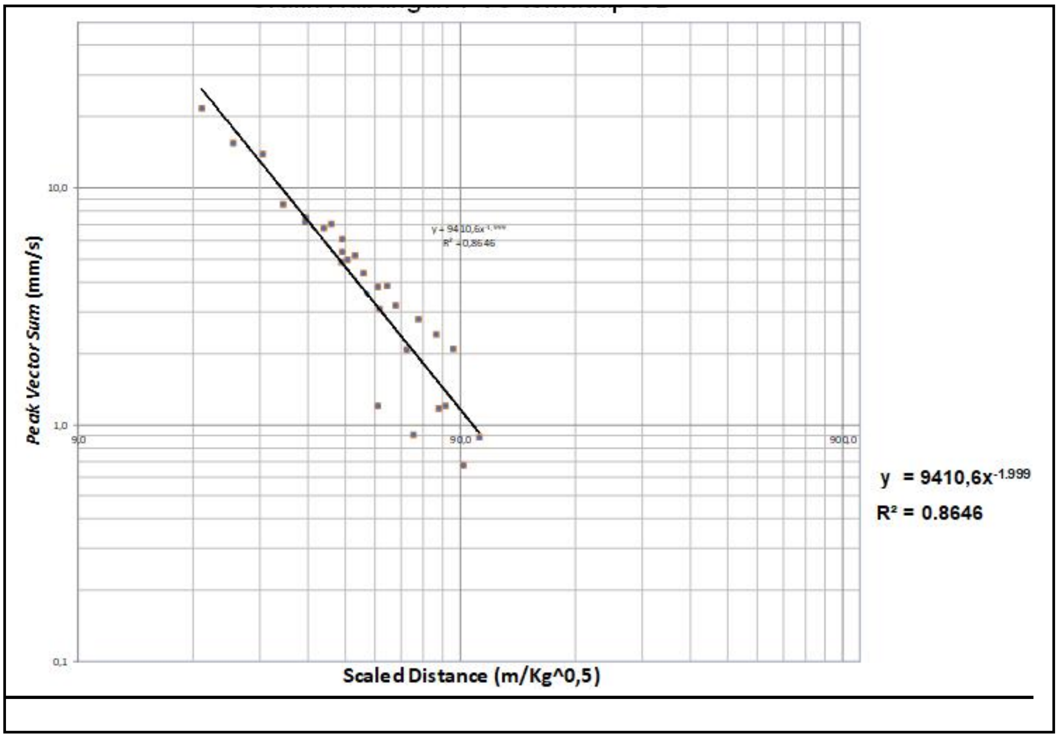
RESULT AND DICUSSION

1. **Relationship Between Scaled Distance and Peak Vector Sum (PVS)**

The relationship between Scaled Distance (SD) and Peak Vector Sum (PVS) was analysed using regression modelling. The regression analysis produced a constant k = 9410,6 and exponent e = -1,999, resulting in the following empirical equation:

$$PPV = 9410{,}6 \times (SD)^{-1{,}999}$$

The coefficient of determination ($ɢ^2$) was 0,8646, indicating that approximately 86% of the variation in PVS values is influenced by the scaled distance, while the remaining 14% is attributed to other factors such as geological conditions, rock characteristics, and variations in blasting patterns. This high $ɢ^2$ value demonstrates that the regression model provides a strong fit and is suitable for predicting PPV values. The relationship between scaled distance and PVS is illustrated in Figure 2.



Source: Research Data

Figure 2 Relationship Between PVS and Scaled Distance (SD)

2. **Scaled Distance (SD) in Ground Vibration Measurement**

After obtaining the constant (k) and exponent (e) values from the simple regression analysis using the United States Bureau of Mines (USBM, 1962) empirical method, a prediction test was conducted to compare the predicted Peak Vector Sum (PVS) values with the actual field measurements. The comparison results are presented in Table 1.

Table 1 Comparison of Actual and Predicted Peak Particle Velocity (PPV) Values

Peak Vector Sum										
Date	K	e	Blasting Location	Micromate Location	Distance (m)	Explosive (kg/hole)	Scale Distance (m/Kg^0,5)	PVS Micromate mm/s	PVS Prediction mm/s	Deviation mm/s
06-Jan-25	9410.6	-1.999	Pit 48 Middle	Gudang Handak	301	71.9	35.51	7.48	7.490	-0.010
06-Jan-25			Pit 48 West	Gudang Handak	495	80.4	55.19	3.09	3.102	-0.012
07-Jan-25			Pit 48 West	Gudang Handak	591	82.1	65.24	2.08	2.220	-0.140
08-Jan-25			Pit 48 middle	Gudang Handak	348	160.9	27.44	13.95	12.543	1.407
09-Jan-25			Pit 48 East	Gudang Handak	477	76.1	54.66	3.83	3.162	0.668
11-Jan-25			Pit 48 East	Gudang Handak	711	136.5	60.86	3.2	2.551	0.649
12-Jan-25			Pit 48 East	Gudang Handak	302	173.2	22.95	15.5	17.923	-2.423
12-Jan-25			Pit 48 East	Gudang Handak	640	60.5	82.28	1.202	1.396	-0.194
13-Jan-25			Pit 48 Middle	Rumah Warga	757	68.4	91.53	0.677	1.128	-0.451
14-Jan-25			Pit 48 Middle	Gudang Handak	386	155.6	30.94	8.518	9.862	-1.344
15-Jan-25			Pit 48 East	Rumah Warga	574	71.7	67.81	0.912	2.055	-1.143
18-Jan-25			Pit 48 Middle	Gudang Handak	545	143.3	45.52	4.992	4.558	0.434
19-Jan-25			Pit 48 Middle	Gudang Handak	250	173.1	19.00	21.68	26.134	-4.454
20-Jan-25			Pit 48 East	Rumah Warga	583	54.6	78.90	1.179	1.518	-0.339
21-Jan-25			Pit 48 East	Rumah Warga	348	62.3	44.09	5.369	4.860	0.509
21-Jan-25			Pit 48 East	Rumah Warga	326	62.2	41.33	7.094	5.529	1.565
22-Jan-25			Pit 48 West	Gudang Handak	728	71.5	86.10	2.095	1.275	0.820
22-Jan-25			Pit 48 West	Gudang Handak	763	57.3	100.81	0.886	0.930	-0.044
23-Jan-25			Pit 48 Middle	Rumah Warga	673	151.5	54.67	1.208	3.161	-1.953
25-Jan-25			Pit 48 East	Rumah Warga	365	69.2	43.87	4.861	4.908	-0.047
26-Jan-25			Pit 48 East	Rumah Warga	342	51.2	47.80	5.19	4.134	1.056
27-Jan-25			Pit 48 East	Rumah Warga	383	58.4	50.14	4.393	3.758	0.635
28-Jan-25			Pit 48 East	Rumah Warga	525	141.3	44.17	6.085	4.842	1.243
29-Jan-25			Pit 48 West	Gudang Handak	509	166.3	39.47	6.779	6.063	0.716
30-Jan-25			Pit 48 East	Rumah Warga	458	42.8	69.97	2.81	1.930	0.880
01-Feb-25			Pit 48 East	Rumah Warga	500	41.5	77.66	2.405	1.567	0.838
02-Feb-25			Pit 48 East	Rumah Warga	469	65.6	57.90	3.851	2.818	1.033
03-Feb-25			Pit 48 East	Rumah Warga	385	119.0	35.30	7.17	7.579	-0.411
04-Feb-25			Pit 48 Midle	Gudang Handak	377	113.1	35.45	7.48	7.515	-0.031
05-Feb-25			Pit 48 East	Rumah Warga	480	87.8	51.24	3.60	3.598	-0.001
Mean						96.8	54.68			

Source: Research Data

Table 2 Accuracy Analysis Between Actual and Predicted Peak Vector Sum (PVS) Data

USBM			
Date	PVS Micromate mm/s	PVS Prediction mm/s	Accurate
06-Jan-25	7.480	7.490	99.85%
06-Jan-25	3.090	3.102	99.61%
07-Jan-25	2.080	2.220	93.25%
08-Jan-25	13.950	12.543	89.92%
09-Jan-25	3.830	3.162	82.57%
11-Jan-25	3.200	2.551	79.74%
12-Jan-25	15.500	17.923	84.36%
12-Jan-25	1.202	1.396	83.84%
13-Jan-25	0.677	1.128	31.34%
14-Jan-25	8.518	9.862	84.21%
15-Jan-25	0.912	2.055	48.00%
18-Jan-25	4.992	4.558	91.32%
19-Jan-25	21.680	26.134	79.44%
20-Jan-25	1.179	1.518	74.34%
21-Jan-25	5.369	4.860	90.52%
21-Jan-25	7.094	5.529	77.94%
22-Jan-25	2.095	1.275	60.86%
22-Jan-25	0.886	0.930	94.99%
23-Jan-25	1.208	3.161	49.94%
25-Jan-25	4.861	4.908	99.01%
26-Jan-25	5.190	4.134	79.67%
27-Jan-25	4.393	3.758	85.56%
28-Jan-25	6.085	4.842	84.37%
29-Jan-25	6.779	6.063	89.45%
30-Jan-25	2.810	1.930	68.69%
01-Feb-25	2.405	1.567	65.17%
02-Feb-25	3.851	2.818	73.19%
03-Feb-25	7.168	7.579	94.26%
04-Feb-25	7.484	7.515	99.57%
05-Feb-25	3.597	3.598	99.95%
Average Accuracy			81.2%

Source: Research Data

From a total of 30 measurement data points, 16 predicted PVS values were higher than the actual values, while 10 data points showed higher actual values compared to predictions. Table 2 presents the average prediction accuracy, which reached 81.2%, indicating that the USBM method demonstrates a strong predictive capability in representing actual field conditions. The discrepancies between predicted and actual PVS values are likely influenced by local factors such as rock mass conditions, variations in explosive density, and weather conditions during blasting operations.

3. **Blasting Geometry Recommendation**

The recommended blasting geometry was designed using the R.L. Ash method to synchronize the geometric parameters with the recommended explosive charge. Data analysis yielded an optimal configuration with a burden of 5.5 m and a spacing of 6.5 m. This geometry, when applied with the recommended charge per delay, achieved a Peak Particle Velocity (PPV) below 4 mm/s and a Scaled Depth of Burial (SDOB) value within the controlled energy category. This configuration is deemed optimal as it successfully balances excavation efficiency with the control of ground vibrations. The proposed geometry is detailed in Table 3.

Table 3 Blasting Geometry Recomendation

RL. Ash	
Hole Diameter, De (Inch)	6 ¾
Burden (B)	5,5 m
Spasi (S)	6,5 m

4. **Optimal Explosive Load Estimation for Surrounding Infrastructure Security**

a. **Recommendations for Residential Areas**

Table 4 Recommendations for Residential Areas Based on Powder Factors

Resident's house					
Prediction Method	Blasting Geometry	Infrastructure Critical Distance	Powder Faktor	Depth	Prediksi PPV
USBM (Duvall dan Fogelson,1962)	5,5m x 6,5m	326 meter	0,21 kg/m^3	5,5 m	3,67 mm/s
			0,20 kg/m^3	6 m	3,81 mm/s
			0,19 kg/m^3	6 m	3,62 mm/s
			0,18 kg/m^3	6,5 m	3,72 mm/s

Source: Research Data

Table 4 presents recommendations for residential areas, determined based on ground vibration predictions using the USBM method with a blasting geometry of 5.5 m × 6.5 m at a distance of 326 meters. Variations in powder factors ranging from 0.18–0.21 kg/m³ were tested to ensure PPV values remained below the threshold limit. The calculation results showed that all combinations produced safe PPV values, ranging from 3.6 mm/s to 3.8 mm/s. This confirms that the selection of appropriate powder factors and borehole depths plays a crucial role in minimizing the impact of vibrations in residential areas.

b. **Recommended Explosives Magazine Areas**

Table 5 Recommended Explosives Magazine Areas Based on Powder Factor

Ammunition Warehouse					
Prediction Method	Blasting Geometry	Infrastructure Critical Distance	Powder Faktor	Depth	Prediksi PPV
USBM (Duvall dan Fogelson,1962)	5,5m x 6,5m	250 meter	0,18 kg/m^3	4 m	3,89 mm/s

Source: Research Data

The recommended explosive charge for the ammunition warehouse area was designed using a blasting geometry of 5.5 m × 6.5 m at a distance of 250 meters, with a powder factor (PF) of 0.18 kg/m³. Predictions based on the USBM method indicate that with a powder factor of 0.18 and a drill hole depth of 4 meters, the resulting PPV value is 3.89 mm/s.

5. **Blasting Geometry Based on Depth of Burial Scale (SDOB)Values**

   a. **SDOB Values for the Recommended Residential Areas**

Table 6 SDOB Value in Residential Areas

Resident's house									
Burden (m)	Spasi (m)	Depth (m)	Powder column (m)	Stemming (m)	Loading Density (Kg/m)	Explosive charge per hole (kg/Hole)	PF (kg/m^3)	SDOB (m/kg$^{0.33}$)	Keterangan
5.5	6.5	5.5	2.1	3.4	19.52	41.3	0.21	1.30	Controlled Energy
		6	2.2	3.8		42.9	0.20	1.42	Very Controlled Energy
		6	2.1	3.9		40.8	0.19	1.46	Very Controlled Energy
		6.5	2.1	4.4		41.8	0.18	1.58	Very Controlled Energy

Source: Research Data

The Scale Depth of Burial (SDOB) values were calculated based on a blast geometry with a burden of 5.5 m and spacing of 6.5 m, using variations in drilling depth and powder factor. The results are as follows:

PF 0.21 kg/m^3, SDOB 1.30 m/kg^{1} ^{3} at 5.5 m depth – controlled energy

PF 0.20 kg/m^3, SDOB 1.42 m/kg^{1} ^{3} at 6 m depth – very controlled energy

PF 0.19 kg/m^3, SDOB 1.46 m/kg^{1} ^{3} at 6 m depth – very controlled energy

PF 0.18 kg/m^3, SDOB 1.58 m/kg^{1} ^{3} at 6.5 m depth – very controlled energy

Since the company's target is to achieve the controlled energy category, the most suitable configuration for the residential area is a drilling depth of 5.5 meters with a powder factor of 0.21 kg/m^3. This combination meets energy control standards and ensures safety for areas surrounding residential zones

   b. **SDOB Values for the Explosives Magazine Areas**

Table 7 SDOB Value in Explosives Magazine Areas

Ammunition Warehouse									
Burden (m)	Spasi (m)	Depth (m)	Powder column (m)	Stemming (m)	Loading Density (Kg/m)	Explosive charge per hole (kg/Hole)	PF (kg/m^3)	SDOB (m/kg$^{0.33}$)	Keterangan
5.5	6.5	4	1.3	2.7	19.52	25.7	0.18	1.14	Controlled Energy

Source: Research Data

The Scale Depth of Burial (SDOB) value was determined based on a blasting geometry with a load of 5.5 m, a spacing of 6.5 m, and a drilling depth of 4 m, using a powder factor of 0.18 kg/m^3. The resulting SDOB was 1.14 m/kg^{1} ^{3}, which falls within the controlled energy category. This indicates that the proposed blasting design aligns with the company's target for energy control while ensuring the safety of surrounding infrastructure.

CONCLUSION

The study, entitled "Optimizing Explosive Loads for Ground Vibration Control during Blasting Activities at PT Riung Mitra Lestari, Energi Batu Hitam Jobsite, East Kalimantan Province," yielded several conclusions. The first conclusion relates to the recommended explosive charge based on the surrounding infrastructure. For a residential area located 326 meters from the blasting point, the optimal explosive charge is 41.3 kg per hole with a load geometry of 5.5 m, a spacing of 6.5 m, and a drilling depth of 5.5 m, resulting in a Peak Particle Velocity (PPV) of 3.67 mm/s. Meanwhile, for an explosives storage area (magazine) located 250 meters from the blasting site, the recommended explosive charge is 25.7 kg per hole with the same load dimensions and spacing but a drilling depth of 4 m, resulting in a PPV of 3.89 mm/s. Both configurations produce ground vibration values below the company's maximum allowable limit of 4 mm/s, indicating that the design is safe for the surrounding infrastructure.

The second conclusion concerns the relationship between Scaled Distance (SD) and Peak Vector Sum (PVS). The analysis conducted using the United States Bureau of Mines (USBM) method demonstrated a very strong correlation between SD and PVS, with a coefficient of determination (R^2) value of 0.8646. This finding suggests that approximately 86% of the variation in PVS is influenced by Scaled Distance, while the remaining 14% is attributed to other factors such as geological conditions, rock mass characteristics, and variations in blast design.

The third conclusion involves the Scaled Depth of Burial (SDOB) analysis. For the residential area, with an explosive charge of 41.3 kg per hole, a powder column of 2.1 m, and stemming of 3.4 m at a drilling depth of 5.5 m, the SDOB value obtained is 1.30 $m/kg^{1/3}$, which falls into the controlled energy category. Similarly, for the explosive storage area, with an explosive charge of 25.7 kg per hole, a powder column of 2.7 m, and stemming of 1.3 m at a drilling depth of 4 m, the resulting SDOB value is 1.14 $m/kg^{1/3}$, also classified as controlled energy. These results confirm that the proposed blast designs meet company standards for energy control and ensure the safety and stability of nearby infrastructure.

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