Blasting Vibration Analysis with Micromate Tools: Experimental Study and Characterization at the PT Semen Padang Mine

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Abstract *- This research investigates the impact of vibrations produced by blasting activities at the PT Semen Padang Mine, with a focus on vibration analysis and experimental characterization using the Micromate tool. The main objective of this research is to understand the vibrations resulting from blasting, analyze the impact of variations in PVS (Peak Vector Sum) values, and evaluate the effect on the surrounding environment, especially employee housing around the mining area. The research method used involves several important stages, first of which is the use of a Micromate tool to measure the vibrations produced during the blasting process. Micromate is a tool that can record and analyze vibrations with high accuracy, thus providing reliable data for further analysis. Apart from that, this research also uses power regression analysis to understand the relationship between PVS and Scaled Distance variables. This analysis is important to determine how variations in blasting distance and intensity affect the resulting PVS values. Then, a distance analysis was carried out to obtain a PVS value below 3 mm/s, which is considered a safe threshold to prevent structural damage to the building. The research results show several important findings. Even though the measured vibration values are below the Threshold Values set by environmental regulations, it is important to comply with all existing regulations to avoid long-term negative impacts. The power regression analysis carried out shows that there is a significant relationship between PVS and Scaled Distance, which means that the greater the distance between the blasting point and the measurement point, the smaller the PVS value detected. The validation results of this analysis are also in accordance with the empirical data collected during the research. In addition to these main findings, this research also provides several practical recommendations. One of them is setting the explosive charge to reduce the impact of the resulting ground vibrations. These arrangements include reducing the amount of explosive per blast or changing the blasting technique to reduce vibration intensity. In conclusion, this research provides an in-depth understanding of the factors that influence vibrations from blasting in a mining context. The results of this research have important implications for the development of more accurate and effective vibration measurement methods as well as for mitigating environmental impacts caused by blasting activities. This research not only provides new insights for the mining industry but also helps in formulating better policies to protect the environment and communities around mining areas. Thus, this research contributes to ongoing efforts to achieve a balance between industrial activities and environmental sustainability.*

Keywords: *Blasting; Ground Vibrations; PPV; Scaled Distance*

INTRODUCTION

This activity is carried out to break or dismantle hard rock from its original position into loose material with a certain fragmentation size, so that the tool (unit) is easy to dig (Tjan et al., 2021). Blasting is a demolition activity on rock whose material is massive. Explosions produce ground vibrations that can cause damage to surrounding structures. In recent decades, explosion-induced ground vibrations and their propagation in rock masses have attracted greater attention. The effects of explosions include changes in rock behavior which have implications for the stability and integrity of structures (Kumar et al., 2016).

Part of the explosive energy released at the explosion source actualizes rock fragmentation, while the remaining energy is released into the environment and produces various adverse environmental impacts, such as ground vibrations due to the explosion, excess air pressure, and others (Akande et al., 2014). The importance of ground vibrations due to explosions has prompted researchers to suggest various ways to measure the magnitude of ground vibrations, such as measuring PPV (Peak Particle Velocity) or peak particle velocity. Direct field measurements require quite a lot of money and time as well as a high level of expertise (Lawal, 2021).

Micromate is a sophisticated vibration measurement tool and can provide data with high accuracy. This experimental study was carried out directly at the Bukit Karang Putih Indarung Limestone Mine to gain a comprehensive understanding of the vibrations produced during the blasting process. Monitoring blast vibrations during actual excavation helps ensure the safety of associated structures as well as providing the data necessary for improvements to blast patterns if necessary (Agrawal & Mishra, 2019). This research aims to understand the vibrations resulting from blasting activities at the PT Semen Padang Mine, characterize experimentally with a micromate for accurate data, analyze the impact of variations in PVS (Peak Vector Sum) values at the PT Semen Padang Mine which affect employee housing around the mining area accordingly. with PT Semen Padang Mine Blasting Work Instructions and Decree of the Head of the National Standardization Agency Number 791/KEP/BSN/12/2023 (Badan & Nasional, 2023).

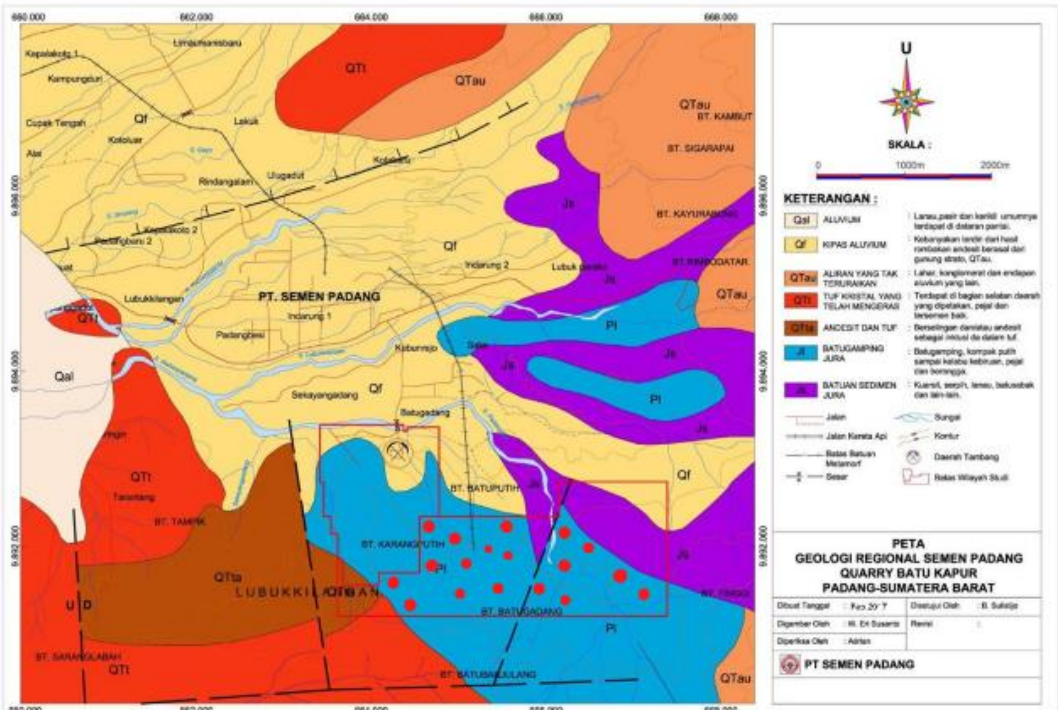

Figure 1. Map of Research Area (red box)

Assessment of the safety of an explosion in the field is a crucial aspect. Analysis of vibrations resulting from blasting is an important benchmark for evaluating its impact on the surrounding environment. This research provides deeper insight into the factors influencing PPV vibrations produced by blasting in a mining context. Through the use of power regression analysis, research shows that variability in particle vibration peaks by Scaled Distance (SD) values, which is an important indicator in assessing blasting safety in the mining industry (Paurush & Rai, 2022). The connection of this research with the field of geophysics is that the analytical method used provides a better understanding of how geophysical variability, in this case PPV, is influenced by certain factors such as blasting load and distance from the vibration source. This provides valuable insight for geophysicists in developing better methods for understanding and controlling blasting impacts in mining contexts. Thus, this research not only provides practical recommendations for reducing peak particle vibration values below established thresholds, but also provides a deeper understanding of the elements that influence this geophysical phenomenon in the context of mine blasting. In Figure 1, the red dots mark the locations of measurements that have been carried out for 18 days, spread across 18 points with different measurement and detonation locations. The study area can be identified by a visible red box.

RESEARCH METHODS

This research adopts a systematic approach to analyze blasting vibrations at the PT Semen Padang Mine using the Micromate tool. This experimental study was carried out directly at the Bukit Karang Putih Indarung Limestone Mine, the measurement results used for this research data were 18 days and the measurement points were at different blasting locations in the Pit Limit of the PT Semen Padang mine. The research method for understanding vibrations resulting from blasting activities at the PT Semen Padang Mine and analyzing the impact of variations in PVS (Peak Vector Sum) values consists of several stages involving various techniques and important steps for understanding and analyzing vibrations resulting from mine blasting.

First, the research began with a literature study to read literature related to vibrations from mine blasting and identify the methods and techniques used in previous research. Then, researchers conducted a field study by collecting data directly from the blasting location at the PT Semen Padang Mine and understanding the geographical and geological conditions around the mine. After that, the researcher identified the problem to be solved in this research, including determining specific research objectives related to understanding vibrations and analyzing the impact of variations in PVS values. In order to obtain data regarding vibrations from blasting, researchers apply seismic methods and understand the characteristics of the resulting seismic waves. Testing of the Micromate tool was carried out to ensure its optimal performance, before then installing it in the right location with a minimum distance of 500 meters from the blasting location. Vibration data resulting from the blast was then collected using a Micromate device. This data was analyzed using power regression techniques in MS Excel software. After that, researchers connected the PVS variable with Scaled Distance (SD) to understand the relationship between the two. Calculation of constant and exponent values was carried out in the power regression model for interpretation of research results. Experiments with measurement distances of 500 m, 1500 m, and 2000 m were designed to understand the impact of distance on the vibrations produced. In addition, this research provides recommendations for optimal Powder Factor values to reduce the impact of vibration. Research results are validated with additional data or other methods if necessary. Finally, conclusions are drawn based on data analysis and experimental results, followed by completion of the research and preparation of a final report containing findings and recommendations. Figure 2 below displays visual documentation of the Micromate tool used in the experimental study. This tool has an important role in collecting data regarding blasting vibrations at the PT Semen Padang Mine.

Figure 2. Micromate Tool Documentation

R. L. Ash's Geometric theory

In the blasting process, there are seven basic standards for blasting geometry, which include burden, spacing, stemming, subdrilling, blast hole depth, fill column length, and tier height (Sunaryadi & Atmojo, 2011).

C.J. Geometry theory Konya

According to Konya (1991), in calculating blasting geometry, not only takes into account the explosive material, rock characteristics, and the size of the blast hole, but also pays attention to correction factors for the position of rock layers, geological structure, and the number of blast holes used. According to Konya, the most vital aspect to take into account is determining the burden value (Sunaryadi & Atmojo, 2011).

Perforated Blasting Volume

Blast volume refers to the space or area around the blast source that is affected by the blast. In the context of hole blasting, the blast volume can refer to the space around the hole or where the blast occurred (Sulistiyono, 2022)

$$V = B \times S \times H \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where:

Explosion Volume (V): This refers to the space or region around the explosion source that is affected by the explosion. In the context of a hole explosion, the volume of the explosion can refer to the space around the hole or where the explosion occurred.

B = Blasting Load : This is the amount of energy released by blasting.

S = Spacing: This is the distance between blasting holes.

H = Height of Burden: This is the height of the load above the explosion site

The following formula is used to calculate burden correlation:

(C.J. Konya's geometric theory)

$$B2 = Kd \times Ks \times Kr \times B1 \quad \ldots\ldots\ldots\ldots (2)$$

In this formula:

$B1$B1 is the previous load.

$B2$B2 is the load after correlation.

KdKd, KsKs, and KrKr are correlation factors related to design, geometry, and blasting environment.

This formula is used to adjust or correct the blasting load based on certain factors before calculating the blasting volume.

Explosion Intensity per Day

Used to calculate how much explosion intensity may occur in one day, taking into account the size of the explosion, the sensitivity of the material, environmental conditions, and the number of holes or channels that influence the spread of the explosion (Sunaryadi & Atmojo, 2011).

(Geometric theory of R. L. Ash)

$$V = B \times S \times H \times \textit{lots of holes} \ldots\ldots\ldots (3)$$

Use of Explosives

The use of explosives involves various factors that must be taken into account to maintain their safety and effectiveness. Loading density is an important aspect in the use of explosives. Loading density refers to the amount of explosive material loaded in a certain volume or space. Choosing the right loading density can affect the performance of explosives (Sunaryadi & Atmojo, 2011). (Geometric theory of R. L. Ash)

Loading density (de)

$$De = 0.508 \times (5)^2 \times 1.30 \quad \text{............} \quad (4)$$

Use of Explosives in Each Hole (E)

The weight of explosives (E) in each explosive filling column is influenced by the diameter, density and length of the explosive column. The weight of this explosive for each blast hole can be calculated using the following formula (Sunaryadi & Atmojo, 2011).

(Geometric theory of R. L. Ash)

$$E = PC \times de \quad \text{..............................} \quad (5)$$

where:

PC = length of explosive filled column (m)

de = diameter of shot hole (inches)

Powder Factor

Powder factor (PF) is the ratio between the amount of explosives used and the blasting volume in units of kg/m³, which is a parameter called the blasting factor (PF). PF can be an indicator of unit production output in a blasting operation, and provides information about the explosive consumption required to produce a certain volume of rock (Sunaryadi & Atmojo, 2011).

(C.J. Konya's geometric theory)

$$PF = n \times \frac{E}{W} \quad \text{..............................} \quad (6)$$

Where:

Pf = Powder factor (kg/m3)

W = Volume of material blasted (m3)

E = Weight of explosives per blast hole (kg)

n = Number of blast holes

Loading Mobile Manufacturing Unit (MMT)

The way to calculate the amount of Dabex to be loaded into the Mobile Manufacturing Unit is by multiplying the amount of Dabex used by 0.3 (or 30%) to get the appropriate amount to be loaded into the MMT (Sulistiyono, 2022).

(Blasting Techniques, Rachmat Hidayatullah; Salmani)

$$AN\ (30\%) = \text{Use of Dabex} \times 0.3 \quad \text{.........} \quad (7)$$

Scaled Distance (SD)

Data on PPV values and explosive contents were then analyzed using the Scaled Distance (SD) theory approach as explained in the Equation (Yin et al., 2018).

$$SD = D\sqrt{w} \quad \text{.....................} \quad (8)$$

Where:

D = distance between the recording device and the explosion source point (m)

w = amount of explosive material/delay (kg)

***Peak Vector Sum* (PVS) and *Peak Particle Velocity* (PPV)**

Peak Vector Sum (PVS) is the value obtained from the vector sum of three vibration waves measured by the MicroMate tool, namely transverse, longitudinal and vertical waves. PVS is the result of the vector addition of these three waves. The PVS value is used to calculate the magnitude of vibrations at a blasting location depending on how far away the blasting location is and the recording distance to the blasting location. PVS = Peak Particle Velocity (PPV) (Erwin Wijaya & Prastowo, 2022)

PPV is the maximum wave speed produced and is used to calculate the magnitude of vibrations at a blasting location depending on how far away the blasting location is and the recording distance to the blasting location. PPV (Positive Predictive Value) and PVS (Positive Sensitivity) are two metrics used in evaluating the performance of classification or diagnostic models, especially in the context of medical diagnostic testing.

1. Positive Predictive Value (PPV): This is a measure of how well a model can predict the presence of a positive condition when the model predicts that the condition is present. PPV is calculated as the number of true positives divided by the total number of predicted positive outcomes (true positives + false positives).
2. Sensitivity (Sensitivity) or True Positive Rate (TPR) or Recall: This is a measure of how well the model can detect the presence of positive conditions overall. Sensitivity is calculated as the number of true positives divided by the total number of positive conditions (true positives + false negatives).

PVS may Refer to Positive Sensitivity, which is a measure of a model's ability to detect positive conditions. If you find that PPV and PVS have the same value, this can happen in several situations:

1. Balanced Data : If you have a dataset where the number of positives and negatives is balanced, then most likely the PPV and PVS will have the same value. This is because in the balanced case, false positives (which affect PPV) and false negatives (which affect PVS) also tend to balance.
2. Consistent Model Performance: If your model has consistent performance in detecting positives and negatives, the PPV and PVS values can be the same because both are influenced by the number of true positives.

The relationship between the SD value and the PPV value using power regression analysis to obtain the constant value (k) and n value, then the k value and n value are calculated using the empirical formula in Equation (Yin et al., 2018)

$$PPV = k\left(\sqrt{w} / D\right)^{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

RESULTS AND DISCUSSION

Results

Vibration measurement results were obtained from field measurement activities (Primary Data) carried out at the PT Semen Padang mine. Even though the vibration value obtained is still below the specified NAB (Threshold Limit Value), PT Semen Padang complies with the regulations set by the National Standardization Agency. According to available information, the NAB (Threshold Limit Value) standard for blasting vibrations in open pit mines in Indonesia refers to the standard vibration level standards set by the Indonesian National Standardization Agency. This standard sets vibration limits for the environment, which explains that blasting activities that produce ground vibrations exceeding the NAB (Threshold Limit Value) can cause disturbance to humans, discomfort and even damage to surrounding building structures. Research related to ground vibrations produced by open-pit mine blasting activities indicates that the NAB (Threshold Limit Value) of the vibrations involved is 5 mm/s, in accordance with the criteria stated in SNI 7571:2023. The level of ground vibration at a distance is influenced by the explosive charge, vibration frequency, rock characteristics, blast hole conditions, and surface wave propagation (Kumar et al., 2016). The following is table 1 of the results of measurements that have been carried out for 18 days and measurement points at different blasting locations in the Pit Limit of the PT Semen Padang mine.

Table 1. Vibration Measurement Results

Date	B	S	Blast Hole		PVS	Distance Measurement	Number of Holes	Anfo	Peak Particle Velocity		
	(m)	(m)	D (inch)	H (m)	(mm/s)	(m)		(kg)	Trans	Ver	Long
23-10-23	4	4.5	5	11	0.369	900	115	31.50	1.206	0.851	1.111
20-11-23	4	4.5	5	11	1.972	700	98	28.50	2.750	2.252	2.150
11-12-23	4	4.5	5	11	4.548	600	120	36.00	1.009	0.473	0.638
12-12-23	4	4.5	5	11	0.439	850	90	30.00	0.520	0.292	0.497
13-12-23	4	4.5	5	11	2.012	650	96	28.50	2.617	2.175	1.939
18-12-23	4	4.5	5	11	0.565	800	136	30.00	1.789	1.852	2.403
19-12-23	4	4.5	5	11	2.553	750	121	36.00	1.111	0.521	0.697
20-12-23	4	4.5	5	11	1.191	750	96	33.00	2.659	2.212	2.050
21-12-23	4	4.5	5	11	0.189	950	112	31.50	1.345	1.111	1.587
05-01-24	4	4.5	5	11	0.956	850	110	31.50	1.206	0.851	1.211
08-01-24	4	5	5	11	1.013	750	86	28.50	1.474	1.356	1.167
09-01-24	4	4.5	5	11	1.275	750	85	28.50	1.235	1.121	0.985
11-01-24	4	5	5	11	1.146	750	70	24.00	0.670	0.646	0.481
15-01-24	4	5	5	11	0.837	800	122	36.00	1.945	0.542	0.275
16-01-24	4	5	5	11	0.667	750	119	39.00	0.980	0.352	0.585
17-01-24	4	5	5	11	1.563	700	118	37.50	0.750	0.252	0.463
18-01-24	4	5	5	11	2.205	700	115	31.50	0.695	0.150	0.290
23-01-24	4	5	5	11	4.165	750	120	36.00	0.987	0.323	0.540

Table 1 summarizes the results of vibration measurements carried out over 18 days and measurement points at different blasting locations in the Pit Limit of the PT Semen Padang mine. Each row in the table represents one measurement on a specific date. The information presented includes the date of measurement, variables B (burden), S (spacing), number of blast holes used with D (diameter) and H (height of blast hole), as well as details related to blasting such as blast length, number of blast holes, and number of Anfo explosives were used. The data also includes Peak Particle Velocity (PVS), which is the maximum speed of particles during vibration, measured in units of mm/s (millimeters per second), as well as the measured distance from the detonation site in three directions: Transverse (Trans), Vertical (Ver), and Longitudinal (Long). Each row provides an understanding of the vibration characteristics produced by blasting at each mine site.

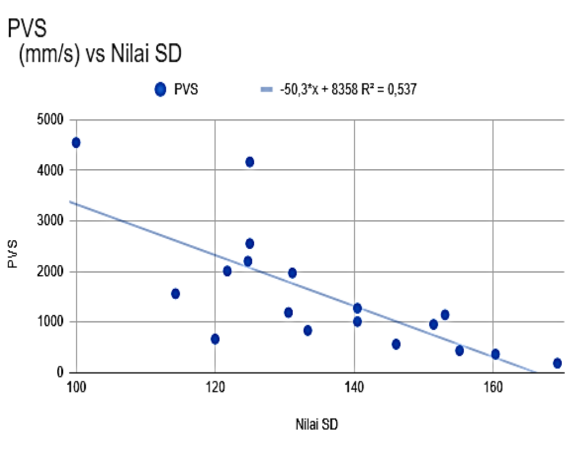

Figure 3. Graph of the Relationship between Measured Distance and PVS

$y = ax^b = -50.3*x^{+-8358}$

a or K = 8357.62518 or 8358

n = 18

$R^2 = 0.537$

The function $y=ax^b$ is an exponential function where a is the coefficient, x is the independent variable and b is the power of the exponent. It describes rapid growth or decline depending on the value of b. The larger b, the steeper the graph. R^2 is a measure of how well a linear regression model fits the observed data. It provides information about how close the data points are to the regression line. In the context of the $=ax^b$ function, R^2 can be used to evaluate how well the model fits the observed data (Rolansyah & Sumarjono, 2021). The higher the R squared value, the better the model fits the data. $y = ax^b = -50.3*x+-8358$, non-linear regression model, looks for the values a and b to conclude the relationship between variables x and y. In this model, a and b are model coefficients, while K, n, and R^2 are the values associated with the regression analysis.

1. a or K (K = 8357.62518 or 8358): This value may be the constant value a of the regression model. The two values given (8357.62518 or 8358) appear to be approximations for the constant. The choice may depend on how the model is analyzed or built.
2. n = 18: This is the number of samples or number of observations used in the regression analysis, which means that in 18 days and with different measurement points at the Pit Limit of the PT Semen Padang mine, there were 18 observations made to evaluate the correlation between variables x and y .
3. R^2 = 0.537: This is the coefficient of determination, R^2 is a measure that reflects the extent to which the regression model fits the existing data. The range of R^2 values is between 0 and 1, where the closer to 1, the better the model fits the data. In this case, the R^2 value is 0.537, which indicates that approximately 53.7% of the variation in the dependent variable (y) can be explained by the regression model.

Discussion

Data measurement results must be arranged according to a curve, because this adjustment provides a mathematical interpretation of the relationship between two variables, namely the independent variable (number of observations or measurements) and the dependent variable (PVS value). The curve equation obtained can be used to predict the value of the dependent variable, namely PVS. Efforts have also been made to produce PVS models that consider the influence of rock discontinuities, rock types, rock formations, rock joints and their orientation, the presence of water, soil-rock interfaces, acoustic behavior, etc. The power curve is the right choice for matching PVS and SD measurement data because the PVS equation has a power function form ($y=ax^b$). Empirical equations for PVS and SD can be identified by using linear curves and SD to predict ground vibration values. According to (Subdictrict & Regency, 2017) Estimated value of the resulting ground vibrations by blasting activity can be done by connecting the results of vibration measurements soil with blasting parameters that influence it. These parameters are distance from the blasting location to data collection and the amount of explosives used when exploding simultaneously. This relationship can be seen in the concept PPV vs SD as stated by the US Bureau of Mines. It is explained that Scaled Distance is a factor that influences the level of ground vibration. The following is table 2 regarding the SD values obtained from the vibration measurement results. The following is a table of 2 Scaled Distance values obtained from a comparison of the vibration measurement distance and the amount of explosive filling in each hole.

Table 2. Scaled Distance During Research

Date	Distance (m)	Filling/Hole (kg)	Mark SD (m/kg1/2)	PVS (mm/s)
23-10-2023	900	31.50	160.36	0.369
20-11-2023	700	28.50	131.13	1.972
11-12-2023	600	36.00	100	4.548
12-12-2023	850	30.00	155.19	0.439
13-12-2023	650	28.50	121.76	2.012
18-12-2023	800	30.00	146.06	0.565
19-12-2023	750	36.00	125	2.553
20-12-2023	750	33.00	130.56	1.191
21-12-2023	950	31.50	169.27	0.189
05-01-2024	850	31.50	151.45	0.956
08-01-2024	750	28.50	140.49	1.013
09-01-2024	750	28.50	140.49	1.275
11-01-2024	750	24.00	153.10	1.146
15-01-2024	800	36.00	133.34	0.837
16-01-2024	750	39.00	120.01	0.667
17-01-2024	700	37.50	114.31	1.563
18-01-2024	700	31.50	124.73	2.205
23-01-2024	750	36.00	125	4.165

Table 2 records the Scaled Distance (SD) values obtained from the comparison between the vibration measurement distance and the amount of explosives filled in each hole during the research. This SD value is calculated using the formula SD = distance between recording devices / amount of explosive material/delay, where distance is measured in meters (m) and fill/hole in kilograms (kg). In addition, the table also records Perceivable Vibration Severity (PVS) which is measured in millimeters per second (mm/s). From table 2, it can be seen that variations in the resulting SD values depend on the combination of distance and filling/hole. PVS also shows the intensity of vibration felt in each combination. The higher the SD value, the higher the vibration intensity felt.

Distance Analysis to Get PVS Values below 3 mm/s

Distance analysis is a method that is often used in the engineering field to assess the level of vibration in a system or structure. The main goal is to obtain a Specific Vibration Acceleration (PVS) value that is below 3 mm/s. By measuring certain distances, it is possible to identify and examine points where vibration is at a low level, which is an indication of good performance or a safe state of the system. This method is very important in ensuring the safety of a structure that is affected by vibration and movement. Table 3 provides recommendations for filling explosives per hole with a design measuring distance of 500 m.

Table 3. Design of Filling Holes at a Distance of 500 m

No.	Distance (m)	Hole Filling (kg)	K	SD (m/kg1/2)	PVS (mm/s)
1.	500	**34.00**	8357.62518	85.74	**1.34**
2.	500	**36.00**	8357.62518	83.34	**2.23**
3.	500	38.00	8357.62518	81.12	3.62
4.	500	40.00	8357.62518	79.06	5.75
5.	500	42.00	8357.62518	91.29	8.91

The design at a distance of 500 m achieves optimal fill weight for a PVS below 3 mm/s, namely 34 kg with a PVS of 1.34 mm/s, and 36 kg with a PVS of 2.23 mm/s. Table 4 provides recommendations for filling explosives per hole with a design measuring distance of 1500 m.

Table 4. Design of Hole Filling Distance 1500 m

No.	Distance (m)	Hole Filling (kg)	K	SD (m/kg1/2)	PVS (mm/s)
1.	1500	**32.00**	8357.62518	265.17	**1.98**
2.	1500	34.00	8357.62518	257.25	3.44
3.	1500	36.00	8357.62518	306.19	5.75
4.	1500	38.00	8357.62518	294.18	9.35

The plan at a distance of 1500 m achieves an optimal fill weight for PVS below 3 mm/s of 32 kg with a PVS of 1.98 mm/s. Table 5 provides recommendations for filling explosives per hole with a design measuring distance of 2000 m.

Table 5. 2000 Distance Perforation Filling Design

No.	Distance (m)	Hole Filling (kg)	K	SD (m/kg1/2)	PVS (mm/s)
1.	2000	**32.00**	8357.62518	353.56	**1.13**
2.	2000	**34.00**	8357.62518	426.41	**1.93**
3.	2000	36.00	8357.62518	408.25	3.24
4.	2000	38.00	8357.62518	392.24	5.27
5.	2000	40.00	8357.62518	377.97	8.35

At a distance of 2000 m, the design achieves the optimal fill weight for a PVS below 3 mm/s, namely 32 kg with a PVS of 1.13 mm/s, and 34 kg with a PVS of 1.93 mm/s.

Ground Vibration Analysis to Reduce Damage

Ground vibration analysis is an important study in the fields of civil engineering and geotechnical engineering. Through this analysis, we can understand how vibrations that occur in the ground affect building structures and other infrastructure. The aim of this analysis is to develop effective mitigation strategies, so that the risk of damage due to ground vibrations can be minimized. Thus, ground vibration analysis becomes important in efforts to maintain the security and sustainability of infrastructure in various locations. Table 6 is a draft Powder Factor calculation. This table explains how to calculate the Powder Factor used to fill holes with different numbers of blast holes. This table presents blast geometry, volume, and powder factor (PF) data from several blast holes. Each hole has a different number of blast holes, depth, diameter, and spacing. Volume and PF are calibrated to the size of the blast hole and the amount of explosive used. The following is table 6 which explains the draft PVS value obtained from the Powder Factor calculation.

Table 6 shows the different PFs for each blast hole, which can be used to reduce soil and blasting material damage. Table 6 shows the fragmentation results obtained from filling 42 – 39 kg, which shows that the fragmentation results are less than 3 mm/s. This table can be used to reduce damage to soil and explosives. Reducing soil damage is important to reduce the negative impacts of blasting, such as dust formation, water use, and reduced soil quality. Reducing damage to blasting materials can increase the efficiency and success of blasting. The use of powder factor (PF) in blasting is important to regulate the amount of explosives used with the volume of material to be detonated. If the PF is too large, it will cause a lot of energy to be lost, whereas if the PF is too small, there will be a lot of oversized material.

Table 6. Powder Factor Calculation Design

Filling/Hole (kg)	Number of Explosion Holes	Total Contents (kg)	Burden (m)	Spasi (m)	Depth (m)	Diameter (inches)	PC	Volume (BCM) (ton)	*Powder Factor* (kg/BCM)
115.57	130	2,146.3	4	5	11	5	7	75,790	0.199
123.825	140	2,311.4	4	5	11	5	7.5	81,620	0.213
115.57	150	2,476.5	4	5	11	5	7	87,450	0.199
123.825	160	2,641.6	4	5	11	5	7.5	93,280	0.213
PVS results with a filling of 42 – 39 kg are < 3 mm/s									

CONCLUSION

Research conducted on ground vibrations produced by open-pit mine blasting activities shows that the NAB (Threshold Limit Value) of the vibrations followed is 5 mm/s, in accordance with the criteria stated in SNI 7571:2010. SNI 7571:2023 concerning Blasting Vibration Levels in Open Mining Activities has been revised from the previous version, namely SNI 7571:2010. The curve equation obtained can be used to estimate the value of the attachment variable, namely PVS (Peak Vector Sum). The power curve is the right choice to match PVS and Scaled Distance measurement data because the PVS equation has a power function form ($y=ax^b$). Empirical equations for PVS and Scaled Distance can be identified using linear curves and power curves to predict ground vibration values.

PT Semen Padang complies with the regulations set by the Indonesian National Standardization Agency regarding the threshold value (NAB) for blasting vibrations in open mines. The standard explains that ground vibrations that exceed the NAB can cause disturbance to humans, discomfort, and even damage to surrounding building structures. The results of vibration measurements were carried out at PT Semen Padang for 18 days at various blasting locations. Regression analysis was carried out to find the relationship between the number of measurements or observations and the resulting Peak Particle Velocity (PVS) value. A non-linear regression model ($y = ax^b$) is used to evaluate the relationship between the variable amount of reinforcement and the Peak Particle Velocity (PVS) value. The obtained coefficient values a and b and the coefficient of determination (R^2) were 0.537, indicating that around 53.7% of the variation in PVS values could be explained by the regression model used. The distance analysis method is used to assess the level of vibration in the system. Based on the distance analysis, it is recommended to design explosive charges per hole with a certain measurement distance to achieve a PVS below 3 mm/s. Designs at distances of 500 m, 1500 m and 2000 m have been prepared with optimal fill weights to achieve the desired PVS. Ground vibration analysis is important in the fields of civil engineering and geotechnical engineering. Used to develop mitigation strategies to reduce the risk of damage due to ground vibrations. The use of Powder Factor (PF) in blasting plays an important role in regulating the amount of explosive used with efficiency. Ground vibration analysis is important in reducing the negative impact of blasting on building structures and the surrounding environment.

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