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Analysis of the Impact of ground vibration on the blast zone within a 200-meter radius based on the values of peak particle velocity and peak vector sum at CV. Handika Karya, Yogyakarta, Indonesia

Singgih Saptono[1*], *Ni Kadek Sintya Dwi* Lestari[2]

[1)]Lecturer, Mining Department, Faculty of Mineral Technology Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jl. SWK 104 (Lingkar Utara), Yogyakarta, Indonesia.
[2)]Mining Student, Mining Department, Faculty of Mineral Technology Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jl. SWK 104 (Lingkar Utara), Yogyakarta, Indonesia.

Abstract. CV. Handika Karya is a private mining company that focuses on andesite mining and operates in Hargorejo Village, Kokap, Kulon Progo Regency. To ensure the achievement of production goals, the exposure action is carried out through a blasting process. The use of the blasting method can cause a blasting effect due to ground vibrations and has the potential to cause damage to surrounding buildings. Civilians were within a 200 m radius of the explosion site. Controlling the resulting vibrations is essential to ensure the comfort of nearby civilians. The measurement location is divided into four areas considering direction, distance, elevation difference to the slope face, and the presence of buildings. After conducting research to determine the value of peak particle velocity (PPV) and the value of peak vector sum (PVS), there are incidents where the PPV value exceeds 3 mm/s and the PVS value exceeds 5 mm/s, which has exceeded the specified limits. Therefore, an updated review of seismic wave values is necessary. Data analysis was carried out using Scaled Distance Theory with the parameters of the distance from the blasting location to the measurement location and the maximum mass of explosives, using a safe limit value approach according to SNI 7571:2010. The first objective of this research is to determine the maximum amount of explosive mass that can be used for blasting while maintaining a PPV value of less than 3 mm/s within a radius of 200 m from the blasting location. After the analysis, it was discovered that the maximum mass of explosives was 83.4 kg/delay. The second objective is to determine the effect of ground vibrations at various measurement locations.

1 Introduction

CV. Handika Karya is a private mining company that specializes in andesite mining, a mineral commodity. Blasting is an excavation technique carried out by companies to achieve specified production targets by breaking rocks. The problem that arises is the distance between residential areas and the blasting location, especially within a radius of 200 m, which is relatively close. Not infrequently, the company receives reports regarding residents' dissatisfaction due to blasting activities. Therefore, it is very important to mitigate the impact of blasting effectively so as not to disturb the comfort of the surrounding community and ensure that company operations can run smoothly.

The application of an explosive approach is still needed in activities that involve empowerment. Ground vibration measurements were carried out at four locations (Figure 1), namely two sites behind the hill at different distances, which were the blasting points (LP1 & LP2), one in front of the hill (LP3), and one on the side of the hill (LP4). PPV is the value of ground vibrations in a metric used to evaluate the magnitude and severity of possible discomfort to humans and damage to surrounding structures and the environment. Scaled distance theory is an effective method for managing vibrations experimentally (Saptono, 2006). This theory allows for the calculations of the amount of material required or the safe distance required for a specific explosive. The concept of scaled distance refers to a specific technique used in vibration analysis. Logarithmic calculations are directly related to PPV when measuring vibrations at a certain

* Corresponding author: singgihsaptono1@upnyk.ac.id

distance. The data is normalized by the simultaneous detonation of a predefined quantity of explosives (Downding, 1984).

The contribution of the research is as follows: to determine the impact of ground vibrations on residential areas 200 m away and to determine the location of blasting measurements. Therefore, an analysis of the ground vibrations obtained must be carried out by paying attention to the position of the slope face and its differences, height at the measurement point, and developing a ground vibration prediction model using Scaled Distance theory and maximum explosion recommendations so that the PPV magnitude does not exceed 3 mm/s.

2 Methodology

The methodology used in this research is illustrated in Figure 1. The material Testing in this final project was conducted in several key stages, including the following: determining the research objectives, collecting theoretical basis, determining research procedures, conducting testing, and analyzing the research results. Stages The test is designed so that the research can run systematically.

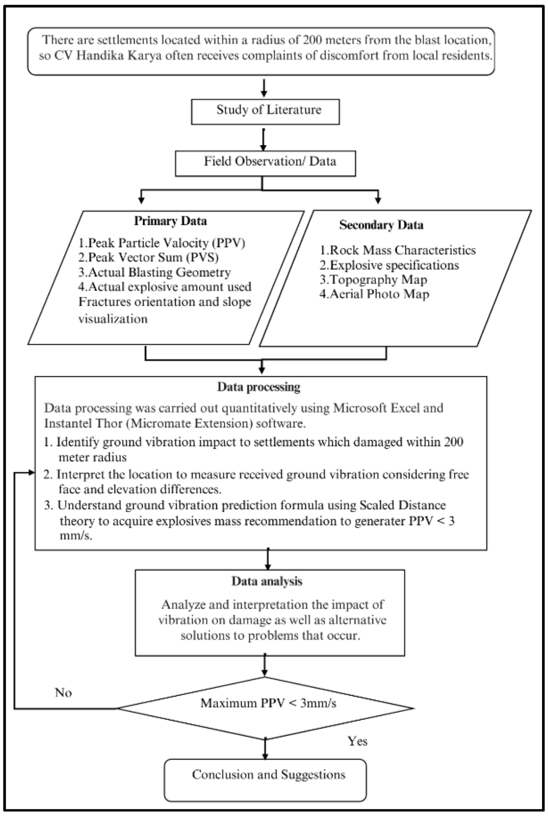

Fig. 1. Research sites for ground vibration measurement.

2.1 Field observation

The measurement location was divided into four distinct sites (Figure 2) selected based on the presence of residential buildings within a radius of 200 meters from the blasting location and the position of the slope face. Variations in these measurements were carried out to evaluate the effect of recorded vibrations on buildings at each site. Additionally, one measurement site was located behind the slope face with two variations in the horizontal distance for further assessments.

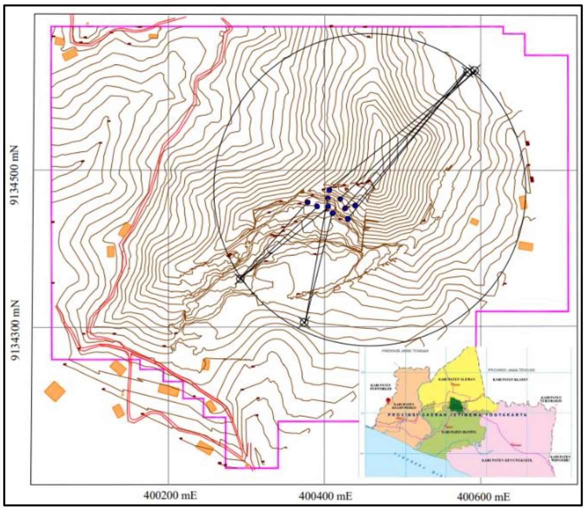

Fig. 2. Research sites for ground vibration measurement.

The Micromate Instantel instrument (Figure 3) was used to measure ground vibration. This tool comprises two channels that capture vibrations generated by blasting activities. The recorded vibrations are represented as waveforms, which consists of three wave components: transverse, vertical, and longitudinal (radial) orientations. The second channel serves to capture the air bursts generated during blasting operations. It is equipped with the following components: a Micromate monitor, a geophone, and a sound level meter.

Fig. 3. The Micromate Instantel instrument.

The Micromate captures waves by converting mechanical vibrations from blasting activities into electrical vibrations using geophone sensors. These electrical vibrations are then processed and stored as numerical data in the device's memory. This allows for direct reading of results on a monitor, typically in the form of PPV, PVS, and the peak value of each seismic wave (Figure 3). For more detailed data analysis, the Micromate can be connected to a computer equipped with Thor Software.

2.2 Data analysis – scaled distance

An effective method for objectively managing vibrations is the application of scaled distance (SD) theory (Saptono, 2006). This approach enables the determination of the number of explosives required or the safe distance for a given quantity of explosives. Logarithmic calculations are directly related to PPV when measuring vibrations at a specific distance, R (in meters). Data are normalized by the simultaneous detonation of a specific number of explosives, denoted by Q (in kilograms). Downding (1984) developed a formulation for the scaled distance theory:

$$SD = \frac{D}{\sqrt{W}} \tag{1}$$

Where: D = Distance from the blasting location to the measurement location, W = Maximum number of explosives per delay, with a tolerance of 8 milliseconds per delay, considered to explode simultaneously.

The parameters of SD theory determine the circumstances under which blasting operations should be avoided. A review of scaled distance theory is necessary if the SD value does not match operational needs. This assumes that vibration levels resulting from blasting activities are consistently within acceptable safety limits. Seismic measurements are needed to support this claim. The way to demonstrate the existence of SD is to compare PPV with SD. This involves assessing the PPV and calculating the SD value. It is important to distribute data from minimum value to maximum value. To achieve this, the data can be used to obtain a series of explosion measurements and adjust the measurement locations to obtain varying distance variables.

2.3 Data analysis – propagation law

The correlation between the weight of explosives per delay and the horizontal distance to the blasting site can be integrated and refined to form a propagation law. Research was conducted to determine the PPV value produced in an explosion. The USBM equation is commonly applied to calculate this (Simangunsong, 2009).

$$PPV = K\left[\frac{D}{W^{\alpha}}\right]^{m} \tag{2}$$

Where: PPV = Ground Vibration, measured as Peak Particle Velocity (mm/s); D = Distance from the blasting site to the measurement location; W = maximum explosive weight per delay < 8 ms (kg); K = Rock constant; a = scaling factor for propagation wave based on $SD = D/\sqrt{W}$; m = rock constant, dependent on geological condition.

2.4 Blasting vibration standards

The impact of surface blasting on buildings is assessed by measuring the PVS value. The PVS value is the resultant effect of three types of waves measured in ground vibrations. This is often referred to as the true PPV, as it can serve as a reference in estimating the velocity of ground vibration particles, as defined in the Indonesian National Standard SNI 7571:2010 (Table 1).

Table 1. PVS Standards Based on Class and Type Building according to SNI 7571: 2010.

Class	Type Building	PPV (mm/s)
1	An ancient building protected by law cultural heritage objects (law no. 6 of 1992)	2
2	Buildings with foundations, brick masonry and cement mortar only, including buildings with wooden foundations and floors given cement mortar	3
3	Buildings with foundations, brick masonry and cement mortar tied with a concrete slab	5
4	Buildings with foundations, brick masonry and concrete sloop cement mortar, columns and frames tied with ring balk	7 – 20
5	Buildings with foundations, brick masonry and cement mortar concrete slab, column and tied with steel frame	12 – 40

Meanwhile, Indonesia has established standard criteria for the impact of ground vibration on structural damage based on the Ministerial decree of the Ministry of Environment, No. 49/Men LH/11/1996. Regarding ground vibration level quality standards, refer to Table 2.

Table 2. Standard Ground Vibration Level according to Minis Decree No. 49/Men/11/1996.

Class	Type Building	PVS (mm/s)
1	The preservation of historical and ancient structures means inheriting their significant historical value.	2
2	There is a crack in the wall of the building, which has already been damaged.	5
3	The building is in decent shape overall, with minor deterioration such as cracked cement.	10

3 Result

3.1 Categories of structures

There are various types of buildings located around the mine site of CV. Handika Karya, each possessing unique characteristics. A building is situated at each location, specifically at the rear observation location, Khayangan Hill (LP1 & LP2). The construction features a sturdy foundation made of masonry, while the walls of the building are plastered using mortar. Additionally, the building incorporates a concrete slab for added stability. The building located in LP1 and LP2 is classified as a Class 3 building according to the standard SNI 7571:2010 (Figure 4), which relates to the standard blasting vibration level for open pit mining activities near buildings.

LP1 Building	Building Structure
	1. Building with foundation 2. Brick 3. Cement mix 4. Concrete slope
Building Classification	3

LP2 Building	Building Structure
	1. Building with foundation 2. Brick 3. Cement mix 4. Concrete slope
Building Classification	3

Fig. 4. Building Characteristics at LP1&LP2.

The building is located on the premises adjacent to Khayangan Hill (LP3&LP4), and has a solid foundation. Measurements were taken at the front and side of the hill. The construction of the building involves the use of various materials, such as wood, brick, and plastered walls made with mortar. However, some buildings do not use plaster. Additionally, the floor is constructed using mortar. This type of construction is classified as a Class 2 building according to the standard SNI 7571:2010 (Figure 5). Residents around the mining site expressed discomfort and fear over the potential damage to their homes due to the blasting activities conducted by CV. Handika Karya. Usually, the company receives these complaints from residents living behind the slope surface. This prompted a decision to conduct vibration measurements at that location (Figure 6) to assess the impact of vibration on building damage.

LP3 Building	Building Structure
	1. Building with foundation 2. Brick 3. Cement mix 4. The Floor Uses Cement mortar
Building Classification	2

LP4 Building	Building Structure
	1. Building with foundation 2. Brick 3. Cement mix 4. The Floor Uses Cement mortar
Building Classification	2

Fig. 5. Building Characteristics at LP3&LP4.

Fig. 6. Ground vibration measurement point.

3.2 Results of ground vibration measurement

Ground vibration measurements will be conducted from March 5, 2024, to May 6, 2024. The magnitude of the recorded vibrations ranges from 0.326 mm/s to 3.689 mm/s. A total of 12 data points were collected from the measurements at LP1 and LP2. The usage statistics indicate that the average quantity of explosives per delay is 64.37 kg, with an average distance of 188 meters. The average Peak Vector Sum (PVS) recorded is 3.599 mm/s in LP1 and LP2, as shown in Table 3. The maximum allowable PVS value based on SNI 7571:2010 for LP1 and LP2 for Class 3 buildings are 5 mm/s.

Upon analyzing the vibration blasting outcomes in LP1 and LP2, it was observed that the PVS findings exceeded the anticipated threshold of 5.148 mm/s (over 5 mm/s). In addition, some PVS results in 5 mm/s, with one specifically measuring 4.162 mm/s. These findings at the LP1 and LP2 locations demonstrate that the blasting activity has a noticeable impact. A total of 5 data points were collected from the ground vibration measurement activities at LP3. The mean quantity of explosives used per delay was 68.38 kilograms, with an average distance of 184 meters. The average Peak Vector Sum (PVS) recorded in LP3 was 0.513 mm/s, as shown in Table 4. According to SNI 7571:2010, the maximum allowable PVS for Class 2 buildings is 3 mm/s.

Table 3. The PVS measurement data acquired from LP1 and LP2.

Date	Location	PVS on site (mm/s)	PVS max (mm/s) SNI 7571:2010
5/3/2024	LP1	3.140	5
5/3/2024	LP1	3.160	5
8/3/2024	LP1	3.810	5
8/3/2024	LP1	5.174	5
15/3/2024	LP2	4.125	5
25/3/2024	LP2	3.591	5
25/3/2024	LP2	2.689	5
25/3/2024	LP2	1.534	5
29/3/2024	LP1	4.743	5
29/3/2024	LP1	3.288	5
29/3/2024	LP1	3.301	5
29/3/2024	LP1	4.629	5

Table 4. The PVS measurement data acquired from LP3.

Date	Location	PVS on site (mm/s)	PVS max (mm/s) SNI 7571:2010
22/3/2024	LP3	0.537	3
22/3/2024	LP3	0.443	3
24/3/2024	LP3	0.547	3
24/3/2024	LP3	0.351	3
24/3/2024	LP3	0.688	3

During the ground vibration observations at LP3 locations, no Peak Vector Sum (PVS) exceeded the specified threshold of 3 mm/s. Therefore, it can be concluded that blasting activities did not cause any disturbance at this observation point. Ground vibration measurements were conducted in LP4 at 7 locations. The mean quantity of explosives used per delay is 74.4 kg, with an average distance of 200 meters. The average Peak Vector Sum (PVS) produced in LP4 is 0.606 mm/s, as shown in Table 5. According to SNI 7571:2010, the maximum allowable PVS for Class 2 buildings in LP4 is 3 mm/s.

Table 5. The PVS measurement data acquired from LP4.

Date	Location	PVS on site (mm/s)	PVS max (mm/s) SNI 7571:2010
29/4/2024	LP4	0.537	3
29/4/2024	LP4	0.543	3
2/5/2024	LP4	0.547	3
2/5/2024	LP4	0.567	3

4 Discussion

4.1 Analysis of data from ground vibration measurements

When examining damage to structures near mining sites caused by blasting-induced ground vibrations, it is more effective to focus on ground vibration velocity (Peak Particle Velocity) rather than using methodologies that consider acceleration or displacement. The Micromate measures three types of PPV: transverse, vertical, and longitudinal. Among these, vertical waves or surface waves, especially Rayleigh waves, have the most significant influence on building damage. Surface waves can cause major disturbances along the surface. However, the measurement findings show that the PPV for vertical waves iss the lowest compared to the PPV of other types of waves.

In Ref. [10], it is noted that surface waves usually have the lowest propagation speed and the highest amplitude, which leads to the highest shear strain and, consequently, the greatest stress on buildings. Rayleigh favored surface waves involves the movement of particles in horizontal and vertical directions, which have the same order of magnitude. However, the horizontal components are more frequent and generally impose the highest maximum tensile strain. The order of typical ground vibration (PPV) values from largest to smallest from the measurement results is as follows: longitudinal waves, transverse waves, and finally vertical waves (Rayleigh waves). Therefore, the PVS method was adopted, and the parameters used in SNI 7571:2010 included both the PVS value and building classification. According to SNI Standard 7571:2010, the permissible level of ground vibration due to blasting operations in residential buildings in LP 1 & 2 (Class 3 Buildings) is PVS of 5 mm/s. For LP 3 & 4 (Class 2 Buildings), the permitted PVS is 3 mm/s. Based on the results of ground vibration measurements results, the PVS magnitude for LP3 & LP4 remains below 3 mm/s, which is within the standards set by SNI. Therefore, ground vibrations in these locations do not pose a riskl to damaging the buildings. Measurements on LP1 show a PVS value of 5.174 mm/s at a frequency of 54 Hz. According to SNI regulations, vibrations with a frequency of up to 54 Hz have the potential to cause building damage if the PPV value reaches 15 mm/s. However, the recorded PVS of 5.174 mm/s in LP1 (Figure 7) is still below this threshold and does not pose a risk of damage to residents' property.

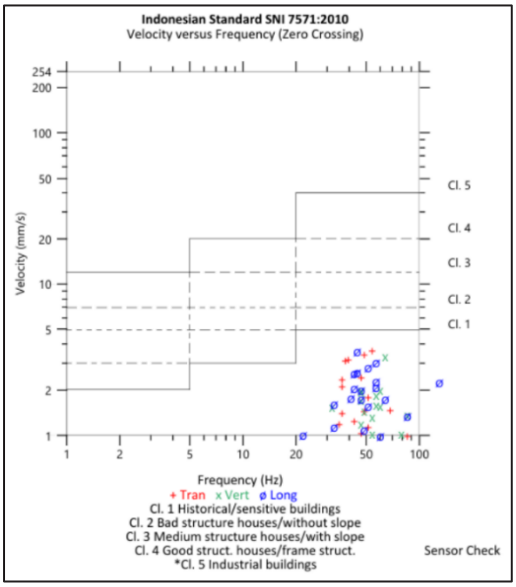

Fig 7. The graph depicts the PPV magnitude and the standard vibration level caused by blasting in open-pit mines, in relation to nearby structures, from Micromate Instantel Instrument.

4.2 Analysis of the effect of the position of the measurement location with the slope face on the PPV magnitude

Measurements were conducted at four distinct locations, considering their positions relative to various slope faces. This analysis provided a summary of data regarding the average use of explosives, average distance, and average Peak Particle Velocity (PPV) values. The results are presented in Table 6.

Table 6. Summary of comprehensive Positive Predictive Value (PPV) measurement data.

Location	Q average (kg)	Distance (m)	PPV average (mm/s)
LP1 & LP2	64.37	188	2.55
LP3	68.38	184	0.42
LP4	74.40	200	0.56

According to Ref. [18], on the near side of the explosion source, the reflected waves are clearly visible due to the free adjacent tunnel wall surfaces, resulting in strong reinforcement of PPV. Meanwhile, on the far side of the tunnel, away from the explosion source, the PPV, reinforced by reflected waves, shows a weakening trend. However, these findings contradict the actual field observations. Various factors in the field can influence the intensity of vibrations caused by blasting activities. The research revealed that the measurement location on the slope surface has a significant influence. The PPV value is higher at positions LP1 and LP2, which are located behind the slope surface, compared to LP3 (in front of the slope) and LP4 (next to the slope), even though they share the same horizontal distance. In addition, further analysis revealed that height differences are a variable that can influence the PPV value received for each position (Figure 8). Based on Figure 9, the PPV magnitude is influenced by variations in height between the blasting location and the measurement position, giving rise to vertical waves. These waves tend to be stronger when the height difference is smaller. If a linear equation is applied, the following condition will emerge: the difference in height can only determine the ratio of the vertical wave magnitude received. However, the geological layering structure at each location remains a limiting factor in this research. m/kg$^{0.5}$.

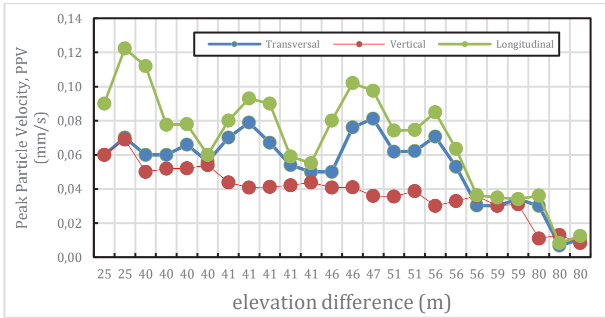

Fig 8. The correlation between variation in elevation difference and wave reception.

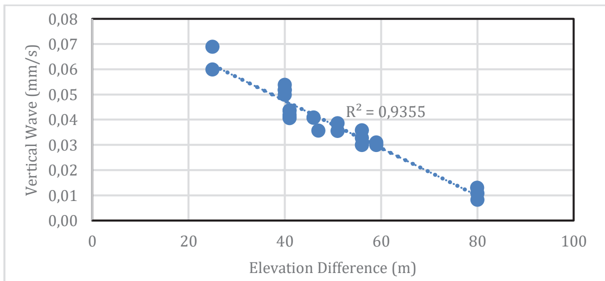

Fig 9. The correlation between variation in elevation and the reception of vertical waves.

4.3 Analysis of PPV using SD

The amount of explosives used during field observations ranged from 27.3 kg to 95.7 kg, while the measurement distance fluctuated between 184 m and 200 m. The scaled distance value can be determined by knowing the exact number of explosives and the distance to the blasting site. The scaled distance values at each location varied from 27 m/kg$^{0.5}$ to 88 m/kg$^{0.5}$, with peak particle velocities (PPV) ranging from 0.718 to 3.689 for locations LP1 and LP2. At the LP3 location, the amount of explosives used ranged from 57 kg to 89 kg, while the Peak Particle Velocity

(PPV) varied between 0.326 mm/s and 0.528 mm/s. At observation point LP4, the amount of explosives used varied between 55 kg and 74 kg, resulting in a peak particle velocity (PPV) ranging from 0.510 mm/s to 0.567 mm/s. Based on the Scaled Distance (SD) calculation, the values for the four measurement locations ranged from 19.44 m/kg$^{0.5}$ to 37.47 m/kg$^{0.5}$, indicating their close proximity. Ground vibration measurements show variations in measurement data even when the scaled distance is similar. For example, at a scaled distance of 22 m/kg$^{0.5}$, the recorded vibrations were 2.7 mm/s, 0.4 mm/s, and 0.5 mm/s. This difference is believed to be caused by a lack of rock homogeneity. The scaled distance data were examined using power regression to determine the PPV, as shown in Figure 10. Regression analysis was performed separately at each location because a single analysis would not be representative due to the heterogeneity of the rocks. The tabulated data are presented in Figure 7. It is important to pay attention to the variations in geological conditions at each location.

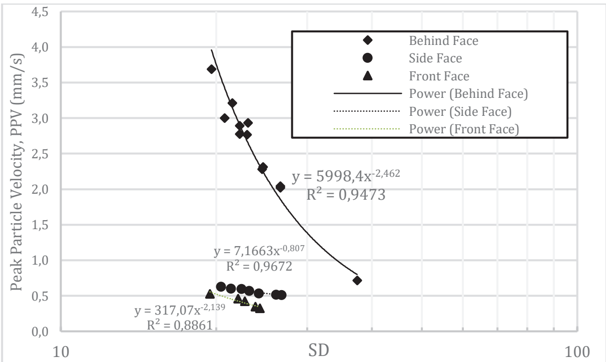

Fig 10. The relationship between the scaled distance and the peak particle velocity relative to the slope face position.

After analyzing the influence of the measurement position on the slope surface, it was discovered that the PPV values at LP1 and LP2 were relatively higher compared to the other two locations. Therefore, a power regression equation was used to determine the maximum recommended amount of explosive per delay that would result in a PPV of less than 3 mm/s. The power regression analysis revealed a correlation between SD and PPV. Specifically, as the scaled distance value increases, the ground vibration decreases, and vice versa (Figure 9). The equation yields the location factors K and b, which are determined based on the concept of scale distance. Specifically, K was found to be 5998.4 and b was -2.5. To achieve a PPV of 3 mm/s or less at a distance of 200 m, the maximum mass of explosives per delay was calculated to be 83.4 kg. It is crucial for companies to limit the use of explosives per delay to minimize the risk of exceeding safe PPV levels in the future.

5 Conclusion

Based on the SNI 7571:2010 standard, the results of the ground vibration measurement study show that the PVS values at LP2, LP3 and LP4 are below the safe threshold for each building class category at their respective locations. However, LP1 exhibits a PVS value that exceeds the safe threshold if the frequency is not considered. To address this, it is necessary to redesign the blasting procedures by limiting the amount of explosives to a maximum of 83.4 kg per delay and conducting regular vibration monitoring to ensure the blasting effect remains within safe limits. This approach is an effective measure to mitigate the impact of blasting considering the limited information available regarding geological conditions at the measurement location.

Additionally, the transmission of ground vibration waves is influenced by the position of the measurement location on the slope surface and the height difference between the blasting and the measurement locations. These variables have a significant influence on vertical waves, with smaller height differences resulting in larger vertical waves.

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