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Analysis of Ground Vibration Levels Due to the Blasting Process at PT. Bumi Suksesindo

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Abstract

Ground vibration is one of the effects of the blasting process; when the ground vibration reaches the highest level, it will disturb comfort and even cause damage to the surrounding building structure. This research aims to determine the magnitude of ground vibrations in Pit A and Pit C, as well as determine the relationship between Peak Particle Velocity (PPV) and scaled Distance, and determine the maximum explosive charge weight per delay based on the SNI 7571: 2010 reference. Actual ground vibration measurement data during research based on PPV theory and the actual PPV power regression relationship with scaled distance was used to obtain a ground vibration prediction formula to be a reference for determining the amount of explosive filling per delay. The ground vibration produced in the blasting process is hoped not to exceed the safe threshold. Prediction of the ground vibration formula at 100 m to 1500 m according to the US Bureau of Mines where the Mean Squared Error (MSE) value is 0.54, the MSE value from the Langefors-Kihlstrom equation is 1.85 while the MSE value from the Ambersays-Hendorn equation is 0.31 with the slightest deviation is very good to use as a reference for predicting ground vibrations with the predicted PPV formula. Hence, the maximum explosive charge with a PPV limit of 2 mm/s is 2.452 kg, a PPV limit of 3 mm/s is 11.332 kg, and a PPV limit of 5 mm/s is 23.040 kg. The factors that influence ground vibration are the Distance from the blasting location to the measurement location and the maximum number of explosives per delay, so the results taken from this research are that blasting in Pit A and Pit C is still categorized as safe for infrastructure and community housing.

Keywords: Blasting Ground Vibration; Scaled Distance (SD); Peak Particle Velocity (PPV); Power Regression.

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Introduction

PT Bumi Suksesindo (BSI) implemented an open-pit mining system (surface mining) using the open-pit mining method. Gold and copper mining activities consist of unloading, loading, and transportation. One of PT Bumi Suksesindo's activities is rock demolition using drilling and blasting methods.

The blasting process in mining activities destroys rock and propagates seismic waves on the earth's surface, which can cause vibrations in the rock mass or surrounding material (Bui et al., 2021). The vibration level in a blast varies depending on the blast design used (Roy et al., 2016).

Ground vibration at a certain level, if it exceeds the threshold, can cause damage to the surrounding environment (Yin et al., 2018). Pit A and Pit C are active pits at BSI is located close to residential areas and temples, which are places of worship for Hindus. The Distance from Pit A and Pit C to residential areas and temples is 1,300 meters. Because the distance is close, more attention must be paid to the effects on the environment from blasting activities so that they do not disturb the comfort and safety of the community (Fadhly et al., 2014; Halimah & Octova, 2018; Himanshu et al., 2018).

This research aims to determine the amount of ground vibration produced by each blast in Pit A and Pit C BSI and its impact on infrastructure and settlements in the surrounding community. The research also aims to determine the relationship between Peak Particle Velocity (PPV) and Scaled Distance (SD) and determine the maximum explosive charge weight with a safe distance in blasting activities based on the SNI 7571: 2010 reference (Ma'rief et al., 2020a). Research to reduce the impact of vibrations has also been carried out at PT Bukit Asam. This research concludes that the PPV value is <3 mm/s with a measurement distance of 1000 meters from the employee housing location, stuffing is needed (Tohirin et al., 2022).

Research Methods

Primary data consists of the mass of the blast hole filling, blasting geometry, field coordinates, distance from the blast source to the recording device, and ground vibrations. Blasting geometry consists of Burden (B), spacing (S), hole diameter (D), and hole height (H). Meanwhile, secondary data includes explosives, reference blasting standards, and patterns. Ground vibration measurements were carried out using the Blastmate III tool, with an accuracy of 0.5 mm/s (Instantel, 2020). Field data collection is in the form of actual field wave velocity or Peak Particle Sum (PVS) (Lawal & Kwon, 2021). PVS is the sum of the peak wave velocities in vertical (V), longitudinal (L), and transverse (T) waves, obtained using Equation 1.

$$PVS = (V^2 + L^2 + T^2)^{0,5} \qquad (1)$$

Research Sites

This research was conducted at BSI in Sumberagung Village, Pesanggaran District, Banyuwangi Regency, East Java Province (Figure 1). The main activity is BSI focuses on the gold and copper production business unit at Tujuh Bukit Operation, better known as Tumpang Pitu. It has a Production Operation Mining Business Permit covering an area of 4,998 ha.

Explosion Concept

The blasting method aims to dismantle or separate a rock from its parent rock. In dispersing rock using the drilling and blasting method, the rock fragmentation resulting from blasting is a significant factor, where the rock fragmentation size is expected to follow the needs of subsequent mining activities (Roy, 2021). A blasting operation is declared successful in mining activities if the production target is met (Nateghi, 2012; Putra, 2023). The use of explosives is efficient, which is expressed in the amount of rock that is successfully dismantled per kilogram of explosives called (powder factor); evenly sized fragmentation is obtained with a few chunks less than 15% of the Number of rocks exposed per blast (Herdy et al., 2015; Moomivand & Vandyousefi, 2020).

Ground Vibration

Blasting activities can cause several risks; there are three types of damage can be caused by blasting: ground vibrations, fly rock, and air blast or sound (Nuñez et al., 2022). Ground vibrations are particle movements that occur due to the propagation of seismic waves. When detonation occurs, the residual energy will produce seismic waves, which cause movement in the ground. The movement in the ground affects the rock mass and propagates in the form of compressive waves (Nguyen et al., 2020). When the magnitude of the compressive wave is greater than the tensile strength of the rock, it will cause a crushed zone (Ma'rief et al., 2020b).

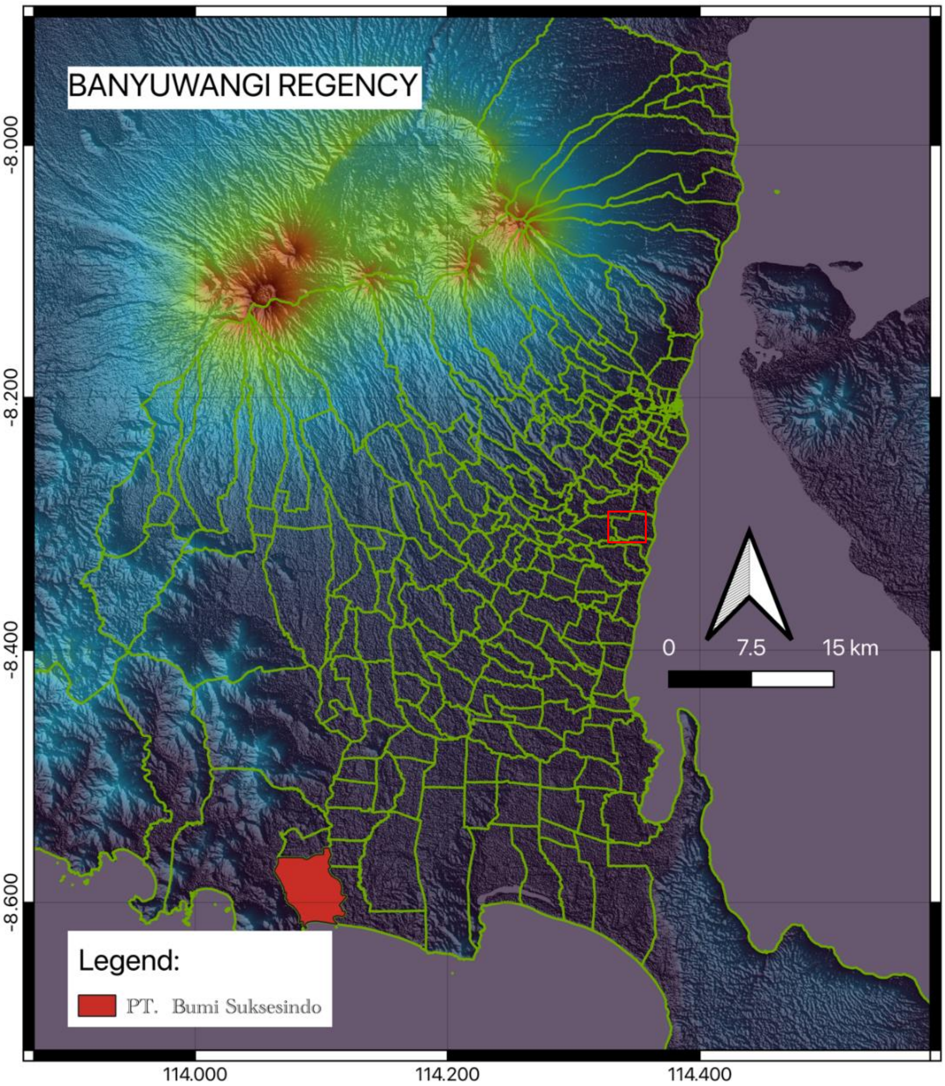

Figure 1. Research location on red square.

Seismic waves are elastic waves that propagate on the earth's surface, representing energy transmission due to explosions. Seismic waves are divided into two large classes: Body and Surface (Kumar & Mishra, 2020). In blasting activities, the rock response to compressive waves is the formation of two body waves and one surface wave (Nuñez et al., 2022). The body waves formed are Primary Waves (P-waves) and Secondary Waves (S-waves). P-waves have a more incredible speed than S-waves. Meanwhile, the surface waves formed are Rayleigh waves (R-wave) (Amiri et al., 2020). Rayleigh waves have a smaller velocity than both body waves.

Peak Particle Velocity (PPV)

Several researchers have conducted investigations and put forth various conventional vibration predictors to predict PPV. These predictors are outlined and summarized in Table 1.

Table 1. The conventional formula used for predicting PPV.

Name	Formula
United State Bureau of Mines (Duvall and Petkof, 1959)	$PPV = K\left[\frac{D}{\sqrt{Q_{max}}}\right]^{-B}$
Langefors – Kihlstrom (Langefors and Kihlstrom, 1963)	$PPV = K\left[\sqrt{\left(\frac{Q_{max}}{D^{2/3}}\right)}\right]^{-B}$
Ambraseys – Hendron (Ambraseys and Hendron, 1968)	$PPV = K\left[\frac{D}{{Q_{max}}^{1/3}}\right]^{-B}$

Table 1 is a compilation of standard vibration prediction equations proposed by a range of scholars, scientists, researchers, and field engineers. The equation for calculating PPV was established by the United States Bureau of Mines (USBM) as follows:

$$PPV = K\left[\sqrt{\frac{D}{Q_{max}}}\right]^{-B} \text{ or } PPV = K[SD]^{-B} \quad (2)$$

Where PPV is the Peak Particle Velocity, SD is the scaled distance, and K and B are site constants. The site constants K and B were determined by plotting graph between PPV and different SD. The general equation of straight line is

$$y = mx + C \quad (3)$$

This implies that the PPV and SD data should demonstrate a linear relationship when plotted on a logarithmic scale graph paper. consequently, y = PPV, x = SD, intercept C = k, and slope −B = m.

Results and Discussion

Blasting activities were carried out using an Epiroc PowerROC T-50 drill using the rotary percussive method. The diameter of the blast hole varies depending on the location to be blasted (Supratman et al., 2017; Moomivand & Vandyousefi, 2020). The diameters used is 115 mm with a staggered drilling pattern. Data of geometry of blasting shown in Table 2 below.

Table 2. Actual blasting geometry.

Location	**n**	**B (m)**	**S (m)**	**D (m)**	***Stemming* (m)**	**PC (m)**
Pit A	567	3.25	3.18	8.41	2.5	5.91
Pit A	752	3.19	3.63	8.26	2.5	5.76
Pit A	351	2.80	3.40	8.39	2.5	5.89
Pit A	345	3.32	3.90	8.69	2.5	6.19
Pit C	584	3.38	3.90	8.22	2.5	5.72
Pit A	495	2.90	3.49	7.94	2.5	5.44
Pit A	922	2.56	3.15	8.44	2.5	5.94
Pit A	1098	3.39	3.55	8.56	2.5	6.06
Pit A	948	3.56	4.27	8.36	2.5	5.86
Pit C	466	3.56	3.69	8.41	2.5	5.91

Where n is number of holes, B is burden, S is Spacing, D is depth.

Ground Vibration Measurement

Ground vibration measurements in the field aim to determine PPV due to blasting. Ten measurements of ground vibrations from Pit A and Pit C blasting were carried out using a micromate with a measurement location inside the mine. Data ground vibration shown in Table 3 below.

Table 3 Actual ground vibration measurement results.

No	PPV (mm/s)			PVS (mm/s)	Distance (m)	Explosives (kg)
	Transverse	Vertical	Longitudinal			
1	1.09	1.06	1.04	1.3	547	29567
2	1.94	0.90	1.88	2.0	644	58552
3	1.33	1.33	1.40	1.6	584	21793
4	1.79	1.47	2.10	2.5	515	21794
5	0.54	0.52	1.26	1.3	787	38507
6	1.92	0.59	1.03	1.9	505	29478
7	1.14	0.65	0.95	1.5	678	51922
8	1.21	0.69	1.55	1.6	767	67218
9	1.58	1.03	1.10	1.8	624	46497
10	7.77	6.98	11.60	12.9	193	17240

Vibration standards resulting from blasting applied by BSI is by SNI Standard 7571:2010. PPV data obtained from ground vibration measurements and SD calculation results were then carried out power regression analysis from the USBM (US Bureau of Mines) equation, the Ambersay – Hendorn (AH) equation, and the Lagefors – equation. Kihlstrom (LK), to obtain a similar relationship between peak particle velocity (PPV) and scaled Distance (SD) (Yilmaz, 2023).

The results of the power regression analysis will obtain the constant values K and n, which are site factors, and the coefficient of determination (R^2), which measures the strength of the relationship between variables (Jalbout & Simser, 2014; Rusmawarni et al., 2017; Rezaeineshat et al., 2020).

In Table 4 below are the results of scaled distance calculations during field research according to the USBM equation, which regresses Power with actual PPV to get the predicted PPV formula, which is PPV= $8024{,}6 \times (SD)^{-2{,}671}$.

Table 4. Calculation of USBM scaled distance values.

No	Distance (m)	Product Charger per Delay (kg)	Scale Distance ($m^{½}/kg^{¾}$)	PPV measured (mm/s)	PPV Predicted (mm/s)
1	547	536	23.62	1,307	1.72
2	644	761	23.34	2,042	1.78
3	584	551	24.86	1,554	1.50
4	515	740	18.92	2,453	3.12
5	787	742	28.89	1,297	1.01
6	505	475	23.15	1,983	1.82
7	678	876	22.91	1,496	1.87
8	767	905	25.49	1,586	1.41
9	624	773	22.44	1,828	1.98
10	193	264	11.87	12.93	10.83

Table 5. Calculation of Ambersay – Hendorn Distance scale values.

No	Distance (m)	Product Charger per Delay (kg)	Scale Distance ($m^{½}/kg^{¾}$)	PPV measured (mm/s)	PPV Predicted (mm/s)
1	547	536	83.01	1,307	1.91
2	644	761	87.98	2,042	1.68
3	584	551	87.85	1,554	1.69
4	515	740	70.92	2,453	2.68
5	787	742	108.35	1,297	1.07
6	505	475	79.42	1,983	2.10
7	678	876	88.81	1,496	1.65
8	767	905	99.46	1,586	1.29
9	624	773	84.86	1,828	1.82
10	193	264	36.22	12,93	11.40

Figure 4 explains that comparing the PPV predicted and PPV measured, the coefficient of determination (R^2) is 0.9857. This value states that the strength of the relationship in the variable value obtained using the USBM equation is 98%.

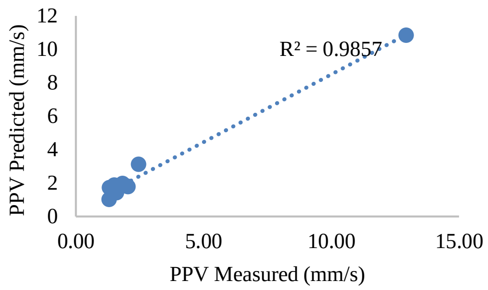

Figure 4 Comparison graph of predicted PPV and actual PPV of USBM.

In Table 5 above are the results of scaled distance calculations during field research according to the equation Ambersay – Hendorn (AH), which is regressed by Power with the actual PPV to get the predicted PPV formula, which is PPV.= $26184 \times (SD)^{-2.156}$.

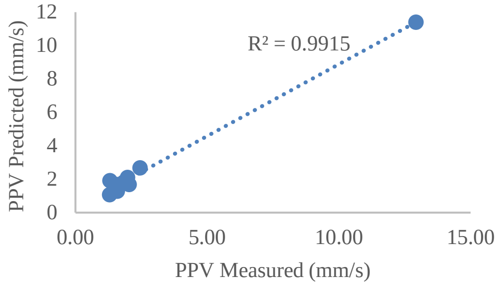

Figure 5 Comparison Chart of Actual PPV and Predicted PPV Ambersay – Hendorn

Figure 5 above explains where the comparison graph of predicted PPV (AH) and actual PPV gets a coefficient of determination value (R^2) is 0.9916. This value states that the strength of the relationship in the variable values obtained using the Ambersay – Hendorn (AH) equation is robust, with a value of 99%.

In Table 6 below are the results of scaled distance calculations during field research according to the Lagefors – Kiehlstrom equation (LK), which is regressed on Power with the actual PPV to get the predicted PPV formula, which is PPV= $1029{,}7 \times (SD)^{-4{,}1}$.

Table 6 Calculation of Lagefors – Kiehlstrom distance scale values.

No	Distance (m)	Product Charger per Delay (kg)	Scale Distance ($m^{1/2}/kg^{3/4}$)	PPV measured (mm/s)	PPV Predicted (mm/s)
1	547	536	4.89	1.31	1.54
2	644	761	4.63	2.04	1.92
3	584	551	5.06	1.55	1.34
4	515	740	3.97	2.45	3.60
5	787	742	5.46	1.30	0.98
6	505	475	4.88	1.98	1.54
7	678	876	4.49	1.50	2.18
8	767	905	4.84	1.59	1.60
9	624	773	4.49	1.83	2.18
10	193	264	3.18	12.93	8.91

Figure 6 below explains where the comparison graph of predicted PPV Lagefors – Kiehlstrom (LK) and actual PPV gets a coefficient of determination value (R^2) is 0.9441. This value states that the strength of the relationship in the variable values obtained using the LK equation is strong, with a value of 94%.

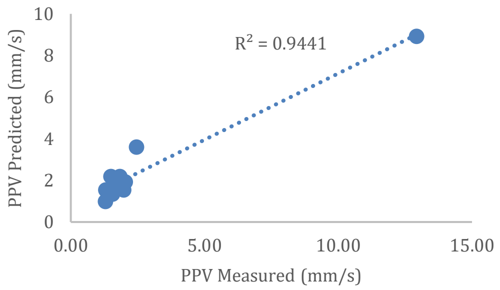

Figure 6 Comparison Chart of Predicted PPV and Actual PPV Lagefors – Kiehlstrom.

From the calculation of the predicted peak particle velocity value based on the equation (USBM, Ambersays-Hendorn, and Langefors-Kiehlstrom), the average Mean Squared Error value compared to the actual (Jianhua et al., 2022). The peak particle velocity deviation value from the actual PPV is obtained, namely using the USBM theory with an MSE value of 0.54, the MSE value from the Ambersays-Hendorn (AH) equation is 0.31, and the MSE value from the Langefors-Kiehlstrom equation (LK) which is 1.85.

The conclusion is that the Ambersays-Hendorn, with an MSE value of 0.31 from the actual, which gives the slightest deviation, is more appropriate for determining PPV predictions based on deviations from the actual PPV (Duvall & Petkof, 1959; Nateghi, 2012). Research on Ground Vibration Levels in Bedrock Blasting Operations in Sorowako East and West Areas of Pt Vale Indonesia Tbk, Sorowako, Nuha District, East Luwu Regency, South Sulawesi Province also shows that the coefficient of determination of Ambersays-Hendorn. The largest compared to USBM and LK is 0.7027 (Yudha et al., 2022).

Recommended Maximum Explosive Charge per Delay

Recommendations for the maximum explosive charge per delay are made because of the BSI blasting location is very close to residential areas, so the effects of ground vibrations resulting from blasting activities need to reach a threshold that could damage buildings belonging to communities around the mine. The location of blasting and residential areas shows in Figure 7 below.

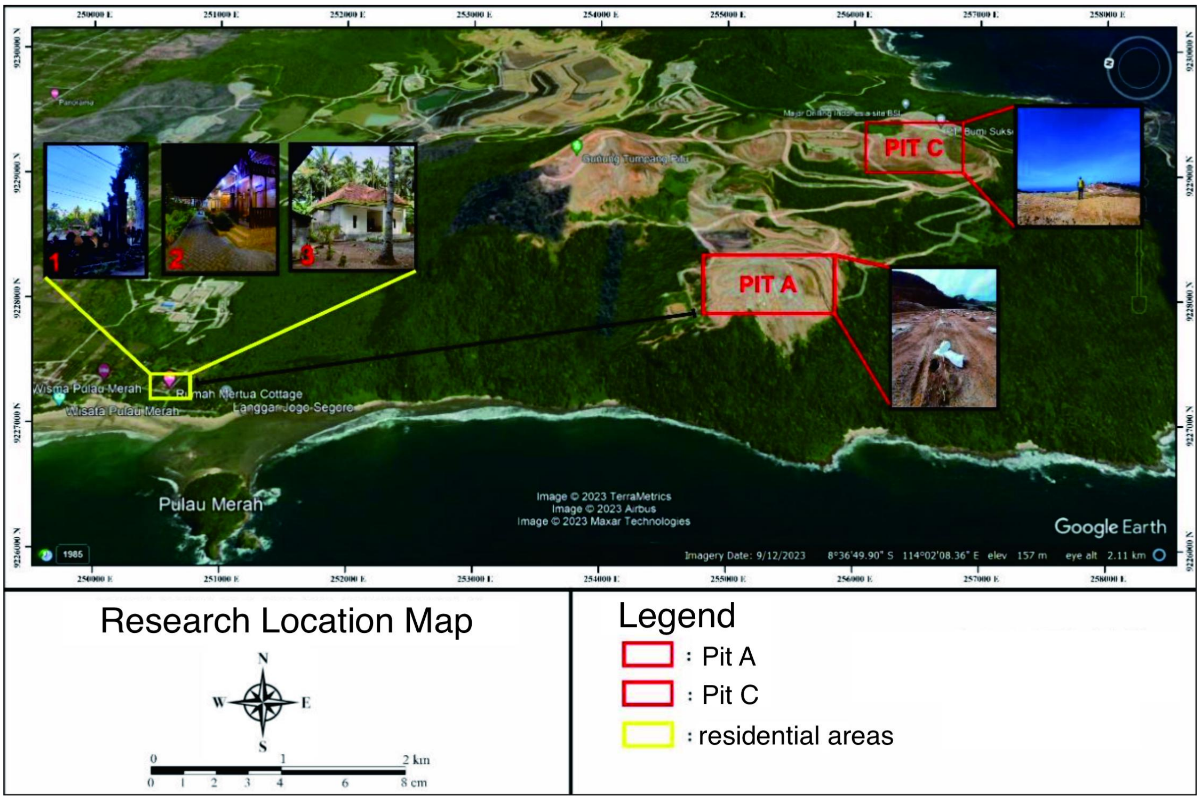

Figure 7. Location of blasting and residential areas.

Table 8 Analysis of the Biggest Explosion Effects on Residential Settlements

PPV Limit	Measured		Prediction	
	Distance (m)	Explosives (Kg)	Distance (m)	Explosives (Kg)
2 mm/s	193	17.240	193	13.745
3 mm/s				24.140
5 mm/s				49.078
12.93 mm/s				183.667

To maximize the blasting process to increase BSI recommended maximum explosive filling per delay from 100 m – 1500 m with a predicted PPV of 2 mm/s, 3 mm/s, and 5 mm/s according to the reference standard SNI 7571: 2010. The equation used to predict the filling explosives per delay, which is the PPV predicted by the Ambersays-Hendorn theory, is described as follows:

$$\text{PPV predictions} = 26184 \times \left(\frac{R}{Q^{1/3}}\right)^{-2.156} \quad (5)$$

The most significant vibration level analysis can be seen in Table 8, which explains the effect of blasting on residential areas. The results obtained are not by measurements in the field because predictably, at 193 m with a PPV limit of 2 mm/s, there are 13.745 kg of explosives, a PPV of 3 mm /s, as much as 24.140 kg of explosives, PPV 5 mm/s as much as 49.078 kg, and PPV 12.93 mm/s as much as 183.667 kg.

Predictively, at the same distance of 193 m with a PPV of 12.93 mm/s, the actual number of explosives is still relatively small, which is 17.240 kg compared to the predicted number of explosives of 183,667 kg. The conclusion obtained from this analysis of the most considerable vibration levels is that the closer the measurements are made in the field, the greater the PPV value obtained, and the farther distance between the vibration measurements carried out in the field, the smaller the PPV level.

Conclusion

The results of ground vibrations during blasting in Pit A, which were carried out 8 times, and the results of ground vibrations during blasting in Pit C, which was carried out 2 times, there was one blast that exceeded the vibration threshold set by PT. Bumi Suksesindo, on April 30, 2023, blasting occurred in Pit C with the most significant ground vibration, which is 12.93 mm/s at a measuring distance of 193 m with actual explosive material of 17,240 kg. However, in analysis, the number of explosives used at the same distance of 193 m with a PPV of 12.93 mm/s, the actual number of explosives is still relatively small compared to the predicted number of explosives with the Amount of 183,667 kg. Therefore, the conclusion that can be drawn is that blasting in Pit A and Pit C is still categorized as safe for infrastructure and community settlements. Factors that influence ground vibration in the field are the distance from the blasting location to the measurement location and the maximum number of explosives per delay. The peak particle velocity deviation using the Ambersays-Hendorn theory gets the smallest deviation value, which is 0.31, so the Ambersays-Hendorn theory is more appropriate for determining the maximum number of explosives at a safe distance during detonation. With the PPV prediction formula= $26184(SD)^{-2,156}$.

The recommended charge/ delay with a PPV value of 2 mm/s during the research is at 100 meters, a maximum charge/delay of 1.912 kg, at a distance of 200 meters, a maximum charge/delay of 15.296 kg, at a distance of 300 meters, a maximum charge/delay of 51.623 kg, at a distance of 400 meters, a maximum charge/delay of 122.365 kg, at a distance of 500 meters, a maximum charge/delay of 238.995 kg, at a distance of 600 meters, a maximum charge/delay of 412.983 kg, at a distance of 700 meters, a maximum charge/ delay of 655.802 kg.

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Author Contribution

During the development of this research journal, multiple authors made contributions to various aspects. Nofry Hence Tarumasely was responsible for data processing and library resources, while Novandri Kusuma Wardana contributed to journal compilation. Additionally, Rizqi Prastowo served as an observer and supervisor in the compilation of this journal.

Conflict of Interest

This study did not involve any funds or finances issued between the authors or the parties engaged in the investigation. for the author to comply with the regulations outlined in the Jurnal Geocelebes.

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