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Measurement of vibrations due to blasting in angouran surface and underground mine on the stability of underground Spaces

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ABSTRACT

The effect of blast-induced ground vibrations on mines and on adjacent structures and facilities is an example of the adverse consequences of the mining cycle. In order to control the vibrations, and also, manage the adverse effects, the measurement and modeling of the concerned wave attenuation are necessary. Usually, by implementing several trial blasts and analyzing corresponding ground vibrations, we can determine the related attenuation model for different sites and mines. The purpose of this research is the measurement of vibration due to blasting in Angouran surface and underground mines on the stability of underground spaced. In this research, blast-induced ground vibrations obtained from the Angouran surface and underground mines are closely examined. In the first phase, the peak particle velocity (PPV) is estimated based on the maximum charge amount per delay (Q) and the distance (R). Therefore, the stability of underground mines in relation to monitoring using common blast patterns in the Angouran open-pit mine (with a diameter of 127 mm, a burden of 4.2 m, and a spacing of 5 m) has been measured using four seismographs. The results indicate that the maximum ground vibrations resulting from open-pit blasting at the underground mine exceed the permissible vibration standards. The vibration frequencies measured in this phase were estimated to be between 6 and 90 Hz. The second phase of the studies was conducted using a new blast pattern (with a diameter of 101 mm, a burden of 3 m, and a spacing of 3.5 m) using the Power Dock method. The results of the analyses showed an acceptable reduction in seismic waves (in the range of 9 to 53) and minimal impact on the underground mine. To reduce possible risks, the managers decided to continue mining operations with the Power Dock method. It was decided to install instruments in the underground mine to monitor stability.

KEYWORDS

Angouran, blasting, vibrations, PPV, stability

I. INTRODUCTION

Adverse effects of blasting are one of the fundamental problems in surface mines. Generally, only a portion of the energy released during blasting is utilized directly for breaking rock within a target range. In contrast, the remainder of the energy is passed and transmitted to the surrounding rock, structures, and environment in the form of ground vibration, noise, flying rocks, back breaks, and air blasts (Lu et al., 2010; Wang et al., 2010; Monjezi et al., 2011). Therefore, it is important to monitor, predict, and control ground vibration arising from blasting. The peak particle velocity (PPV) of blasting vibration is commonly used as the key indicator for evaluating the induced vibration in the drilling and blasting method. However, due to the abrupt nature of blasting events, some parameters are difficult to measure accurately. The existing methods for evaluating PPV are often based on a large amount of field test data and regression analysis using empirical formulas. However, these empirical formulas usually only consider factors such as blasting distance and explosive charge. Moreover, due to the nonlinearity and anisotropy of the explosive detonation and the rock and soil medium, as well as variations in properties with time, temperature, and complex boundary conditions, the fitting results often deviate significantly from the actual values (Sun et al., 2024). For instance, Shi and Chen (2011) successfully reduced the vibration intensity by controlling the maximum charge amount per delay and selecting the optimum interval time in a surface mine. Simangunsong and Wahyudi (2015) and Gorgulu et al. (2013) studied the ground vibrations induced by surface blasting. The purpose of this research is to manage using an artificial neural network. With the increase in surface and underground combined mining and the occasional need for surface mining, several underground workings may be located in proximity to an operating surface mine. In these cases, ground vibrations generated due to open pit blasting may be hazardous to the stability of adjoining underground workings as well as surface building structures and residences (Singh, 2009; Singh et al., 2015). Different rock mass characteristics at the surface

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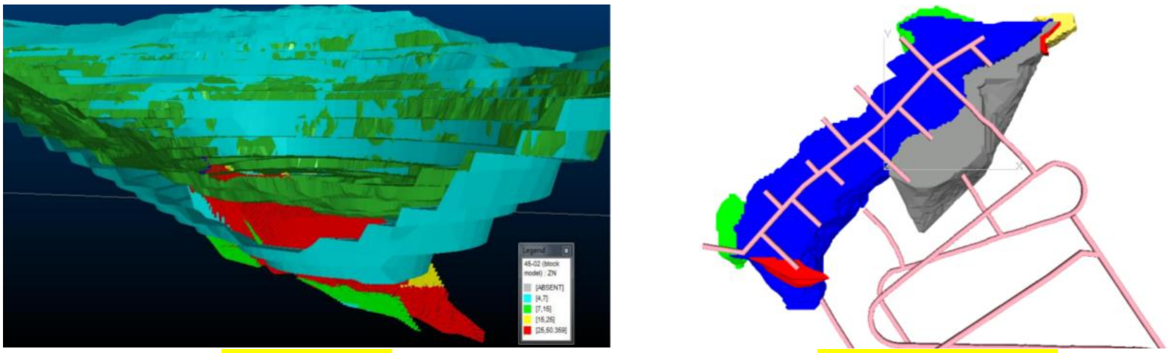
and at underground levels cause underground vibration damping (Singh and Roy, 2010; Shi et al., 2016; Zhou et al., 2016).In recent years, with the development of computer technologies such as machine learning and artificial intelligence, the utilization of algorithms for effective regression and fitting of nonlinear data has contributed to achieving practical regression analysis of sample data with a small quantity, nonlinearity, and multiple factors (Sun et al., 2024). The necessity of conducting this research is to investigate the impact of an explosion in the Angouran open-pit mine on its underground mine. Considering that the gap between the open-pit and underground mine is 5 meters, there is a particular sensitivity. It should be noted that no study has been conducted in this mine so far. In this research, blast-induced ground vibrations obtained at surface and underground mines are comparatively examined. In the first phase, the peak particle velocity (*PPV*) is estimated based on the maximum charge amount per delay (Q) and the distance (R). After comparing it with the Korean standard, phase two studies will be conducted, and finally, the issue will be discussed and reviewed.

II. Description of the Angouran Lead and Zinc Mine

The Angouran lead and zinc mine is located in Mahenshan City, 135 km west of Zanjan province. It is located at 36°37'N and 47°24'E, with an elevation of sea 3100 meters above level. Due to its location in a mountainous region, it has very harsh and long winters and mild summers, with a minimum temperature of -30°C in the winter and a maximum temperature of 22°C in the summer. Precipitation is generally high, and snow falls from early November to April. The reserve of this mine consists of two parts, carbonate and sulfur, and is pear-shaped with the deep expansion of the sulfur part. Most of the carbonate reserve has been extracted. The production capacity of the surface mine is 800,000 tons per year, with an average grade of 25-30% zinc and 3-6% lead. It is considered one of the largest metal mines in the country. The final slope of the mine is 45 degrees in waste rock and 35 degrees in mineral matter. The height of the benches is 10 meters (except for the highest horizon, which is 15 meters high) and with a slope of 74 degrees in the tailing and 60 degrees in the mineral. In the current transportation system, the extracted minerals are transported to high-grade, medium-grade, low-grade, and tailing dumpsites around pit via dump trucks from the ramp of the open-pit mine. Due to the impossibility of the lateral expansion of the cavity due to the topographical limitations, especially the falling schists on its western side, the depth advancement of the levels causes the working spaces of the machines to be limited (Ghadimi, 2023). The extraction method in underground mining is a room-and-pillar system with concrete filling. The mineral in this section is in the form of a mass that extends from the continuation of the open-pit mine and reaches up to the level of 2700. The open pit-underground limit is located at a level of 2745 meters (Angouran Lead and Zinc Mine, 2025). A view of the Angouran surface mine and an isometric view of the Angouran surface and underground mines are shown in Fig.s 1 and 2.

Fig. 1. A view of the Angouran mine



a. surface mine

b. underground mine

Fig. 2. Isometric view of the Angouran surface and underground mines (Angouran Lead and Zinc Mine (2025)

A. *Blasting Parameters*

Tables 1 and 2 show the common parameters in blasting operations at the Angouran mine.

Table 1. Design parameters of blasting patterns in open-pit mine (Ghadimi, 2023)

Location of blast (Level)	2760	2770	2830
Diameter (mm)	127	127	127
Burden(m)×Spacing(m)	4.2×5	4.2×5	4.2×5
Hole length(m)	4	7	11
Sub drilling (m)	0.5	0.5	1.3
Stemming(m)	1.4	3.5	4
Maximum charge per delay (kg)	31.8	41.4	81.5
Explosive	ANFO		
Nonel detonator	PHC 25/500		

Table 2. Design parameters of blasting patterns in the underground mine.

Date	2024 DEC.11			2024 DEC.12		
Location of blast (Level)	2737-49E	2733-44E	2737-23E	2737-49E	2733-44E	2737-23E
Diameter (mm)	42					
No. holes	28	34	40	25	29	40
Hole length(m)	1.4	1.6	1.6	1.4	1.4	1.4
Maximum charge per delay(kg)	10	8	10	7	7.5	10
Nonel detonator	PLP					

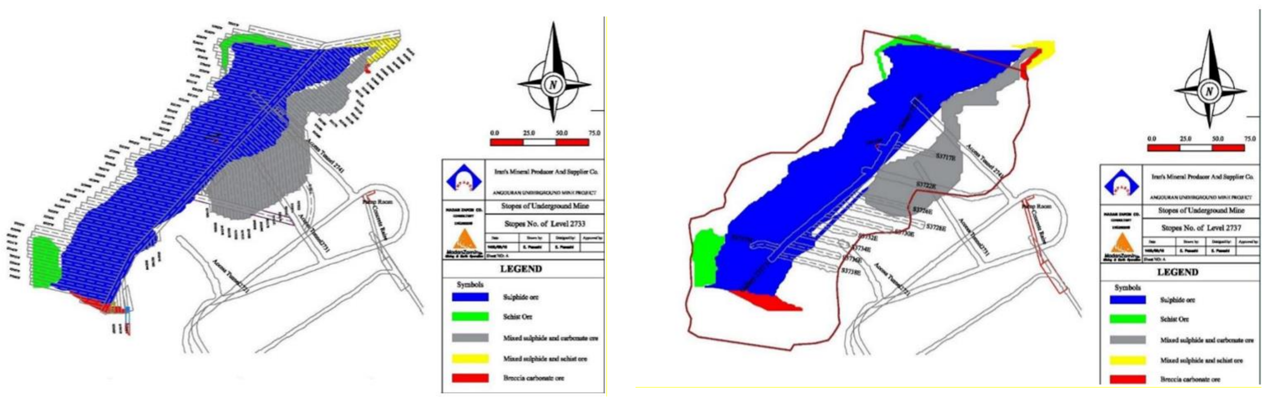
B. *Blasting Vibration Monitoring*

The location of the open-pit blast blocks at levels 2760, 2770 and 2830 relative to the underground galleries at levels 2733 and 2737, as well as the extraction spaced, has been discussed and investigated. Four Recorder Blast 224, 3-component seismographs were used to investigate the effects of the Angouran open-pit and underground blasting operations on the underground structures in the blast area. The seismographs are arranged in such a way that the radial component N is directed towards the direction of the explosion. The other two components include the tangential component T, which is perpendicular to the radial component, and the vertical component Z, which is perpendicular to the plane formed by these two components. Seismic data collection was performed by three open-pit blasting operations and six underground operations on dates 2024 DEC.11 and 12. Thus, 12 three-component maps from three open-pit blasting operations with the 500/25 PHC system, equivalent to 36 vibration components, and 13 three-component maps from 6 underground blasting operations with the PLP system, equivalent to 39 vibration components, resulted in a total of 75 vibration components that were collected, processed, and analyzed. Fig. 3 shows the stopes of underground mining at levels 2733, and 2737. The station S1 is installed on the mine ramp. Also, station number S2 has been installed in stopes number 23E and 49E at level 2737 and stations S3 and S4 have been installed in stope 44E at level 2733. Stations S1 to S4 are shown in Fig.s 4 to 7.

Fig. 8 shows the location of level 2770 of the open-pit mine and the seismographs installed in the underground mine. The distance between stations S1 to S4 from the center of the explosive block at level 2770 of the open pit mine is 218.2, 65.5, 320.2 and 217 meters, respectively.

III. ANALYSIS OF SURFACE AND UNDERGROUND VIBRATIONS (PHASE 1)

To prevent and control the vibrations resulting from blasting, the laws of transmission of vibrations were established considering the type of rock mass, the explosive charge, and the distance, using data obtained on the surface and underground. Peak particle velocity (PPV) is generally a direct function of the maximum charge per delay called “Q” and is negatively related to the distance between the blasting point and the recording point (Abulghasemifar et al., 2018). These equations are scaled based on the distance, i.e., the distance from the blasting site divided by the power of the maximum charge weight used per delay. The most important of these have been summarized in Table 3.



a. level 2733 b. level 2737

Fig. 3. Isometric view of levels 2733 and 2737 (Angouran Lead and Zinc Mine, 2025)

Fig. 4. Station S_1 on the underground mine ramp

Fig. 5. Station S_2 in level 2737

Fig. 6. Station S_3 in level 2737

Fig. 7. Station S_4 in level 2733

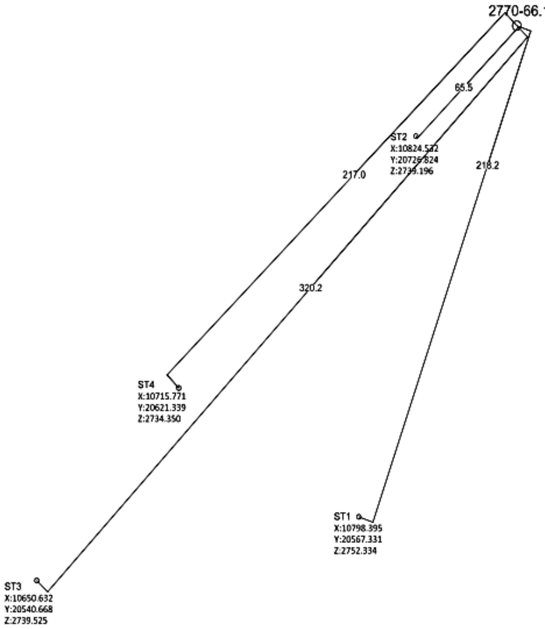


Fig. 8. location of level 2770 of the open-pit mine and the seismographs installed in the underground mine.

Table 3. Scales of predicting ground vibration (Abulghasemifar et al., 2018)

1	$PPV = K\left(D/\sqrt{Q_{max}}\right)^{\beta}$	USBM (Duvall and Fogelson, 1962)
2	$PPV = K\left(D/\sqrt[3]{Q_{max}}\right)^{\beta}$	Ambraseys-Hendron, 1968
3	$PPV = K\left(D/\sqrt{Q_{max}/D^{2/3}}\right)^{\beta}$	Indian Standard, 1973
4	$PPV = K\left(D/\sqrt{Q_{max}/D^{3/2}}\right)^{\beta}$	Longefors and Kihlstrom, 1973
5	$PPV = K\left(D/\sqrt[3]{Q_{max}}\right)^{\beta} e^{\alpha \times D}$	Ghosh and Daemon,1983
6	$PPV = K \times R^{\alpha} \times Q_{max}^{\beta}$	Birch and Chaffer,1983
7	$PPV = K\left(Q_{max}/D^{3/2}\right)^{\beta} e^{\alpha \times D}$	Gupta, 1973
8	$PPV = K\left(Q_{max}^{2/3}/D\right)^{\beta} e^{\alpha \times D}$	Gupta et al, 1973
9	$PPV = K\left(D/\sqrt{Q_{max}}\right)^{\beta} e^{\alpha \times \frac{D}{Q_{max}}}$	Gupta et al,1988
10	$PPV = K\left(D/\sqrt[3]{Q_{max}}\right)^{-1} + \beta$	Roy P. P., 1991
11	$PPV = K\left(D/\sqrt{Q_{max}}\right)^{-1} + \beta$	CMRI, 1993
12	$PPV = K \times D^{\beta} \times Q_{max} \times e^{\alpha}$	Rai and Singh, 2004
13	$Q_{max} = K(PPV \times D^2)^{\beta}$	Rai et al, 2005
14	$PPV = K\left(D/\sqrt{Q_{max}}\right)^{\beta}$	USBM (Duvall and Fogelson, 1962)

In 2006, Chang et al. (2006) proposed a maximum PPV based on the elapsed time of concreting operations based on data from the Korean Geological and Mining Society (Table 4).

The results of the observations are presented in Tables 5 to 7. It should be noted that the results in PPV were obtained by summing the vectors.

Seismic components from the blasting at levels 2760 and 2733-44W, measured at station S4, are shown in Figs. 9 and 10.

Table 4. Korean Standard (Chang et al., 2006)

Time after pour	PPV (mm/sec)
0-3 hours	50.8
3-24 hours	6.3
1-3 days	25.4
3-7 days	50.8
7-10 days	127
>10 days	254

To find a mathematical expression of the determination of the laws of transmission of vibrations, the "scaled distance," which is defined as the relation between the distance and the energy of the explosive charge, was used (Simangunsong and Wahyudi, 2015). The scaled distance was calculated as:

$$D_{scaled} = \frac{D}{\sqrt{Q}} \tag{1}$$

Where Dscaled is the scaled distance, D is the distance between the emitted point and the received point in m, and Q is the amount of maximum charge per delay in kg. The empirical relation between the PPV and the scaled distance is then obtained, which takes the following form:

$$PPV = K \times (D_{scaled})^{\alpha} \tag{2}$$

Table 5. Recording of blasting vibrations in the surface mine on the stable underground mine (2024 DEC.12)

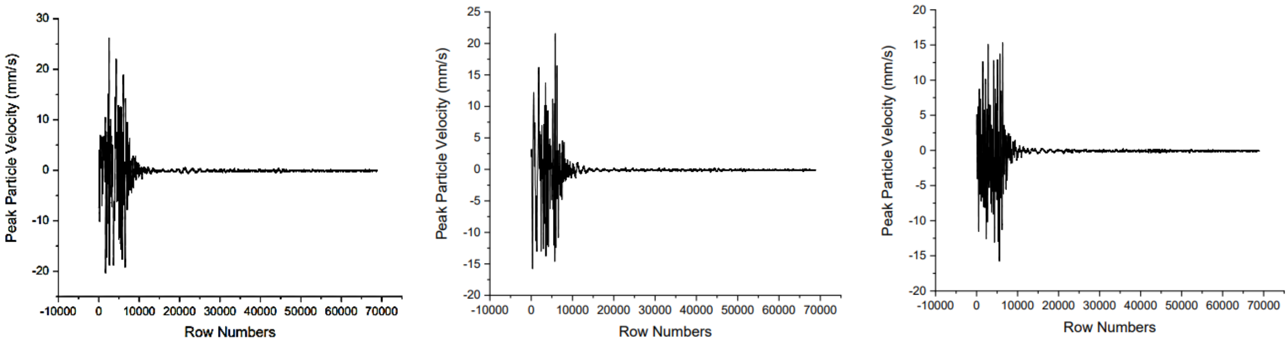
Level	Blast recorder	Distance (m)	Charge weight (Kg)	PPV (mm/sec)				Frequency (HZ)		
				vertical	radial	Tangent	Result of PPV	vertical	radial	Tangent
2770	S_1	218.2	41.4	0.67	0.42	0.20	0.82	181.9	49.6	38.9
	S_2	65.5		42.5	51.6	36.10	75.97	68.7	68.7	59.5
	S_3	320.2		2.72	2.49	2.44	4.42	14.3	17.5	15.9
	S_4	217		5.93	3.08	9.69	11.77	10.6	20.5	10.5
2760	S_1	48.4	31.8	1.47	2.50	2.50	3.83	87.94	56.77	55.90
	S_2	160.8		8.95	9.25	8.34	15.34	8.83	77.96	73.89
	S_3	110.4		4.23	8.94	11.68	15.30	9.62	68.70	17.70
	S_4	53.2		26.19	21.61	15.69	37.40	75.18	77.96	50.21
2830	S_1	402.5	81.5	1.29	2.23	1.74	3.11	88.59	59.26	19.69
	S_2	248.8		3.73	4.68	7.41	9.52	76.10	76.10	70.25
	S_3	501.4		1.11	1.99	1.43	2.69	8.40	6.85	5.97
	S_4	397.7		1.86	1.54	1.43	2.81	7.74	6.43	5.36

Table 6. Recording of blasting vibrations in the underground mine on the stability of the underground mine (2024 DEC. 11)

Level	Blast recorder	Distance (m)	Charge weight (Kg)	PPV (mm/sec)				Frequency (HZ)		
				vertical	radial	Tangent	Result of PPV	vertical	radial	Tangent
2737-49E	S_3	37.6	10	15.2	19	12.4	27.31	87.70	53.2	36.2
2733-44W	S_3	99.5	8	6.9	10.6	11.4	17.03	77.5	53.6	34.8
2737-23E	S_2	89.6	10	10.3	7.3	14.5	19.23	59.5	54.7	59.5
	S_3	168.3		2.5	2.9	3.7	5.32	88.6	70.9	38.6

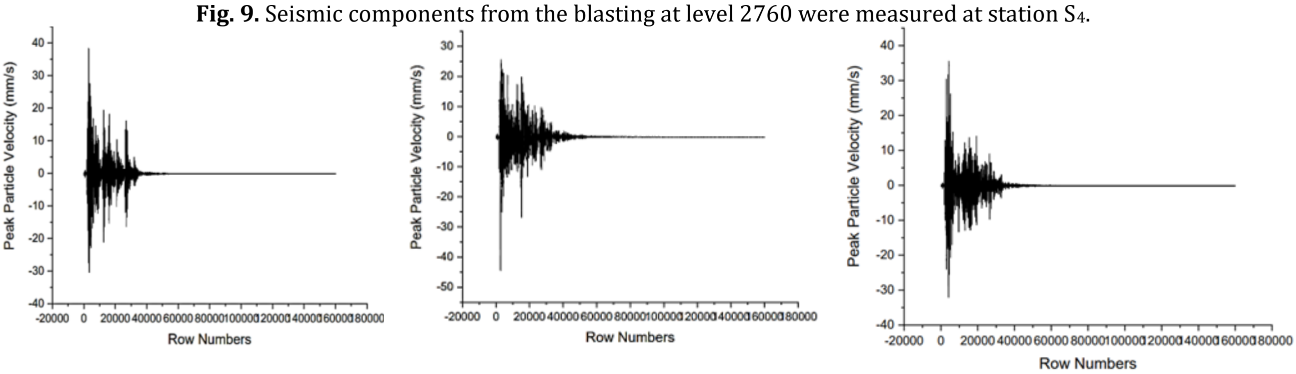
Table 7. Recording of blasting vibrations in the underground mine on the stability of the underground mine (2024 DEC.12)

Level	Blast recorder	Distance (m)	Charge weight (Kg)	PPV (mm/sec)				Frequency (HZ)		
				vertical	radial	Tangent	Result of PPV	vertical	radial	Tangent
2737-49E	S_2	230.7	7	1.03	2.11	1.47	2.77	36.50	37.30	35.62
	S_3	39.5		41.7	56.4	57.5	90.69	77.96	77.96	31.7
	S_4	85.9		1.36	1.48	1.27	2.38	77.96	68.7	61.58
2733-44W	S_2	171.7	7.5	2.21	4.95	2.66	6.04	35.97	36.79	37.34
	S_3	100.3		4.88	5.09	7.85	10.55	37.47	34.90	38.25
	S_4	41		38.48	44.66	35.74	68.94	67.68	40.42	70.33
2737-23E	S_2	89.5	10	14.74	20.57	19.25	31.79	76.09	35.50	31.71
	S_3	169		2.22	2.46	5.16	6.13	33.83	32.44	33.48
	S_4	70.2		6.44	7.49	7.43	12.36	77.03	60.19	58.45



a. vertical b. radial c. Tangent

Fig. 9. Seismic components from the blasting at level 2760 were measured at station S_4.



a. vertical b. radial c. Tangent

Fig. 10. Seismic components from the blasting at level 2733-44w were measured at station S_4.

The values obtained for PPV and Dscaled are plotted to determine the value of the constants K and α, which will depend on geological conditions. Then, the equation of the regression curve that best fits the plot is obtained. The law of transmission of surface vibration was obtained using the data from Table 5-7. Therefore, the relationship between PPV and the scaled distance is presented for surface mining.

$$PPV = 3230.6 D_{scaled}^{-1.804} \quad (3)$$

Using equation 4, the PPV of the underground mine is:

$$PPV = 7977.1 D_{scaled}^{-1.79} \quad (4)$$

After processing the seismic data, the general relationship of wave propagation resulting from the blasting of open-pit operations in the area of the Angouran underground lead and zinc mine for the 22/500 PHC system was estimated as a power equation based on the square root of the scaled distance with constants of 3230.6 and -1.804. The general relationship between the propagation of waves resulting from the explosion of the underground operations of Angouran within the limits of this mine for the PLP Nonel system was estimated as a power function based on the square root of the scaled distance with constants of 1.7977 and -1.79. The vibration frequencies measured in this study were estimated to be between 6 and 90 Hz. The maximum measured particle velocities from open-pit blasting on underground mining sites have been recorded in the range of 2.8 to 75.9 mm/s, and the maximum measured particle velocities from underground explosions on underground mining sites have been recorded in the range of 2.7 to 90.7 mm/s. Therefore, it can be concluded that the maximum particle velocity from open-pit blasting with the 25/500 Nonel system and underground blasting with the PLP Nonel system in underground mining spaced is not within the permissible vibration standards according to the Korean standard. The positions and values outside the permissible range according to the Korean standard are shown in Table 8.

Table 8. The positions and values outside the permissible range according to the Korean standard

Level	Blast recorder	Distance (m)	Charge weight (Kg)	PPV (mm/sec)	Korean Standard (mm/sec)
2770	S_2	65.5	41.4	75.97	1 to 3 days after pour, the PPV value should not exceed 25.4 mm/sec.
2760	S_4	53.2	31.8	37.40	
2737-49E	S_3	39.5	7	90.69	
2733-44W	S_4	41	7.5	68.94	
2737-23E	S_2	89.5	10	31.79	

IV. Analysis of Surface and Underground Vibrations (Phase 2)

In order to reduce ground vibration, the blast patterns used in phase one were modified, and the power deck blasting system was employed in open-pit and underground blasting operations. Therefore, in the second phase, to investigate the effects of vibration from open-pit blasting operations on mining sites, drilling and blasting patterns were first implemented in the carbonate and sulfur zones based on 4-inch (101 mm) blast holes using Nonel 25/500 PHC blasting systems with the power deck spending method. Table 9 shows the design parameters in blocks 2770-56, 2760-32, and 2760-34.

Table 9. Design parameters of blasting patterns in the open-pit mine

Location of blast	2770-56	2760-32	2760-34
Diameter (mm)	101	101	101
Burden (m)×Spacing (m)	3×3.5	2.7×3.2	3×3.5
Hole length (m)	7.30	6	6
Number of holes	21	27	25
Sub drilling (m)	--	--	0.5
Stemming(m)	2.30	2.70	3
Maximum charge per delay (kg)	30	20	30
Primer	One-pound pentolite booster		
Booster-Ammolite (kg)	1	0.8	0.8
Water status	dry		
Explosive	ANFO		
Nonel detonator	PHC 25/500		

In the second phase, the hole diameter, burden, and spacing were reduced by 20%, 28.5% and 30% respectively. Based on the control of the effective parameters, the trial-and-error method was used. For optimal use of the explosive energy, the Power Dock method is employed. The air column considered at level 2760-32 is 50 cm, and at level 2770-56 is 70 cm.

Fig. 11 shows the drilling rig and Power Dock spacers in the explosive block 2760-32.

Fig. 11. The drilling rig and Power Dock spacers in the explosive block 2760-32

Fig. 12 shows the location of level 2770-56 of the open-pit mine and the seismographs installed in the underground mine. The results of the observations are presented in Table 10.

Seismic components from the blasting at level 2770-56, measured at station S2, are shown in Fig. 13.

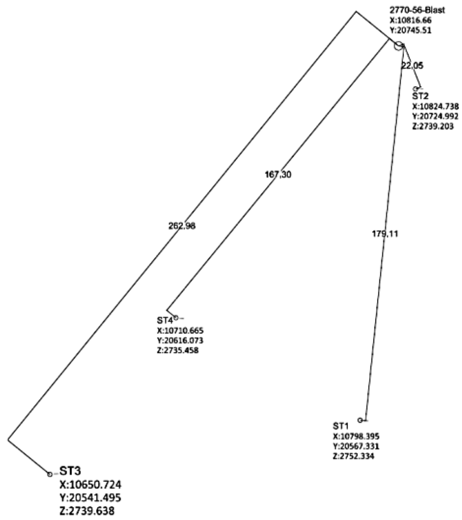
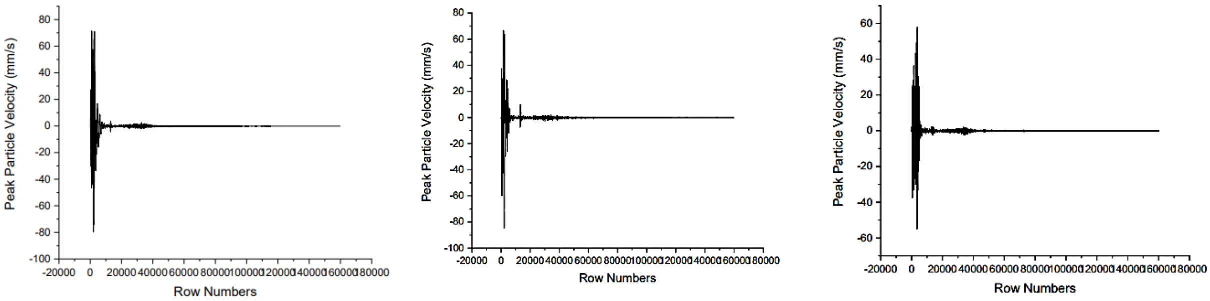


Fig. 12. location of level 2770-56 of the open-pit mine and the seismographs installed in the underground mine

Table 10. Recording of blasting vibrations in the surface mine on the stable underground mine.

Level	Blast recorder	Distance (m)	Charge weight (Kg)	PPV (mm/sec)				Frequency (HZ)		
				vertical	radial	Tangent	Result of PPV	vertical	radial	Tangent
2770-56	S_1	179.11	30	8.33	6.03	6.54	12.19	11.80	9.85	12.30
	S_2	22		79.50	84.70	57.60	129.66	12.20	23.40	23.38
	S_3	262.98		2.88	2.63	3.94	5.54	8.3	12.27	9.56
	S_4	29.8		7.10	9.06	9.68	15.04	10.28	12.94	8.66
2760-32	S_1	110.64	20	3.09	4.60	4.15	6.92	11.38	11.65	9.40
	S_2	43.6		2.78	2.19	2.35	4.25	13.98	10.24	12.36
	S_3	10.4		10.85	12.39	19.09	25.21	12.75	53.79	22.32
	S_4	9.8		24.13	8.99	8.93	27.25	12.49	29.90	23.42
2760-34	S_1	152.81	30	3.70	3.35	3.05	5.85	88.59	59.26	19.69
	S_2	153.50		4.60	4.14	4.56	7.69	11.36	15.84	16.19
	S_3	129.53		6.38	5.23	6.85	10.72	21.58	66.39	23.81
	S_4	58.18		19.47	19.51	14.61	31.16	15.71	31.86	33.26



a. vertical b. radial c. Tangent

Fig. 13. Seismic components from the blasting at level 2770-56 were measured at station S_2

Therefore, the relationship between PPV and the scaled distance is presented for surface mining (sulfide zone):

$$PPV = 692.13 D_{scaled}^{-1.192} \tag{5}$$

After processing the seismic data, the general relationship of wave propagation resulting from the explosion of open-pit operations in the sulfur zone within the underground mine for the PHC25/500 Nonel system was estimated as a power function based on the square root of the scaled distance with constants of 692.13 and -1.192.

Using equation 6, the PPV of the Carbonate zone:

$$PPV = 493.38 D_{scaled}^{-1.287} \tag{6}$$

The general relationship between the propagation of waves resulting from the explosion of open-pit operations in the carbonate zone within the underground mine for the PHC25/500 Nonel system was estimated as a power function based on the square root of the scaled distance with constants of 493.38 and -1.287. Also, the measured vibration frequencies ranged from 9 to 53 Hz, which are within the safe range.

In fact, using the Power Dock method has reduced frequencies in the underground mine by 60%. As shown in Fig. 14, the level of vibrations caused by explosions (with the same diameter and height of the hole) using the power dock method is lower than the so-called explosive methods in the Angouran mine.

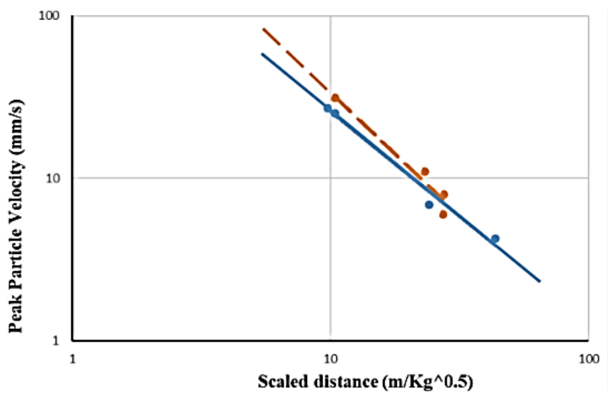


Fig. 14. Comparison of the PPV of the conventional explosive method (dashed line) with the Power Dock (solid line)

However, it was suggested that blast holes in the lower levels of the open-pit mine be constructed with a diameter of 3.5 inches, a burden of 2.4 meters, a spacing of 2.8 meters, the removal of excess excavation, the removal of boosters, and the use of ammolite as a primer using the power deck method.

V. Conclusions

The purpose of this research is the measurement of vibration due to blasting in Angouran surface and underground mines on the stability of underground spaced. Vibrations obtained from measurement devices in open-pit mines and underground mine spaced are studied.

- In the first phase, the peak particle velocity (PPV) is estimated based on the maximum charge amount per delay (Q) and the distance (R). Therefore, the stability of underground mines in relation to monitoring using common blast patterns in the Angouran open-pit mine (with a diameter of 127 mm, a burden of 4.2 m, and a spacing of 5 m) has been measured using four seismographs. The vibration frequencies measured in phase 1 were estimated to be between 6 and 90 Hz. The maximum measured particle velocities from open-pit blasting on underground mining sites have been recorded in the range of 2.8 to 75.9 mm/s, and the maximum measured particle velocities from underground explosions on underground mining sites have been recorded in the range of 2.7 to 90.7 mm/s. The results indicate that the maximum ground vibrations resulting from open-pit blasting at the underground mine exceed the permissible vibration standards.
- The second phase of the studies was conducted using a new blast pattern (with a diameter of 101 mm, a burden of 3 m, and a spacing of 3.5 m) using the Power Dock method. The results of the analyses showed an acceptable reduction in seismic waves (in the range of 9 to 53) and minimal impact on the underground mine. In other words, using the Power Dock method has reduced frequencies in the underground mine by 60%.
- However, it was suggested that blast holes in the lower levels of the open-pit mine be constructed with a diameter of 3.5 inches, a burden of 2.4 meters, a spacing

of 2.8 meters, the removal of excess excavation, the removal of boosters, and the use of ammolite as a primer using the power deck method.

- To reduce possible risks, the managers decided to continue mining operations with the Power Dock method. It was decided to install instruments in the underground mine to monitor stability.

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