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RESEARCH ARTICLE

EVALUATION OF GROUND VIBRATION AND AIR BLAST MEASUREMENTS INDUCED BY BLASTING IN A QUARRY MINE

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ABSTRACT

The energy released during blasting in underground and surface mines for excavation purposes can cause flyrock, excessive level of ground vibration and air blast. In this study, ground vibration and air blast induced by blasting were measured and evaluated for a quarry mine in the Kangal district of Sivas province. Within the scope of this study, observations and measurements were made before, during, and after two blasting operations in a quarry mine to evaluate the environmental effects of blasting. The environmental effects of blasting were assessed by considering both the blasting parameters and the ground vibration and air blast measurement results.

Keywords: *Quarry mine, Blasting, Ground vibration, Air blast*

1. INTRODUCTION

The use of explosives in underground and surface mines continues to increase. The energy newly entering the environment as a result of blasting disrupts the equilibrium position in the environment and causes land motions. If the blasted environment does not show an elastic property to the new incoming energy, the energy is damped and only reflected as waves with reduced vibrations. If the environment exhibits elastic properties, the neighboring environments leave the equilibrium position as a result of the disrupted environment and create an oscillation similar to the spring-weight mechanism [1]. Ground vibration, airblast, and fly rocks problems may occur as a result of these oscillating movements. Parameters related to ground vibrations can be divided into two main classes as controllable (blast geometry parameters) and uncontrollable parameters (rock characteristics and site geology) (Siskind et al., 1980). The peak particle velocity (PPV) is considered most appropriate and accurate indicator of the damaging capabilities blast vibration [2].

Nowadays, environmental effects during blasting are monitored, evaluated and necessary precautions are taken in order to determine and control the environmental effects caused by blasting. Particle velocity and frequency are taken into account in most blasting safe limit criteria developed by numerous researchers [3 – 12]. In addition to these studies, the principles regarding the control of environmental vibration induced by various vibration sources have been determined under the heading of "Environmental Vibration Principles and Criteria" of the environmental noise assessment and management regulation in Turkey dated 04.06.2010. Approaches based on predicting the particle velocity depending on the scaled distance have been introduced with the development and use of geophones and pressure sensing microphones. The scaled distance-based prediction of the peak particle velocity has been accepted in most studies in the literature [13].

Within the scope of this study, ground vibration and air blast were measured at 6 points for two different blasts in a quarry (basalt) mine, and the effects of blasts on the Kangal-Zara highway, which is located at a distance varying between 50-100 m from the mining site, were evaluated.

2. MATERIAL and METHODOLOGY

2.1. Study Area

Basalt is produced by the open pit mine method in a quarry mine located in the Kangal district of Sivas province (Figure 1). Basalt masses (30-150 cm) fragmented-loosed by blasting are loaded on the truck with an excavator and transported to the crusher in the mine. The Kangal-Zara highway (which is separated from the D260 Sivas-Divriği highway) passes parallel to the east boundary of the mine at distances varying between 50-100 m.

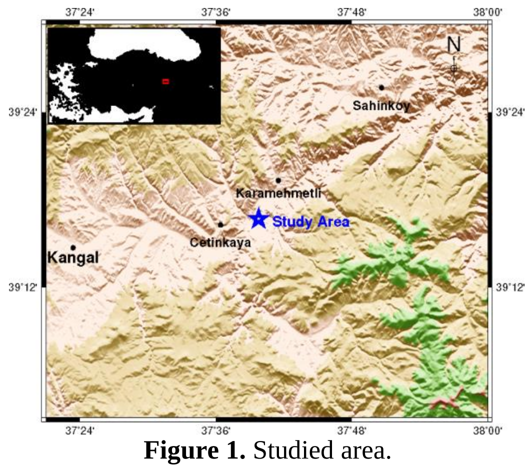

Figure 1. Studied area.

3. OBSERVATION and MEASUREMENT RESULTS

A detailed research was carried out before, during, and after two blasts performed at different times in the study area [14]. Ground vibration and air blast measurements of the blasts performed within the mine area were selected from among the points close to the highway. Two trial blasts were planned and implemented to reveal the environmental effects of controlled bench blasting in the quarry. In these trial blasts, there are no two free faces in bench blasting, but there is only one free face since

Before Blasting (First Blasting)

After Blasting (First Blasting)

Before Blasting (Second Blasting)

After Blasting (Second Blasting)

Figure 2. Controlling of blasting area.

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only the top part of the blasted mass is open. Ground vibration and air blast were measured simultaneously at three points during the trial blasts (Figure 2). The specific charge amount of the first blast was calculated as 0,444 kg/m^3, whereas the specific charge amount of the second blast was calculated as 0,449 kg/m^3. The specific charge amounts in question may be reduced to lower values due to the presence of two free faces in bench blasting. In this case, lower ground vibration and air blast values can be obtained because the maximum charge per delay will decrease. Table 1 contains the blasting parameters applied in these blasts. In the surface mine using ANFO as an explosive, the average charge per hole was applied as 35,65 kg in the first blast and 56,95 kg in the second blast. Since a single hole is blasted simultaneously in both blasts (Table 2), the maximum charge per delay values are the same as the charge per hole values. Moreover, a delay of at least 8 ms, predicted in the literature [15], was ensured between the holes in both blasts (Figure 3). First, data on the basic blasting parameters of the above-mentioned blasts were obtained. After performing detailed examinations in the field for each blast, geophones and pressure sensing microphones were placed to measure ground vibration and air blast along the east boundary of the mine, and their distances from the blasting point were found (Figure 4 and 5). The locations of the geophones and pressure sensing microphones used in the blasts are presented in Figures 6 and 7. In the first blast, the geophones and pressure sensing microphones coded CUM-1 were placed closest to the blasting point (Distance: 168 m), while the other two (CUM-5 and CUM-3) were placed along the highway north of CUM-1 (Figure 6). The distances of CUM-5 and CUM-3 to the blasting point are 185 m and 253 m, respectively (Table 3). In the second blast, the geophones and pressure sensing microphones coded CUM-5 were placed closest to the blasting point (Distance: 150 m), and the other two (CUM-1 and CUM-3) were placed along the highway north and south of CUM-5 (Figure 7). Table 3 contains the distances of the geophones and pressure sensing microphones to the blasting point.

The results of ground vibration and air blast measurements induced by blasting are presented in Table 3. The peak particle velocity and frequency were measured as 4,57 mm/s and 39 Hz, respectively, and the peak noise was measured as 119,2 dB in the first blast, while the peak particle velocity and frequency were measured as 15,10 mm/s and 37 Hz, respectively, and the peak noise was measured as 114,0 dB in the second blast. While the peak particle velocity varied between 2,03-15,10 mm/s in the blasts, the frequencies varied between 27-39 Hz. Furthermore, the calculated scaled distance values are presented in Table 3. Scaled distance is a concept introduced using the amount of explosive that affects the distance and the basis of seismic waves or creates energy in air blasts. The scaled distance is correlated with the amount of land motions' blasting levels at varying distances. Scale is a unitless factor used depending on distance [16]. The scaled distance is derived from combinations of charge per delay, impacting seismic development and air blast energy, and the distance between the blast and the measurement point. The formula of the scaled distance (SD_1) most frequently used in the literature and this study is presented below. The safe distance can also be computed using the same formula. Furthermore, it is used in air blast predictions (SD_2).

$$SD_1 = R/\sqrt{W} \quad ; \quad R = SD\,\sqrt{W}$$
$$SD_2 = R/\sqrt[3]{W}$$

Here,

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SD : Scaled distance
R : Distance to blasting point or safe distance (m)
W : Maximum charge per delay (kg)

Since the charge shape used in surface mine studies is usually cylindrical (if the charging level-hole diameter ratio is ≥ 6, it is considered cylindrical, if the ratio is < 6, the charge is considered spherical), the waves from the column charge are propagated with the expanding shape of this cylinder. It is an accepted approach that the volume of this pressure cylinder varies with the square of its radius.

Table 1. Blasting parameters.

Blasting Parameters	First Blasting	Second Blasting
Type of blasting	Loose	Loose
Hole diameter (mm)	89	102
Hole slope (°)	85-90	85-90
Drilling patern	Staggered	-
Burden (m)	2,5	3,5
Spacing (m)	3,5	3,5
Hole depth (m)	10	11
Subdrill (m)	1,0	1.0
Stemming (m)	2,0	2,9
Stemming material	Hole material	Hole material
Charge type	Colon	Colon
Charge per hole (kg)	35,65 (35 kg ANFO+0,5 kg Dyn.)	56,95 (55 kg ANFO+1,5 kg Dyn.)
***Specific charge (kg Anfo)/m^3)**	0,444	0,449
Number of holes	48	10
Number of rows	4	1
Maximum charge per delay (kg)	35,65 (35 kg ANFO+0,5*1,3Dyn.)	56,95 (55 kg ANFO+1,5*1,3 Dyn.)
Total charge (kg)	1680 kg ANFO 24 kg Dynamite	550 kg ANFO 15 kg Dynamite
Firing system	Non-electric capsule	Non-electric capsule
Delay order		
• **In the hole (ms)**	0	0
• **Between holes (ms)**	25	25
• **Between rows (ms)**	42	-

** Specific charge= kg Anfo/(Burden x Spacing x (Hole depth - subdrill))*

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Table 2. Firing times of blast holes.

First Blasting							
Row_A Hole_#	**Time (ms)**	**Row_B Hole_#**	**Time (ms)**	**Row_C Hole_#**	**Time (ms)**	**Row_D Hole_#**	**Time (ms)**
#1	25	#13	92	#25	159	#37	226
#2	50	#14	117	#26	184	#38	251
#3	75	#15	142	#27	209	#39	276
#4	100	#16	167	#28	234	#40	301
#5	125	#17	192	#29	259	#41	326
#6	150	#18	217	#30	284	#42	351
#7	175	#19	242	#31	309	#43	376
#8	200	#20	267	#32	334	#44	401
#9	225	#21	292	#33	359	#45	426
#10	250	#22	317	#34	384	#46	451
#11	275	#23	342	#35	409	#47	476
#12	300	#24	367	#36	434	#48	501
Second Blasting (Single Row)							
#1	25	#4	100	#7	175	#9	225
#2	50	#5	125	#8	200	#10	250
#3	75	#6	150				

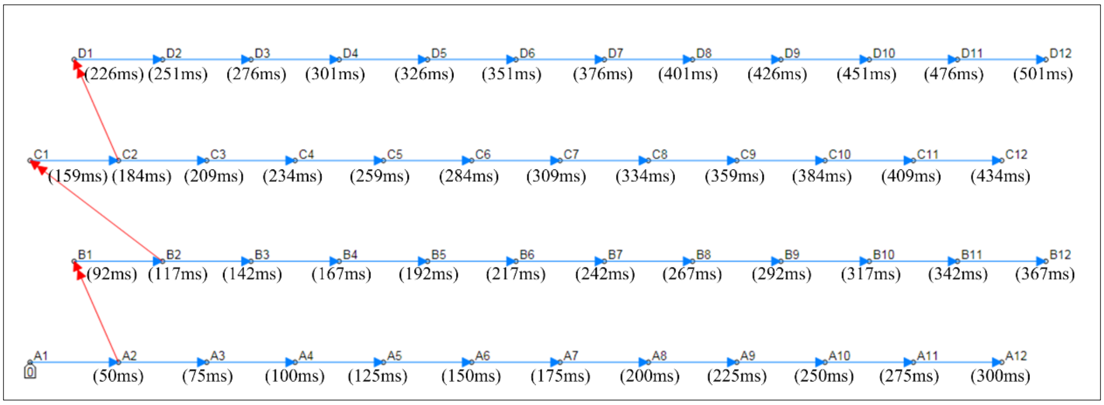

Figure 3. Drilling patern and firing times of first blasting holes.

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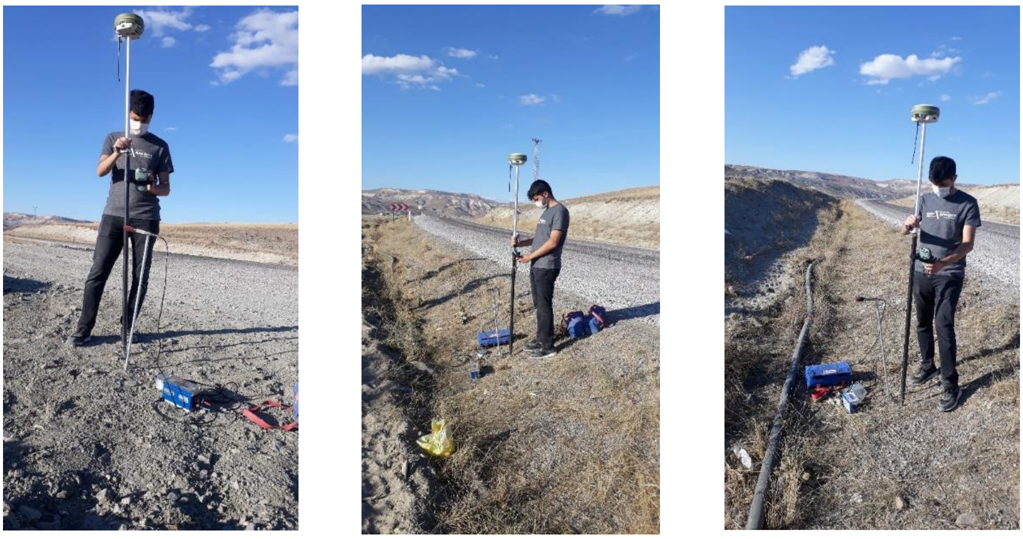
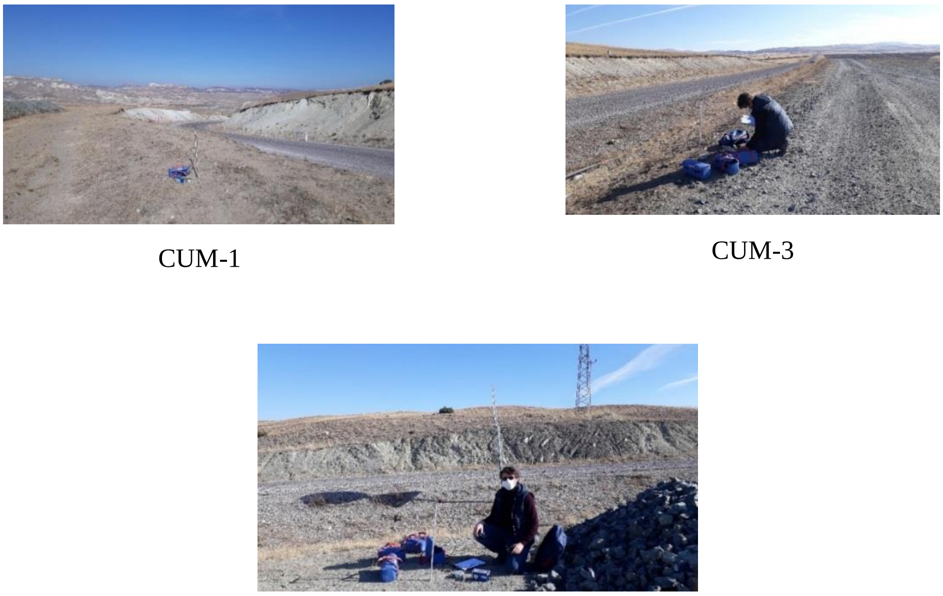


CUM-1 CUM-3 CUM-5

Figure 4. Placing of geophones and microphones (First blasting).



CUM-1 CUM-3

CUM-5

Figure 5. Placing of geophones and microphones (Second blasting).

Figure 6. Measurement points of ground vibration and air blast (First blasting).

Figure 7. Measurement points of ground vibration and air blast (Second blasting).

Table 3. Measurement results of ground vibration and air blast.

Geophone Number	Partical Velocity (Transverse) PVT mm/s [Frequency,Hz]	Partical Velocity (Vertical) PVV mm/s [Frequency,Hz]	Partical Velocity (Longitudinal) PVL mm/s [Frequency, Hz]	Peak Partical Velocity PPV inch/s (mm/s) [Frequency, Hz]	Noise N dB (Pa)	Distance R (m)	Scaled Distance SD	
							SD_1	SD_2
				First Blasting				
CUM-1	3,05 [57]	2,67 [30]	4,57 [39]	**0,180** (4,57) [39]	**119,2** (18,3)	168	28,14	51,04
CUM-5	3,30 [37]	2,29 [37]	2,79 [51]	**0,130** (3,30) [37]	**115,4** (11,8)	185	30,98	56,21
CUM-3	2,03 [73]	1,14 [85]	2,03 [27]	**0,08** (2,03) [27]	**110,9** (7,0)	253	42,37	76,81
				Second Blasting				
CUM-1	3,56 [32]	2,41 [18]	2,41 [43]	**0,140** (3,56) [32]	**106,5** (4,25)	271	35,91	70,44
CUM-5	5,21 [30]	7,75 [34]	9,02 [30]	**0,355** (9,02) [30]	**114,0** (10,0)	150	19,88	38,99
CUM-3	9,91 [32]	6,60 [37]	15,10 [37]	**0,594** (15,10) [37]	**108,0** (5,0)	173	22,92	44,97

4. EVALUATION of the MEASUREMENT RESULTS

4.1. Evaluation of ground vibration measurement results

In the current study, the calculated scaled distance (SD_1) values varied between 28,14 - 42,37 in the first blast and 19,88 – 35,91 in the second blast (Table 3). Numerous studies in the literature state that there is no need for seismic recording as long as the scaled distance factors (Table 4) of the U.S. Office of Surface Mining (OSM) are applied. Considering the distance values from the blasting points in the trial blasts, the SD value must be higher than 55 to perform blasting without seismic recording.

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The fact that all the SD values calculated are lower than 55 indicates the necessity of vibration and air blast measurements.

Table 4. Recommended scaled distance factors for lack of siesmic monitoring [7].

Distance from the blast site		**Scaled distance to be applied without seismic monitoring**
ft	**m**	**(SD)**
0 – 300	0 – 90	50
301 – 5000	91 – 1500	55
>5001	>1500	65

The ground vibration and air blast values measured simultaneously at three points in both blasts were evaluated by considering the approaches of some researchers [3 - 7] and the "Regulation on Evaluation and Management of Environmental Noise; Environmental Vibration Criteria in Buildings (28.07.2013) in force in our country. It was found that the ground vibration and air blast measurement values (Table 3) did not have the risk of damaging any structure in the places where the measurements were performed according to these damage criteria.

The ground vibration and air blast measurement results (Table 3) were evaluated by considering the OSM, 1983 alternative criterion analysis approach, which is commonly employed nowadays and overlaps with the regulation in Turkey (Figure 8). As seen in Figure 8, the ground vibration values induced by the blasts were in the permitted region and did not carry any risk.

Simple regression analysis was conducted between the measured particle velocity and scaled distance values (Table 3), and as in the literature, the highest correlation was acquired in the power relationship (Figure 9). Figure 10 shows the correlation between the particle velocity acquired using this relationship and the measured particle velocity values. As is known, it is recommended in the literature to have more than 30 data pairs so that this relationship, in which site factors are determined, can be more reliable and more highly correlated. In the present study, 6 different measurements were carried out. Since bench blasting will be performed during the operation phase, lower particle velocities can be expected. However, ground vibration measurements should be made at more than 30 points to make the relationship between particle velocity and scaled distance (Figure 9) more reliable. Nevertheless, controlled bench blasting can be performed by considering this relationship to be acquired.

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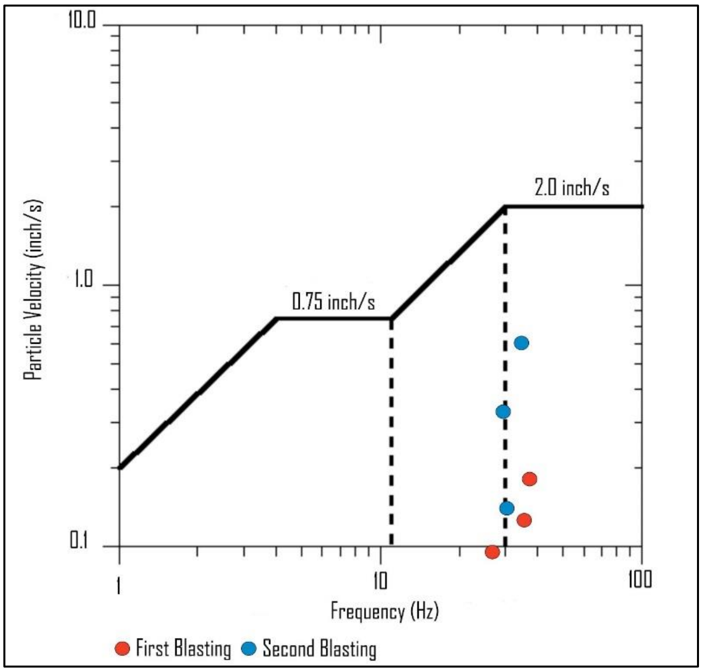

Figure 8. **S**afe limit criteria [7].

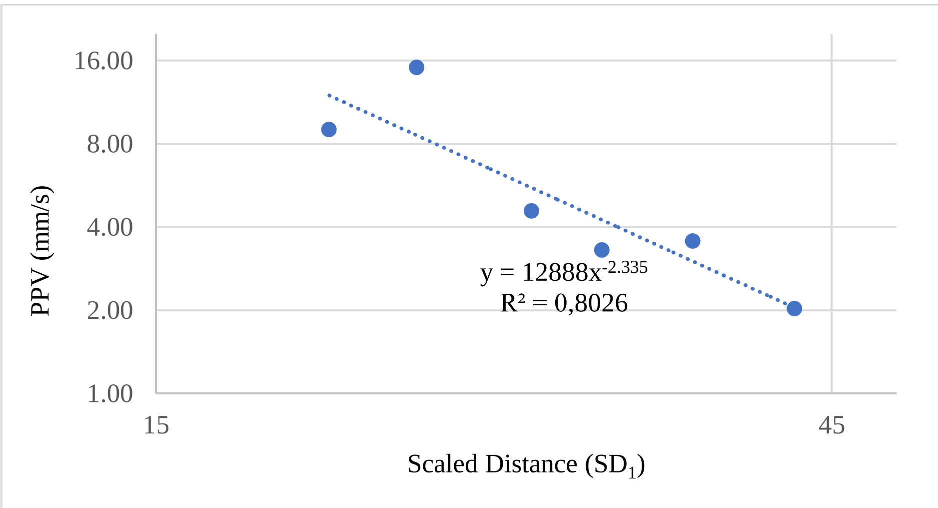

Figure 9. Relationship between peak particle velocity and scaled distance.

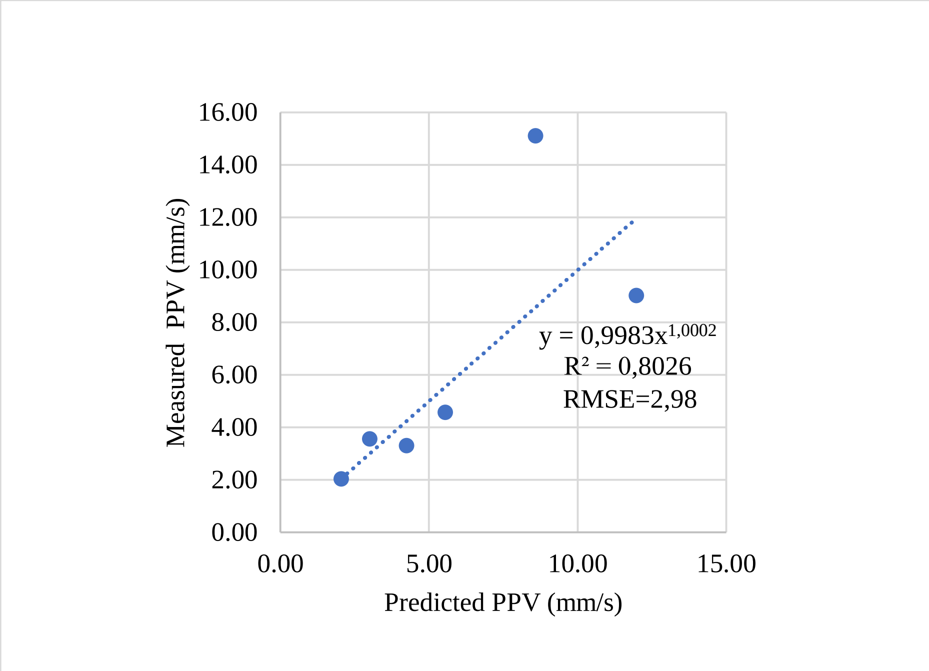

Figure 10. Relationship between measured and predicted peak particle velocities.

4.2. Evaluation of Air Blast Measurement Results

It is known that the propagation of the blast-induced air blast wave depends on atmospheric and topographic conditions, such as temperature, wind, and altitude. Even cloud closure at a particular distance can sometimes cause the pressure wave to be reflected back to the ground. The intensity of the audible parts of the blasts is usually between the noise caused by pneumatic breakers and the aircraft during landing. In the legal regulations in the US [5, 7], the air blast level corresponding to 140 decibels is determined as the starting level of damage and the top level of noise. In Turkey, the daily exposure limit values were given as (LEX, 8 hours) = 87 dB(A) or (Peak) = 200 Pa [140 dB(C) re. 20 µPa] under the heading of the "Exposure duration values and exposure limit values" (Second Section, Article 5) of the Regulation on the Protection of Employees from Risks Related to Noise, published in the Official Gazette dated 28.07.2013. The peak air blast values measured as 119.2 dB (18,3 Pa) and 114.0 dB (10,0 Pa), respectively, in the first and second blasts in the study area are below the starting level of damage and the top level of noise predicted by both regulations, and the exposure duration is very short (< 1 minute). Simple regression analysis was also carried out between the air blast and scaled distance values (Table 3). An acceptable correlation (R^2=0,0526) between air blast and SD_1 could not be acquired. However, an acceptable correlation (R^2=0,6642) was determined between air blast and SD_2 (Figure 11).

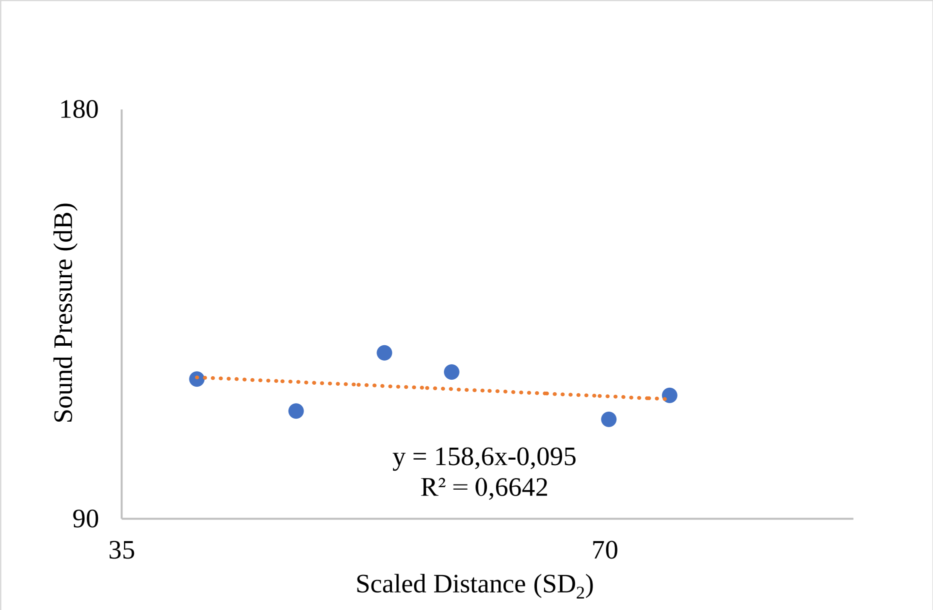

Figure 11. Relationship between sound pressure and scaled distance.

5. CONCLUSIONS and RECOMMENDATIONS

This study evaluated the ground vibration and air blast measurement results induced by two trial blasts performed for controlled blasting in a quarry mine.

ANFO was used as an explosive in the trial blasts, and the maximum charge per delay was applied as 35,65 kg in the first blast and 56,95 kg in the second blast. The specific charge amounts were calculated as 0,444 kg/m^3 and 0,449 kg/m^3 in the first and second blasts, respectively. It was indicated that the specific charge amounts could be reduced to lower values due to the presence of two free faces in bench blasting, and in this case, lower ground vibration and air blast values could be acquired since the maximum charge amount per delay would also decrease. Ground vibration and air blast measurements were performed simultaneously at three points during each of the blasts, and it was revealed that the blasts to be performed over a distance of 50-100 m did not have the risk of damaging the highway and/or any structure or building located after this distance. Simple regression analysis was carried out between the measured particle velocity and scaled distance values, and a highly correlated relationship was developed. Furthermore, a good correlation was found between the particle velocity obtained using this relationship and the measured particle velocity values. On the other hand, similar evaluations were performed for the air blast. It was seen that the measured air blast values were below the starting level of damage and the top level of noise. An acceptable correlated relationship was also acquired between the air blast and the scaled distance.

It was indicated that lower particle velocities could be expected since bench blasting would be performed during the operation phase. However, it was recommended to perform ground vibration measurements at more than 30 different points in order to make the particle velocity and scaled distance relationship more reliable for controlled bench blasting.

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