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IDENTIFICATION AND REDUCTION OF BLAST – INDUCED EFFECTS ON A LIMESTONE QUARRY

IDENTYFIKACJA I OGRANICZENIE SKUTKÓW PROWADZENIA PRAC STRZAŁOWYCH W KAMIENIOŁOMIE WYDOBYWAJĄCYM WAPIENIE

In Turkey, a great increase in mining and tunneling operations is seen in recent years. Production is generally done by drilling and blasting method in metallic mines, quarries and a part of coal mines and also in tunnels. It is known that the blast-induced vibrations can be cause undesired effects on nature or construction in around. In this study, field works and analysis of the blast-induced vibration in order to minimize are given for chosen quarry. Methodology for Minimizing Blast-Induced Vibrations (Turkish Patent Institute – TPI 2007/03459) was used for measurement of blasting and modelling of blasting data in compliance with Turkish and German standards.

Keywords: blasting; ground vibration; delay time; limestone quarry

W ostatnich latach w Turcji notuje się znaczny wzrost ilości prac związanych z wydobyciem surowców i drążeniem tuneli. W kopalniach rud metali, kamieniołomach oraz w części kopalń węgla produkcja odbywa się w głównej mierze przy wykorzystaniu odwiertów i prac strzałowych, w niektórych kopalniach drążone są tunele. Jest kwestia powszechnie wiadomą, że drgania wywołane pracami strzałowymi wywołują niekorzystne oddziaływania w środowisku naturalnych i budowlach znajdujących się w pobliżu. W artykule przedstawiono wyniki analiz i badań terenowych drgań wywołanych pracami strzałowymi w wybranym kamieniołomie w celu ich minimalizacji. Metodologia minimalizacji poziomu drgań wywołanych pracami strzałowymi (Turecki Instytut Patentowy – TPI 2007/03459) wykorzystana została do pomiarów zasięgu oddziaływań prac strzałowych i modelowaniu danych i parametrów prac strzałowych zgodnie z tureckimi i niemieckimi normami.

Słowa kluczowe: prace strzałowe, drgania gruntu, czas zwłoki, kamieniołom, wapień

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1. Introduction

Drilling and blasting are the most widely adopted excavation techniques for mining and civil engineering. Rock blasting results in ground shock and vibration which may cause damage to the surrounding structures such as buildings, bridges, dams, tunnels, etc., therefore, blast-induced ground shocks and their propagation in rock mass have been drawing more and more attention (Wu et al., 1998).

Blasting is one of the most energy/economic-efficient methods of rock fragmentation which is widely used in mining, civil, construction, and environmental projects around the world. However, there are several drawbacks, including but not limited to: nearby residents' complaints, damage to residential structures, damage to adjacent rock masses and slopes, damage to the existing ground water conduits, and the ecology of the nearby area (Kahriman, 2001; Faramarzi et al., 2014; Torano et al., 2006; Singh et al., 1997; Gad et al., 2005; Nateghi et al., 2009; Afeni et al., 2009; Khandelwal et al., 2009; Marilena et al., 2012)

Companies using blasting operations are often faced with the necessity of limiting the vibration levels in order to minimize or eliminate the possibility of damage to the nearby structures. Therefore, proper blasting design is necessary to ensure both the safety of employees and the protection of nearby structures from the vibration effects (Ak et al., 2009). The most important effect of the rock excavations made by blasting is the vibrations created by explosion-induced seismic waves on the structures.

Engineering experiences show that the vibration level at any particular site is affected mostly by the maximum charge weight per delay (W), distance from the blast site (D), vibration frequency (f), and initiation method (Basu & Sen, 2005).

The prediction of ground vibration components plays an important role in the minimization of environmental complaints. In recent years, one of the problems encountered by technical personnel who are responsible for excavation with blasting is the rightful or unjustifiable complaints of people or organizations in the neighborhood (Felice, 1993; Kahriman et al., 2006a; Ozer et al., 2008).

Theory of the propagation mechanism of blast-induced waves, their potential effects on structures and seismic response of the structures to those vibrations have been investigated by many researchers (Zhang et al., 2005; Ewing et al., 2009; Constantopoulos et al., 2012; Mahmoud, 2014; Oncu et al., 2015; Xuelong et al., 2015; Uyar & Babayigit, 2016).

There are regulatory limitations on blasting vibrations which require that the users only need to know the maximum charge weight per delay and the distance to the location of concern. If there are concerns of the potential blasting damage, several established damage criteria (Turkish 2002/49/EC, DIN 4150) can be used to confirm the design (Siskind et al., 1980; DIN 4150-3, 1999). However, if the charge per delay is relatively small far the distance involved, it is generally true that the ground vibration caused by a blast will not be potentially damaging (Chen & Huang, 2000).

Instead of the conventional method of "determining the maximum amount of explosive per delay in order to be able to stay below the damage limits" to reduce the blast-induced vibrations of the blasting source, the "method of minimizing the blasting source vibrations" developed by G. Uyar and B. Ecevitoğlu (TPE 2007/03459).

Since the method is based on the principle of suppression of blast-induced surface waves, it deals only with the seismic wave and aims to give the most appropriate delays to provide destructive interactions of the seismic waves with each other. The most crucial point of the method is to model the seismic signal of the group detonation using the seismic signal of the pilot detonation.

Since the pilot signal contains all the effects along the line it travels (features related to detonation, confusion in the geology, etc.), no assumption or geological modeling is required in the modeling of the group exploitation. Two seismic signals are used in the method:

– Pilot-blasting signal: pilot blasting consisting of several holes in one part representing each hole in the group blasting
– Group explosion_ modeled signal: The linear superposition theory, which is obtained by linearly summing pilot burst signals, (Aldas & Ecevitoglu, 2007). Just as it is in world mining industry, it is important to minimize the vibrations and environmental effects of explosion in Turkish mining industry. In this study, a blasting design study was carried out in order to reduce the vibrations originating from blasting in a limestone quarry based on Turkish and German standards.

2. Geology of the study area

The study area is located in İzmir Province. Considering the geological structure in a regional sense, Mesozoic aged Izmir-Ankara Zone rocks and Paleozoic Menderes Metamorphic zone are spreading in large scale in the study region. The Menderes Metamorphics are composed of mica-schists, calc-schists and massive marbles in the upper parts of the southern part of İzmir (Erdogan & Gungor, 1992)

On the basic rocks, units belonging to İzmir-Ankara Zonu are over thrusted with overlay fault. Upper Cretaceous-Paleocene İzmir-Ankara Zone rocks have tectonic melange characteristics and consist of tectonic slices represented by sandstone-shale, spilite, serpentinite and chert and limestone blocks in various beds. In İzmir region, Neogene aged lacustrine sedimentary rocks and volcanic rocks cover Menderes metamorphics and İzmir-Ankara Zone rocks. All the mentioned units are covered by Quaternary alluvium. Menderes Metamorphics, Neogene Aged units and Quaternary alluvial alluvium are observed in the study area (Baris, 2008) (Fig. 1).

The mechanical-physical properties of the limestones observed in the study area are given in Table 1.

TABLE 1

Mechanical-Physical properties of the limestone

Properties	**Unit**	**Value**
Moh's Hardness	—	3-4
Unit Volume Weight	g/cm^3	2.71±0.02
Porosity	%	0,68
Uniaxial Compressive Strength	MPa	73.54±1.04
Water Absorption	%	0.85±0,11

3. Instrumentation and data measurement

Blast-induced vibrations were monitored by a seismograph. Seismograph has three channels, are allocated to the vibration measurement in three directions, i.e. longitudinal (Lon.), vertical (Ver.), transverse (Tran). This seismograph also records the dominant vibration frequency, peak

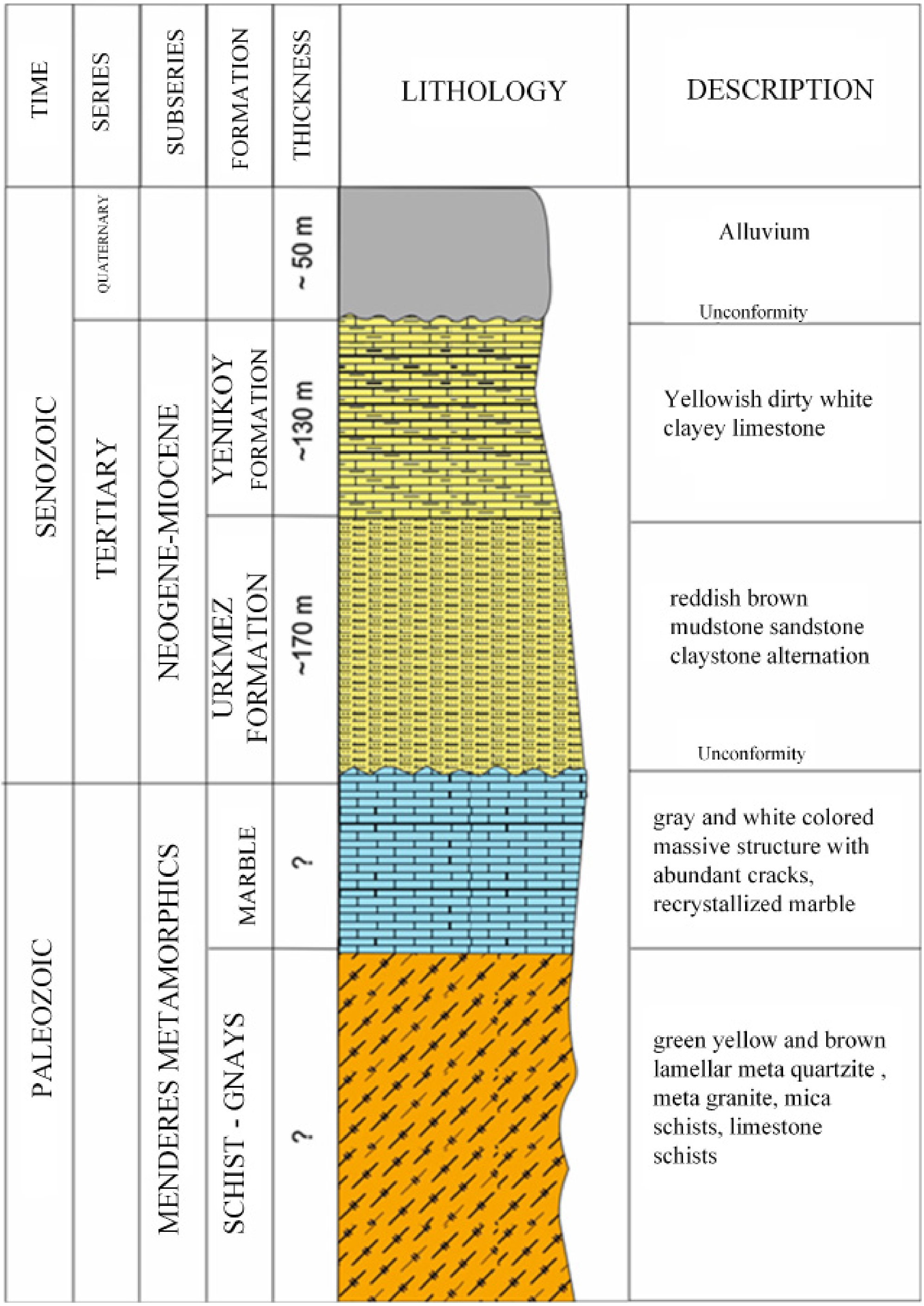

Fig. 1. Generalized column section of study area (by changing Baris, 2008)

particle acceleration (PPA), and peak particle displacement (PPD),and computes the peak vector sum (PVS) of vibration. PVS represents the resultant particle velocity magnitude, and is defined as follows

$$PVS = \sqrt{V_L^2 + V_T^2 + V_V^2} \tag{1}$$

Where V_L, V_T, and V_V are the longitudinal, transverse, and vertical components of vibration, respectively. In fact, the frequency of blast-induced waves is generally controlled by geological conditions and delay arrangements. There are geological forms and structures that are favorable to the formation of different types of frequency waves. When the incoming vibration has a frequency in the range of natural frequency of the structure, resonance occurs and the resultant amplitude of vibration on the structure is amplified (Rosenthal & Morlock, 1987).

The Instantel seismometers with three components 1 Hz geophone was used in the limestone quarry in this study (as shown in Fig. 2). 4 Hz geophones are often used, but the measurement of vibrations on 1-4 Hz is more important because the blast-induced vibrations do the damage (Siskind et al., 1980). The peak particle velocity (PPV) is recorded by seismometers and then, the records are transferred to a computer by Blastware software of the Instantel (Aldas & Ecevi-toglu, 2008).

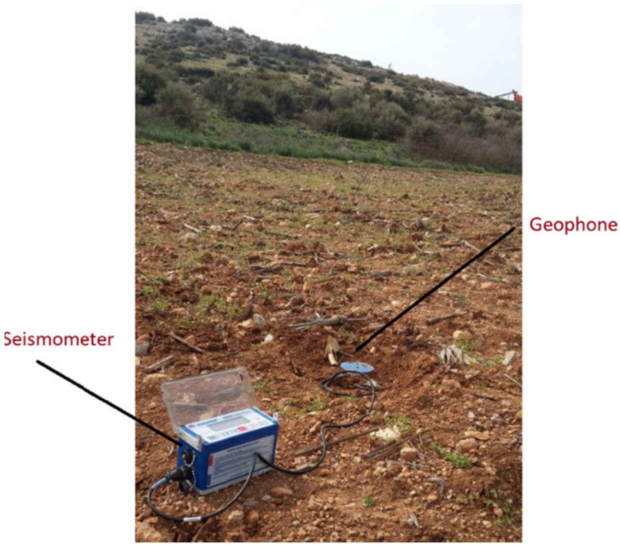

Fig. 2. Seismometer and geophone

4. Measurement location

The study area is located in Çileme/ Menderes at İzmir (as shown in Fig. 3). The operat-ing license covers 97.82 hectares area, which is far from 2.5 km to Karakuyu, 3.5 km to Tekeli Ataturk District and 2.5 km to Çileme. Boundaries of the operating license (OL) and permitted operating area (POA) of the limestone quarry, which belongs to the private corporation, are shown in Fig. 4. There are water wells belonging to General Directorate of State Hydraulic Works (DSI) and individuals that are critical in terms of the blasting activities. Distances from operating license boundary to DSI and individuals water wells are given in Table 2 according to related documents and analysis of field works.

TABLE 2

Distances from operating license boundary to water wells

Nearest Corner of Permitted Operating Area	Water Well No.	Distance
POA5	DSI 1	3.1 km
	DSI 2	2.9 km
	DSI 3	2.8 km
	DSI 4	2.5 km
	DSI 5	3.1 km
	DSI 6	3.1 km
	DSI 7	3.2 km
	DSI 8	2.3 km
	DSI 9	2.2 km
	DSI 10	2.2 km
	DSI 11	2.2 km
POA2	Water well 1	601 m
	Water well 2	353 m
	Water well 3	365 m
	Water well 4	430 m
	Water well 5	343 m

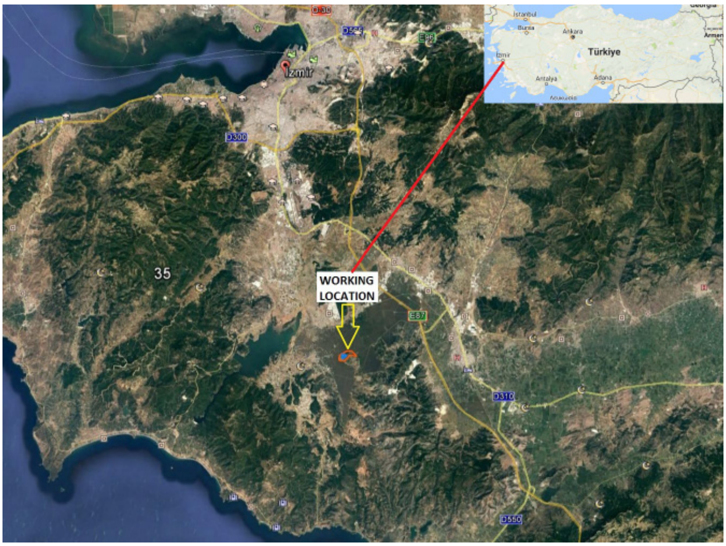

Fig. 3. Site location map

Fig. 4. Boundaries of the operating license and permitted operating area
(Blue Lined Area: Permitted operating area – Red Lined Area: Boundaries of the operating license)

5. Field work

The distances from the blasting site to the monitoring stations were measured precisely by means of a hand-held global positioning system (GPS) instrument, and the amount of charge weight per delay was recorded for each shot by controlling the hole charges.

In determining the maximum charge per delay, the amount of dynamite used as priming was added to the amount of blasting agent. In the blasting operations, ANFO (blasting agent) and gelatin dynamite were used as the explosives during the study. The blast holes were vertical and 89 mm in diameter. The holes length are 11 m, with approximately 1 m of sub-drillings, 3.5 m of hole length as stemming and 7.5 m of hole length as explosives (ANFO) for all blast patterns. An electrical millisecond delay system was used to initiate the charge.

Methodology for Minimizing Blast-Induced Vibrations (TPI 2007/03459), which was developed by G.G. Uyar and B. Ecevitoglu, is used instead of the conventional method “Peak Particle Velocity (PPV)/Scaled Distance (SD)” for minimization of blasting vibrations (Aldas & Ecevitoglu, 2007)

5.1. Application of the methodology

- The pilot-blast underlies the methodology.
- Firstly, a pilot-blast is fired.
- The group-blast is made up of pilot blasts, therefore, the pilot-blast hole should be charged as representing each one of the group-blast holes.
- Unlike classical approach, the geometry of the blast hole or amount of the charge is not important in the methodology, which cares only seismic waves. While the blast-holes are charging, acting in accordance with the instructions of the engineer (Aldas & Ecevitoglu, 2008)
- The blast-hole is charged and then, waiting for the time-delay given by SeisBlast software running in MS-DOS environment.

- After the pilot-blast signals are identified by software at this stage, it is decided that how the blast-holes are grouped and what the time-delay is.
- A comparison is made between the group-blast data and the model data, which is obtained from the software program results.

5.2 Fieldwork: measurement and analysis of blast-induced vibrations

Field studies have been carried out to reduce the vibration of the blast-induced seismic waves below the permitted limits in the target location by using the methodology previously mentioned in section 4.1. Blast-induced seismic waves between the pilot-blast and target location were analyzed and a group-blast was modeled according to the analyzed results. Field works were carried out in two stages. The pilot-blast was fired and vibration measuring was taken from near the water wells with three seismometers in the first stage on 6th March 2017. Then, a group-blast model was created to minimize the blast-induced vibrations by using the pilot-blast signals and the time-delays were estimated on the target location. In the second stage on 22nd March 2017, the simulated group-blast signal and the real group-blast signal are compared.

Fig. 5. Locations of the pilot-blast and record stations (16th March 2017)

TABLE 3

Blast-Induced vibration records

Blasting	D (mm)	H (m)	Q (kg)	Seis-mometer	R (m)	Velocity and Frequency		
						Transversal mm/s	Vertical mm/s	Longitudinal mm/s
Pilot-Blast	89	11	45 kg ANFO 0.5 kg Dynamite	3	479	0.254 3.7 Hz	0.385 6 Hz	0.508 3.7 Hz
				2	2900	—	—	—
				1	2500	—	—	—

5.2.1. First stage: analysis and measurements on 16th March 2017

A pilot-blast, which represents the real group-blast of the quarry, was charged and fired at this stage. The pilot-blast hole has the same specifications of the each one of the blast-holes were grouped.

The pilot-blast hole was drilled at where group-blast will be fired to see blast-induced peak particle velocity (PPV). Besides, the signature of the seismic waveforms of the pilot-blast was get between the source and target locations. The group-blast model was generated without the need details of the complex geology model by using seismic waveform signature (Aldas & Ecevitoglu, 2008). The locations of the pilot-blast and record stations are shown in Fig. 5. Blast-Induced vibration records are shown in Table 3. Seismometer 1 and 2 were placed in the DSI water well, while Seismometer 3 was placed next to an individual water well 2, 500 meters from the pilot hole.

The purpose of these measurements is to ascertain surface waves, which are on the signals or not, to 2500-2900 m distance. While a group-blast were planning, it was aimed that higher amplitudes of surface waves than the seismic waves are on the no signals before getting on the target by using 45 kg ANFO and appropriate time-delays. Before arriving the real group-blast seismic waves to target (DSI-water well), they are going to be ensured on the no signal by using the simulated group-blast. At this field work, the seismic waves of the pilot-blast were taken from the just one target location (individual water well) by Seismic Recording Unit 3. The group-blast was modeled with the pilot-blast results by using Seisblast software, which is developed by G.G. Uyar and B. Ecevitoglu (2007). Blast-hole design with 15 holes is shown in Fig. 6, which also includes the time-delays.

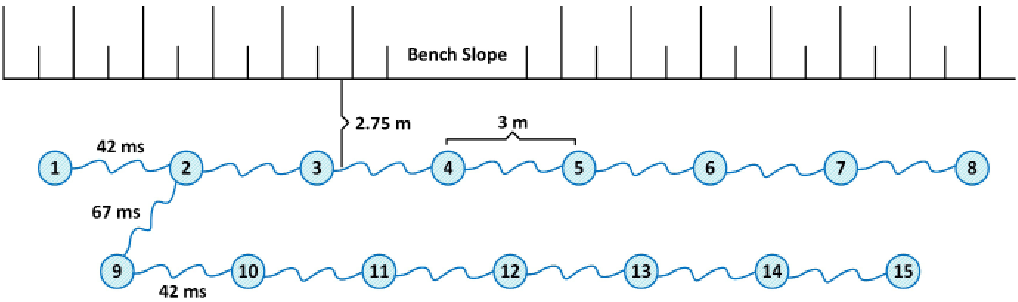

Fig. 6. The blast-hole design with 15 holes

The blast-hole design was used in Seisblast software and the results are shown in Fig. 7. When time-delays are at 42 ms between the blast-holes and at 67 ms between the blast-lines and inter-hole delays are 500 ms, the blast-induced vibrations are minimizing.

5.2.2. Second stage: analysis and measurements on 22nd March 2017

A pilot-blast and a group-blast with 15 holes were fired on 22nd March 2017. The first pilot-blast and the second one have same specifications and the group-blast model was done according to the first pilot-blast seismic signals. To minimize blast-induced vibrations in the group-blast, delays are obtained at 42 ms between the blast holes and 67 ms between the blast

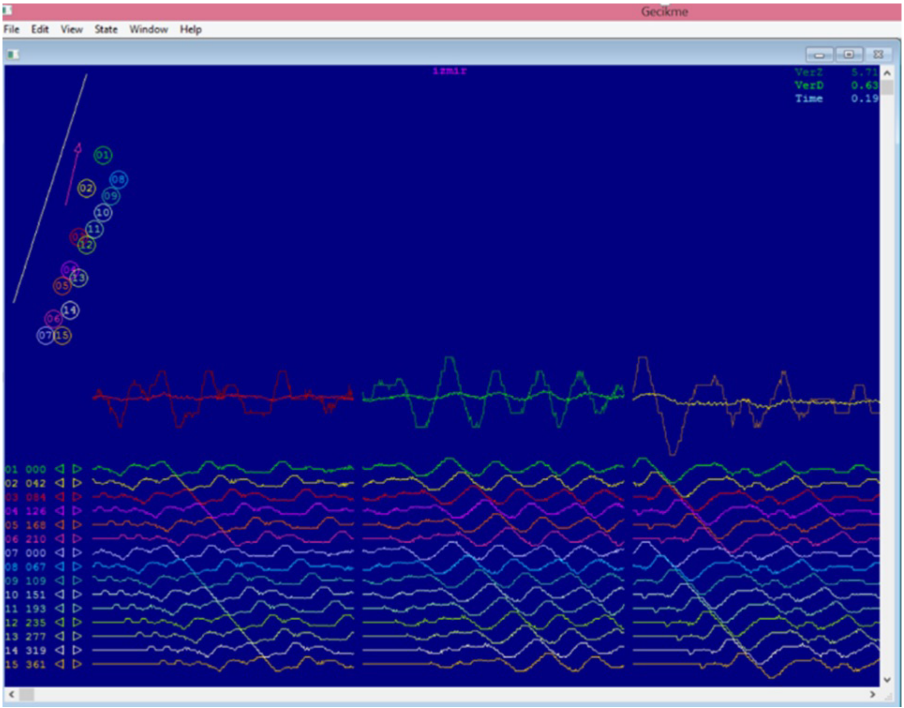

Fig. 7. Model for delays at 42 ms between blast-holes and 67 ms surface delay

lines. The delays as a mentioned before were used in the group-blast on 22nd March. In addition, one more the pilot-blast with one blast-hole was fired before the group-blast fired to control the time-delay is appropriate or not. Then, a comparison was made between the signals one more time and a new group-blast was created. Target location and record stations are shown in Fig. 8 for the pilot-blast and Fig. 9 for the group-blast.

Fig. 8. The second pilot-blast location and record stations (22th March 2017)

TABLE 4

The pilot-blast and the group-blast vibration records (22th March 2017)

Blasting	D (mm)	H (m)	Q (kg)	Seis-mom-eter	R (m)	Velocity and Frequency			Sum
						Transversal mm/s	Vertical mm/s	Longitudinal mm/s	
Pilot-Blast	89	11	42 kg ANFO 0.5 kg Dynamite	3	140	0.635 mm/s 8 Hz	0.762 mm/s 9.5 Hz	0.889 mm/s 6 Hz	1.092 mm/s
				1	269	0.381 mm/s 11.25 Hz	0.381 mm/s 8.25 Hz	0.508 mm/s 6 Hz	0.554 mm/s
				2	464	—	—	—	—
The group-blast	89	11	40 kg ANFO 1 kg Dynamite	3	2400	—	—	—	—
				1	452	0.635 mm/s 3.87 Hz	0.889 mm/s 5.12Hz	0.762 mm/s 6.25 Hz	1.032 mm/s
				2	464	0.635 mm/s 6 Hz	0.635 mm/s 5.87 Hz	0.762 mm/s 3.75 Hz	0.842 mm/s

Fig. 9. Location of the group-blast and record stations (22th March 2017

The signals were taken from Seismometer 3 and Seismometer 1 except Seismometer 2, where near individual water well in the pilot-blast. The group-blast was fired with applied time-delays. The time-delays of the group-blast with 11 blast-holes are shown in Fig. 10. The group-blast which was modeled with the pilot-blast time-delays was fired but the Seismometer 1 where is near DSI water well did not have any signals.

The blast-induced vibrations taken from Seismometer 1 and Seismometer 2 are under the permitted limits according to both German DIN-4150 and Turkish Standards. Comparison between the blast-induced vibrations and the Standards are shown in Fig. 11 and Fig. 12. As a result, the peak particle velocity (PPV) of vibrations are under the permitted limit value for constructions when compared to both standards.

As can be shown in Table 4, the group-blast-induced seismic surface waves were not on signals before arriving DSI water well. Time-delays between blast-hole groups were determined as in Fig. 10.

The group-blast, which was created according to surface waves of Seismometer 1 signals, have not yet time-delays (as shown in Fig. 13). The amplitude of the simulated group-blast is same in transversal (red), vertical (green) and longitudinal (yellow) seismic waves. Surface waves of the blast-holes with appropriate time delays, which is at 42 ms between the blast-holes and 67 ms between blast-lines are shown in Fig. 14. The amplitude of the group-blast with time-delays are nearly set to zero. The simulated group-blast is reliable because of the amplitude of the real group-blast is around 0.762 mm/s.

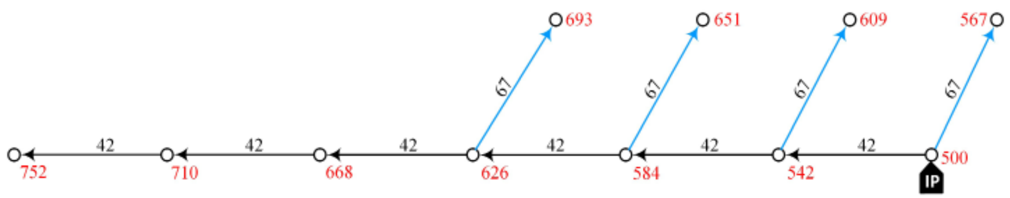

Fig. 10. Time-delays of the group-blast

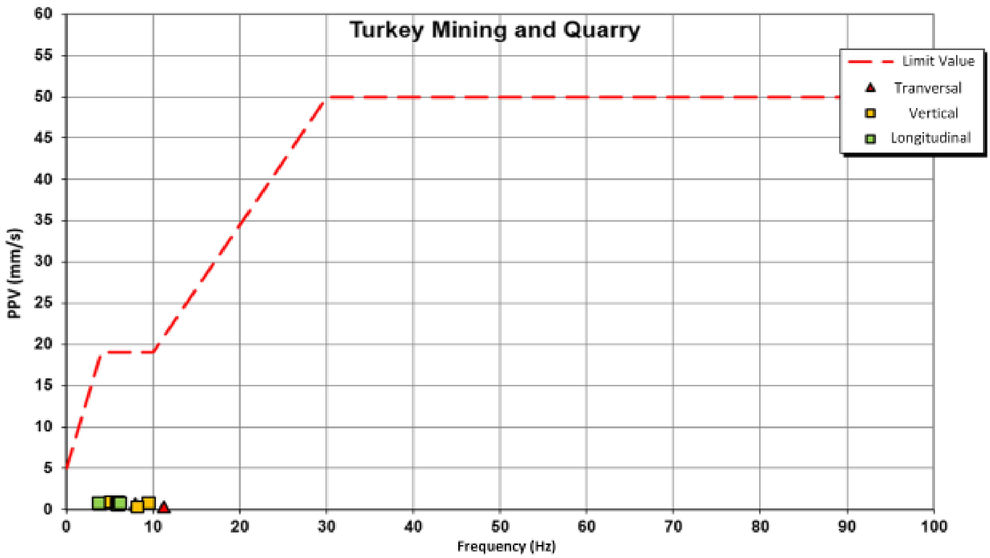

Fig. 11. Turkey Mining and Quarry

6. Conclusions

In this research study, as mentioned above our aim was to propose a general blast-induced vibration predicting model for limestone quarry. There are the pilot-blast vibration results at the

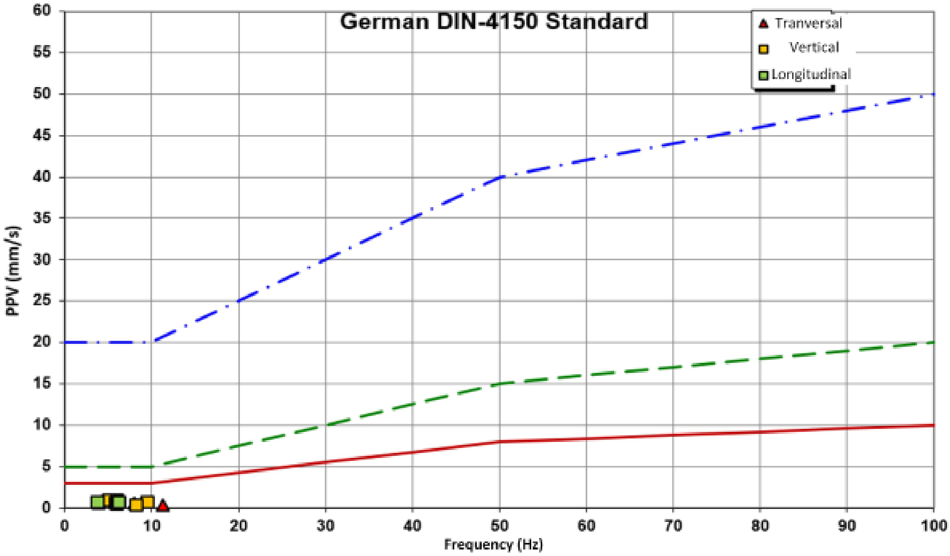

Fig. 12. German DIN-4150 Standard

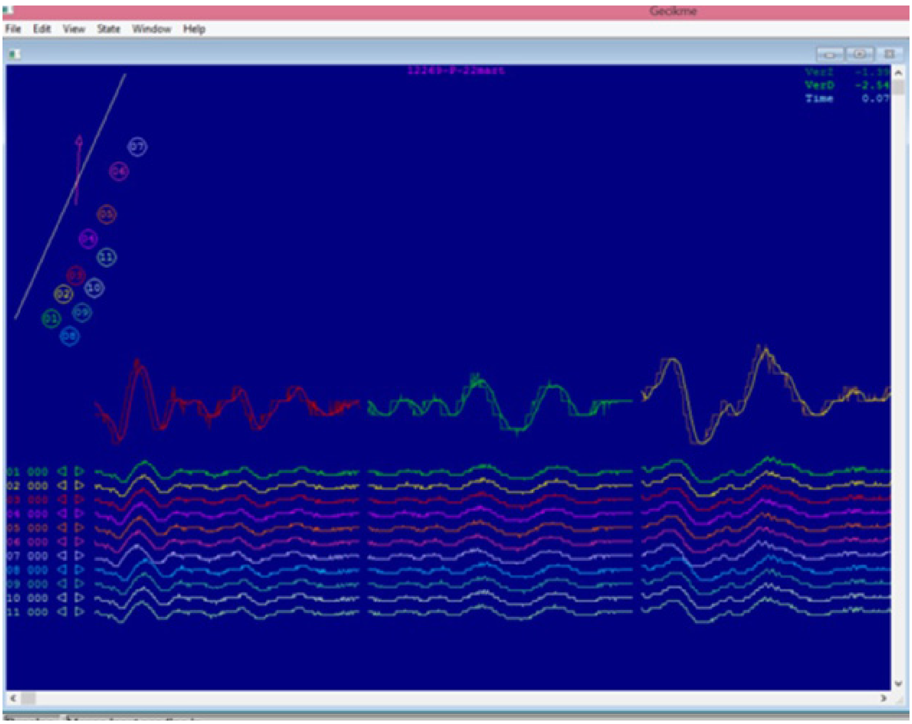

Fig. 13. The pilot-blast-induced seismic waves screen. There are no time-delays yet

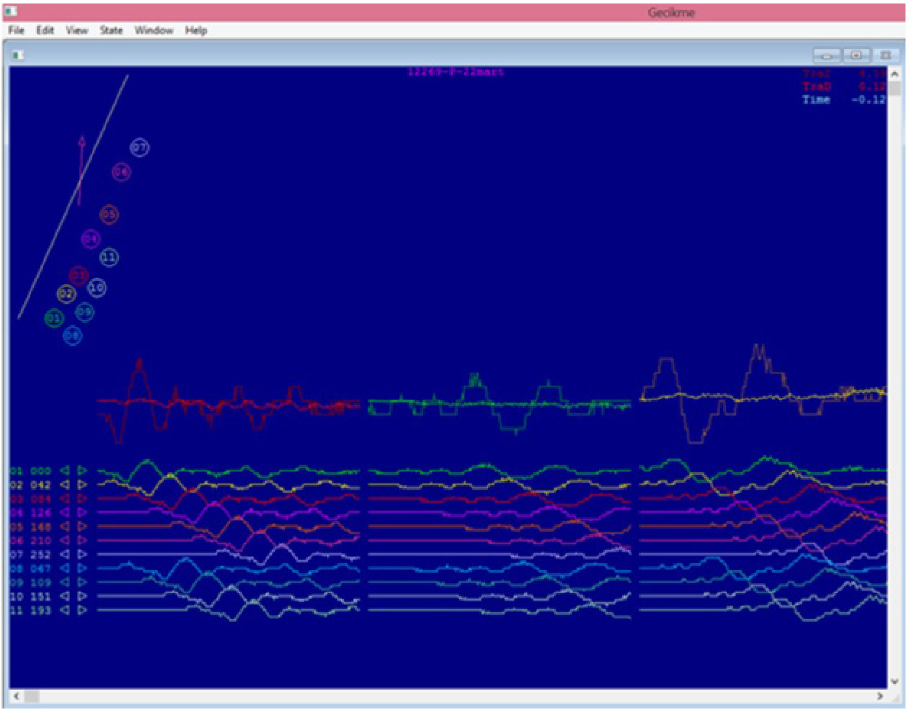

Fig. 14. The group-blast-induced seismic waves screen. The time-delays are at 42 ms between the blast-holes and 67 ms between blast-lines

target locations which are DSI and individual water well by using three seismometers on 16th March 2017 and the group-blast modeling which was fired on 22nd March 2017 in this study.

"Methodology for Minimizing Blast-Induced Vibrations (TPI 2007/03459)", which was developed by G. G. Uyar and B. Ecevitoğlu, was used in modeling. Because the methodology is more advantageous than the classical method "Peak Particle Velocity (PPV)/ Scaled Distance (SD)". Especially, evaluation of results do not based on the greatest particle velocity; the frequency characteristic and the vibration period, there is no restriction of the amount of the explosive, and the record from a single seismograph can be used for accurate analysis. The base of the methodology is damping surface waves each other at target locations. Firstly, a pilot-blast was fired while surface wave signals were been recording and then, a group-blast model was created in implementation of the methodology.

The time-delays should be at 42 ms between the blast-holes and 67 ms the blast-lines to stay under the limits and minimize blast-induced vibrations according to the model at the target location (DSI and individuals water well). The appropriate amount of ANFO should be under 40 kg (each one of the time-delays) for 89 mm diameter and 11 m deep blast-hole to minimize the blast-induced vibrations. Moreover, stemming should be higher than 3.5 m for blasting recovery and avoiding to rock burst (for 11 m deep and 89 mm diameter blast-hole).

The model results have been applied the real group-blast. The seismometer, which is near DSI water well, has any signal. The other seismometer results are below permitted limits according to the Turkish and German DIN norms. The amount of feeding-sensitive and capsule sensitive explosives which are used at target location are appropriate for the environment.

It is as important exposing time of the target locations as amplitudes and frequency of seismic waves. Because of this reason, data were investigated during exposing time of the seismic waves and it was seen that the vibration times were under the 1.5 s. It is known in the literature that the exposing time of vibration should not be higher than 2 seconds to not damage construction in around so, the exposing time of this work is appropriate. The fieldworks should be repeated and supervised in terms of change of the quarry operating direction and blasting slope depth for protection of around construction and underground water during the operation. It can be considered that the blasting pattern can be changed if it is necessary after analysis done during the operation.

At the end of these analyses, there are no harmful effects of blasting on DSI and individuals water wells, which are around the operating license boundaries, by using suggested blasting parameters and blast-pattern as a result.

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