Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 34(2), ss. 241-248, Haziran 2019
Çukurova University Journal of the Faculty of Engineering and Architecture, 34(2), pp. 241-248, June 2019

Development of a Preliminary Blasting Design and Assessment of Environmental Impacts for a Quarry

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Geliş tarihi: 02.04.2019 Kabul tarihi: 28.06.2019

Abstract

The most commonly used excavation method in the mining, quarry and construction sectors is the drilling and blasting method. This method has many advantages as well as disadvantages in terms of environmental impacts. The most important adverse environmental effects caused by blasting can be said as vibration, air shock and dust emission. In order to minimize these environmental impacts, a proper blasting design plays an active role by taking the principles of controlled blasting into account. In this study, an appropriate pre-blasting design was performed to meet the production capacity increase in a quarry, and the environmental impacts of this design on the settlements and olive groves, which were determined as a critical structure near the quarry, were estimated. The risk of damage to critical structures is found to be low with assessment of the estimated peak particle velocity (PPV) values for the amount of charge per delay in the proposed blasting design model due to the fact that these values are well below the permissible threshold damage limits in the regulation. According to air shock and dust emission value analysis, the estimated values were found to be below the limit values given in the related regulations. As a result, it was determined that the proposed design model for the quarry is a suitable model in terms of its environmental impacts, but the design should be tested with the test shots in the field.

Keywords: Drilling and blasting, Blasting design, Ground vibration, Dust emission, Air shock

Bir Taş Ocağı için Ön Patlatma Tasarımı Geliştirilmesi ve Çevresel Etkilerinin Değerlendirilmesi

Öz

Maden, taş ocağı ve inşaat sektörlerinde en yaygın olarak kullanılan kazı yöntemi delme-patlatma yöntemidir. Bu yöntemin birçok avantajı olduğu kadar çevresel etkileri açısından dezavantajları da olduğu bilinmektedir. Patlatmadan kaynaklanan olumsuz çevresel etkilerin en önemlileri titreşim, hava şoku ve toz emisyonu olarak sıralanabilir. Bu çevresel etkileri en aza indirmede, kontrollü patlatma ilkeleri gözetilerek uygun bir patlatma tasarımı yapılması etkin rol oynamaktadır. Bu çalışmada, bir taş ocağında üretim kapasitesi artışını karşılayacak uygun bir ön patlatma tasarımı yapılmış ve yapılan ön tasarımın

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ocağın yakınında kritik yapı olarak belirlenen yerleşim yerlerine ve zeytinliklere olan çevresel etkileri tahmin edilmiştir. Önerilen patlatma tasarım modelindeki gecikme başına düşen şarj miktarı için tahmin edilen en yüksek parçacık hızı (PPV) değerlerinin, yönetmelikte izin verilen eşik hasar sınır değerlerinin oldukça altında olması nedeniyle, kritik yapılar üzerindeki hasar riskinin en az olacağı öngörülmüştür. Hava şoku ve toz emisyonu değerleri için yapılan analizlerde, tahmin edilen değerlerin ilgili yönetmenliklerde verilen sınır değerlerin altında kaldığı görülmüştür. Sonuç olarak, taş ocağı için önerilen tasarım modelinin, çevresel etkileri açısından uygun bir model olduğu, ancak tasarımın sahada yapılacak deneme atımlarıyla test edilmesi gerektiği belirlenmiştir.

Anahtar Kelimeler: Delme patlatma, Patlatma tasarımı, Yer sarsıntısı, Toz emisyonu, Hava şoku

1. INTRODUCTION

Drilling and blasting is widely used in mining, quarrying, construction sectors and other infrastructure works requiring excavation. Due to the increasing industrialization in the world and in our country, the need for raw material increases rapidly. Depending on this increasing demand, these activities where excavation with blasting is inevitable are approaching settlements.

One of the most important inputs of production costs in a quarry is the drilling and blasting costs. In addition, drilling and blasting directly affect the costs of post-excavation activities. For this reason, blasting designs should be done carefully in order to achieve the desired level of blasting results [1]. There are a number of parameters that have an impact on the safe and economical blasting design (Hoek and Bray [2], Atlas Powder [3], Tamrock [4], Bilgin [5], Olofsson [6], Konya and Walter [7], Singh [8]). In the literature, various researchers have proposed experimental approaches to design blasting according to operating conditions. The most widely used approaches can be listed as Langefors and Kihlstrom [9], Olofsson [6], Atlas Powder [3], Konya and Walter [7], Jimeno [10]. However, the powder factor and the appropriate burden, which are the most important parameters of a blasting design with these approaches, are difficult to determine precisely beforehand. Therefore, the blasting design developed prior to application in the field is considered as preliminary blasting design, and it is suggested that this preliminary design is tested by trial and error blasts in the field. According to the results of the test blasts carried out, if necessary, the preliminary design is updated and the final design is obtained for the site.

Widely used drilling and blasting methods can cause environmental problems such as ground vibration, dust emission and air blast. People, livestock and structures in settlements close to excavation sites can be adversely affected by these environmental impacts of blasting. This situation may cause various disagreements and problems between the people of the region and the firm. Therefore, one of the most important results expected from a good blasting practice is that the shots should be safe and sensitive to environment. With the design to be made; minimizing the environmental impacts caused by blasting should be targeted. It is important to implement controlled blasting techniques to achieve this goal [11].

The aim of this study is to design an appropriate pre-blasting pattern to meet the production capacity increase in a quarry near the Cihatlı Village of Gemlik District of Bursa Province and also to estimate and assess the environmental impacts that will be caused by applying the developed pre-blasting design on the settlements and olive groves.

2. TEST SITE AND GEOLOGY

Test site is a quarry which is producing rock fill material in various sizes. The quarry's license limits on the plan view taken from Google Earth and the overview of the quarry are shown in Figure 1.

Figure 1. Satellite view and overview of the quarry

In the field study; it has been determined that there are settlements and olive groves at closer distances compared to the settlements, where they are at the risk of possible environmental impacts of blasting operations. In the Environmental Impact Assessment (EIA) report prepared for this quarry, the current production capacity is 72000 tons per year and it is planned to increase the capacity to 390000 tons per year.

The regional geological setting of Gemlik and adjacent areas is given in the study of Avşar [12] as "Geological structure in the environs of Gemlik is represented by basement rocks around the Qaternary deposits on which Gemlik settlement is located. The basement rocks in the area are composed of Triassic metabasic lava, metaspillite, radiolarite, chert with calc-schist and marble lenses; Early-Middle Jurassic micritic limestone; Middle Jurassic to Early Cretaceous meta-sandstone, metapelite, phyllite, slate, metashale, quartz-sericite schist, clayey schist, calc-schist and marble; Early Cretaceous recrystallized limestone; Early-Middle Eocene sandstone-siltstone and shale alternation with volcanic intercalations; and Quaternary alluvium, talus and beach sand deposits". The geological map of the region is shown in Figure 2 [12].

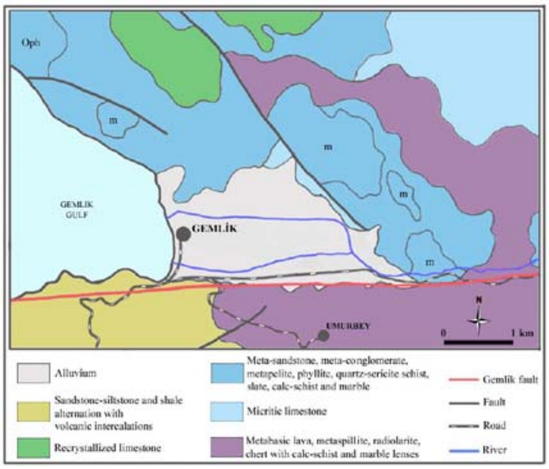

Figure 2. The geological map of the region [12]

In order to get an idea about the strength of the rock formation in the quarry, the Schmidt hammer test was carried out at three different points. As a result of the experiments, it was found that the uniaxial compressive strength of the limestone formation from Schmidt hammer test data is found to be between 40 and 75 MPa. Therefore, it is concluded that the excavation with blasting in this field is inevitable.

3. PRE-BLASTING DESIGN MODEL

The application of the principles of Controlled Bench Blasting is proposed to be used in the design in order to ensure the use of the energy released from the explosion of explosive material to break down rock material effectively by minimizing the energy forming the seismic wave and other environmental effects.

In design, ANFO was selected as the main explosive. However, in the case of water in the blasting holes, it is also proposed to use a primer-sensitive emulsion-type explosive. As a primer cartridge, a suitable dynamite with a length of twice the diameter was chosen. Each hole was intended to detonate separately with the usage of nonelectric detonators with millisecond delay as initiating system, resulting in keeping the charge per delay at minimum level.

Two-row staggered pattern with sufficient delay between the rows will be used. The design conditions of the blasting pattern are given in Table 1. According to the conditions given in Table 1, the preliminary blasting design model parameters calculated using Olofsson [6] approach are given in Table 2.

Table 1. The design conditions of the blasting pattern

Parameter	Unit	Value
Bench Height (K)	m	12
Blasthole Diameter (D)	mm	89
Charge Concentration	kg/m	5.29
Main Explosive		ANFO
Hole Inclination	o	79
Correc. for Hole Inc. (R1)		0.98
Rock constant (C)		0.4
Correc. for Rock cons.		1

According to the pre-blasting design, the amount of explosive used per delay in each shot was determined as 57 kg. The planned production capacity is 390000 tons annually after the capacity increase. In the calculations; the density of limestone was taken as 2.6 ton/m^3 and the assumption of the fact that the quarry will be operated in 10 months of a year and 24 days of a month is made. The amount of rock to be exploded in shot which is planned as one shot per week is found to be 9750 tons or 3750 m^3.

Table 2. Preliminary blasting design model parameters

Parameter	Unit	Value
Maximum Burden (Bmax)	m	3.1
Subdrilling (U)	m	0.9
Hole depth (H)	m	13.2
Error in Drilling (E)	m	0.5
Practical Burden (B)	m	2.6
Practical Spacing (S)	m	3.2
Specific Drilling (b)	m/m^3	0.13
Height of Stemming (ho)	m	2.6
Height of Charge (h)	m	10.6
Primer (Dynamite)	kg	1
Charge Weight per Hole (Q)	kg	57
Specific Charge (q)	kg/m^3	0.57

In order to achieve the planned production quantity, the number of blasting holes required to be drilled is found to be 42 holes per shot. The representative plan and section views of the proposed pre design model for the site are shown in Figure 3.

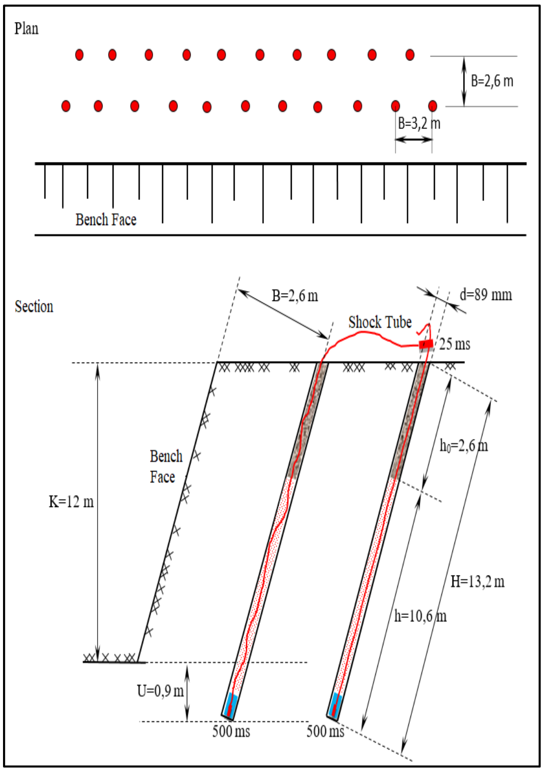

Figure 3. The representative plan and section views of the proposed pre design model

4. ASSESSMENT OF ENVIRONMENTAL IMPACTS AND RESULTS

During the field study carried out in the quarry, it was determined that there were two settlements in the immediate vicinity and olive groves in the west and southwest directions. These settlements and olive groves were determined as critical structures in terms of the environmental impact of blasting. The distances of these critical structures to the center of the operation permit area are measured on the map and are given in Table 3.

Table 3. The distances of critical structures to the quarry

Name	Distance (m)
Şahinyurdu 1	2050
Şahinyurdu 2	1980
Cihatlı 1	1350
Cihatlı 2	1250
Olive grove (W)	550
Olive grove (SW)	350

The effects of environmental impacts such as vibration, dust emission and air shock on the critical structures that could be induced by the proposed preliminary design model is investigated using the approaches accepted in the literature.

4.1. Ground Vibration

One of the important environmental impacts of blasting is the negative effects of ground vibrations on structures. The most commonly used concept in the estimation of blast-induced vibrations is the concept of Scaled-Distance (SD), which is generally defined by considering the distance from the blasting point and the amount of charge per delay. After determining the SD for each shot, univariate regression analysis is performed by using particle velocity values and SD values to find the parameters of an estimation equation [13]. Although various estimation equations are proposed by different researchers, the most common form of estimation equation is the given in Equation 1.

$$PPV=K\cdot SD^{-\beta} \quad (1)$$

PPV: peak particle velocity, m/s
K, β: field constants
SD: scaled distance ($R/\sqrt{W}$), $m/kg^{1/2}$
R: distance to blasting point, m
W: maximum charge per delay, kg

As a result of the analysis, field constants of vibration attenuation equation specific to this site are determined. After determining the field constants, the peak particle velocity (PPV) values that may occur at different distance and different charge (explosive) amounts for the field can be estimated with the help of this equation. However, in the quarry where this research is carried out, there is no excavation due to various reasons. Therefore, vibration attenuation equation constants of this quarry could not be determined by this measurement method.

In the literature, it is recommended to use the field constants given in Table 4 in order to be used in the estimation of ground vibration of the sites where field constants are unknown due to various reasons [14].

Table 4. Field constants

	K	β
Lower bound	172	-1.6
Average	1140	-1.6
Upper bound	1725	-1.6
Common Bound	4316	-1.6

The field constants given as the upper bound in Table 4 are selected to predict PPVs in this study. This selection has been made because PPV values calculated with the upper bound constants are higher than the PPV values calculated with average and lower bound constants. Thus, a more conservative and safe prediction is provided. Using these field constants, PPV values were estimated for the site, using the distances given in Table 3 and the amount of charge per delay of 57 kg recommended in the blasting design model Table 5.

Table 5. Predicted PPV values

Name	Distance (R), m	PPV, mm/s
Şahinyurdu 1	2050	0.22
Şahinyurdu 2	1980	0.23
Cihatlı 1	1350	0.43
Cihatlı 2	1250	0.49
Olive grove (W)	550	1.81
Olive grove (SW)	350	3.72

These estimated PPV values are well below the permissible limit (5 mm/s) at the lowest frequency in Turkish regulation. Therefore; It is foreseen that blasting to be done in accordance with the proposed blasting design model will not have any negative effects on vibration and present any risk of damage on settlements and olive groves surrounding the quarry. Furthermore, in the case of blasting getting close to settlements or growth of settlements, PPV values for different distances and different maximum charges per delay (calculated for different hole diameters) are estimated by using these field constants Table 6.

Table 6. PPV values for different distances and different maximum charges per delay

(D) (mm)	(W) (kg)	PPV, mm/s					
		Distance (R, m)					
		350	550	1250	1350	1980	2050
76	43	2.97	1.44	0.39	0.34	0.19	0.18
89	57	3.72	1.81	0.49	0.43	0.23	0.22
102	72	4.49	2.18	0.59	0.52	0.28	0.27
110	83	5.03	2.44	0.66	0.58	0.31	0.30
115	89	5.32	2.58	0.69	0.61	0.33	0.31
127	106	6.12	2.97	0.80	0.71	0.38	0.36

As it can be seen from Table 6, nearly all predicted PPV values are found to be below the allowed limit value except the values calculated for blastholes of 110 mm and higher in diameter at the distance of 350 m.

4.2. Dust Emission

Another significant environmental impact of blasting is the dust emission. According to the proposed pre-blasting design, 9750 tons of limestone are planned to be excavated at each shot. According to the Turkish Regulation on the Control of Industrial Air Pollution, it is projected that the dust emission mass flow rate will be 0.08 kg/ton in uncontrolled blasting and zero in controlled blasting (water application before blasting). In the case of uncontrolled blasting, the amount of dust emitted in each blast is calculated as 780 kg/blast by using Equation 2.

$$\text{Dust emission amount} = A_p \cdot 0.08 \qquad (2)$$

A_p: Excavation amount planned in each blast, ton

80% of the dust resulted from blasting produces particles larger than 10 microns and precipitates and the rest is carried with the wind. In this case, the amount of dust (PM10) less than 10 microns carried after blasting is 156 kg / blast.

According to meteorological observations of Gemlik Cihatlı Village, when the weather conditions and wind direction were taken into consideration, wind speed and the maximum height at which the dust emerged during blasting was accepted as 3.7 m/s and 40 m, respectively. Dust dispersion was calculated with the following Equation 3 using the box model [15].

$$P_k = M_k / u \cdot R \cdot H \qquad (3)$$

Pk: Mass balance concentration, µg/m^3
Mk: Mass input rate, µg/s
U: Wind speed, m/s
R: Distance, m
H: Height, m

Mass balance concentrations and 24-hour dust concentrations were calculated and given in Table 7 for the blasting.

Table 7. Mass balance concentrations and 24-hour dust concentrations

Name	Distance (m)	PM10 (µg/m^3)	PM10/24 (µg/m^3)
Şahinyurdu 1	2050	143	6
Şahinyurdu 2	1980	148	6
Cihatlı 1	1350	217	9
Cihatlı 2	1250	234	10
Olive grove (W)	550	532	22
Olive grove (SW)	350	837	35

Air Quality Limit Values in the plant impact area given in the annex of the regulation on the Control of Industrial Air Pollution for Airborne Particulate Matter (PM10) is 60 µg/m^3 for 2018 and 50 µg/m^3 for 2019 and after, not allowing to exceed these values more than 35 times a year within a 24-hour period.

It is determined that the emission value of PM10 dust particles, which will be released as a result of blasting and being airborne, will be below 50 µg/m^3 even for the nearest olive grove in case of uncontrolled blasting.

4.3. Air Blast

Another important environmental impact of blasting is the propagation of air shock induced by blasting as noise. Generalized Equation 4 is used in the estimation of overpressure (air blast) resulting from blasting [16].

$$SPL=20\cdot\log\left[K\cdot\left(\frac{R}{W^{1/3}}\right)^{-\beta}/P_r\right] \qquad (4)$$

SPL : Air blast, dB
P_r : Reference value of overpressure, 2.10^{-5} Pa
R: Distance, m
W: Max. charge per delay, kg
K, β: Field constants
$R/(W)^{1/3}$: Scaled distance, m/kg$^{1/3}$

The same field constants used in the prediction of ground vibrations are selected to predict the air blast values, and calculated air blast values for critical structures are given in Table 8.

Table 8. Calculated air blast values

Name	Distance, m	Air blast, dB
Şahinyurdu 1	2050	71.45
Şahinyurdu 2	1980	71.93
Cihatlı 1	1350	77.26
Cihatlı 2	1250	78.32

These values of air blast are found to be well below the limit (100 dB) stated in the related regulation.

5. CONCLUSIONS

In this study, a preliminary blasting design model is developed in order to meet the planned production capacity increase in a quarry and the environmental effects of this model in the field are investigated. Based on the data obtained during field observations, a preliminary blasting design model was proposed for use in blasting excavation activities.

The preliminary design models are generally tested on the field with test shots and then blasting results are carefully reviewed and designs are modified if necessary. However, the proposed blasting design model could not be implemented in the field due to the expiration of blasting license period of the company. Therefore, the proposed model in this study could not be tested with test shots at the site.

The environmental impacts of this proposed blasting design in terms of vibration, air shock and dust emission have also been investigated. In the ground vibration assessment, PPV values for critical structures is predicted by using the upper limit field constants recommended for the areas where the vibration characteristic is unknown. It is found that the damage risk of vibrations to be induced by blasting to settlements and olive groves will be well below the permissible threshold damage limit values in the regulation. However, it should be kept in mind that real PPV values may occur lower or higher than estimates.

In the dust emission assessment, mass balance concentrations and 24-hour dust concentrations are estimated under the uncontrolled blasting conditions. In the estimations made, it can be seen that the predicted emission values of PM10 dust particles to be released as a result of blasting will be below permissible limit given in the related regulation. Therefore, if the proposed blasting model is used in the field as it is, dust emissions will not probably damage the human health, olive groves and agricultural areas.

In the air blast assessment, air blast values for critical structures are estimated. In terms of air blast to occur if the proposed model to be used in the quarry, it can be said that the air shock to be caused by the blasting will not exceed the limit values stated in the related regulation. For this reason, it can be concluded that the damage risk of air blast to critical structures will be very low.

As a result, it should be kept in mind that the proposed bench blasting design model for the blasting to be performed at the site is a preliminary design model. Therefore, in the light of the data to be obtained by carefully observing the shots in the field and monitoring with vibration monitors, it is suggested to review this design model and to make necessary corrections and modifications by taking rock behaviors and environmental effects into account.

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