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Analysis and improvement of blasting operation in porphyry, diorite dyke, and trachyte Sungun zones: In-situ investigations

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ABSTRACT

The infrastructures of the Sungun copper mine are located inside the ultimate extraction limits where blasting operation is carried out in their proximity. In such cases, investigating blast-induced phenomena is at most important to reduce their adverse impacts on the mine and surrounding environments. The main objective of this study is to analyze and improve the most critical adverse outcomes of over 100 cases of blasting in different zones of Sungun mine to make it feasible from an operational viewpoint. Hence, the blasting operation and its adverse outcomes recorded in the mine were first studied. Moreover, the important factors that resulted in blast-induced phenomena were investigated. These investigations were in the form of observation, acquisition, and complete field studies at the site. Then, the technical problems and weaknesses of the blasting operation resulted in undesirable outcomes, and their negative impacts on the mine and surrounding environment were extracted and analyzed using checklists, specification forms, and recorded observations. Given the results of the qualitative and quantitative analysis of operation based on a trial blasting strategy, an improved blasting scheme was discussed to enhance the current conditions and reduce the undesirable outcomes down to the permissible limits. The present study could provide a practical framework to identify, analyze, and reduce the critical adverse blast-induced phenomena in metallic open-pit mines.

Keywords: *Blasting, Undesirable consequence, Fragmentation, Specific charge, Sungun copper mine*

1. Introduction

Blasting operation is an operative way to quickly break down the ore and waste rocks in mines. Only about 20% of the total detonation energy results in rock fragmentation and the rest of the energy is wasted in the forms of undesirable blast-induced outcomes. Some of the most important outcomes of blasting operation in surface mining are flyrock [1,2], ground vibration [3,4], air overpressure [5,6], toxic gases [7,8], dust [8,9], and backbreak [10,11]. These outcomes can affect the mine and its surroundings in both desirable and undesirable ways, and affect the general conditions of the blasting operation and their subsequent stages [12]. The increasing demand for mining products has led to an increase in mining and blasting activities, especially in surface mines [13]. A blasting plan should be optimally designed to keep the undesirable blast-induced outcomes within allowable limits. Otherwise, the impacts of ground vibration and flyrock on nearby infrastructures and humans can be critical [14]. Furthermore, the dust and gaseous pollutions due to blasting can be also hurtful to the health of humans and animal and plant species [9,15]. Therefore, a technical investigation is needed in practice to optimize blasting plans with allowable adverse outcomes, especially when different rock types with a variety of geomechanical characteristics are within the mine limit.

According to the Sungun copper mine report provided by Iranitok Company in 2009, blasting operation is carried out close to the office, residential, industrial, and semi-industrial buildings, which are located inside the final mine limits. Accordingly, the mine area was divided into two normal and critical areas based on drilling and blasting parameters and geomechanical characteristics. The geology of the area is an important parameter in the performance of seismic waves caused by the blasting operation. The control of blast-induced ground vibration in Sungun mine has become a serious challenge, and its control is of special importance [16]. Furthermore, improving other adverse outcomes resulting from blasting operation is very significant. Hence, various studies have been done to investigate the impacts of blasting parameters on blast-induced outcomes in the Sungun copper mine. Most of these studies have only predicted the outcomes of routine blasting operations at Sungun copper mine. Fewer attempts have been made to improve adverse blasting outcomes and conditions in practice. They have highlighted how to apply artificial intelligence, statistical analysis, Monte Carlo, image processing, etc.

A summary of the most important studies in this field with emphasis on the Sungun copper mine is reviewed as follows. Dimensional analysis and statistical analysis were integrated to provide a relationship for determining the burden in the Sungun copper mine [17]. The results of several conventional equations were compared to determine a burden in the Sungun copper mine [18]. An integrated approach based on dimensional analysis and Monte Carlo simulation was used to predict the blast-induced flyrock distance in the Sungun copper mine [19]. Faramarzi et al. [10] developed a model to predict backbreak and the risk associated with a blast in the Sungun copper mine using rock engineering systems. In a different study, the same team developed a different model to predict rock fragmentation by blasting based on the same concept in the Sungun copper mine [20]. Badroddin et al. [21] suggested an image processing approach with minimum processing errors to measure the mean particle size of fragmentation in Sungun mine. An equation based on the concepts of dimensional and statistical

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analyses was developed to determine the mean particle size of fragmentation resulting from Sungun mine blasts [22].

The selection of the most appropriate blasting pattern for the Sungun copper mine was considered a multi-attribute decision-making (MADM) problem. Therefore, MADM techniques such as AHP-TOPSIS [23], DEA and ELECTRE [24], and linear assignment method [25] were used. Abdollahisharif et al. [7] monitored the gaseous and dust pollutants due to the traditional blasting operation at Sungun copper mine. They indicated that a large amount of these pollutants could be emitted into the atmosphere of the mine and the surrounding environment. Abdollahisharif et al. [8] introduced a green biocompatible procedure by adjusting the traditional blasting operation at Sungun copper mine to decrease the gaseous and dust emissions. Bakhtavar et al. [1] developed an integrated approach based on Mamdani's fuzzy inference system and dimensional analysis to predict the blast-induced flyrock at Sungun copper mine. Bakhtavar and Yousefi [16] developed an integrated approach using data envelopment analysis and failure mode and effects analysis under a fuzzy environment to analyze blast-induced ground vibration risks on the infrastructures of the Sungun copper mine.

The present study provides a technical framework to assist mining experts in improving desirable/undesirable blasting phenomena. Hence, the results of the blasting patterns obtained by over 100 cases of blasting at the Sungun copper mine site and available rocky zones were recorded and investigated. The study of the aforementioned patterns and extracting the technical bugs related to each of them was performed in the framework of field observation and acquisition. After checking out and comparing the results and analyzing them, improved patterns and implementation strategies to modify the current patterns were provided. The proposed pattern leads to lower fragmentation costs and reduction of adverse outcomes to the permissible limit. Therefore, resolving the existing problems in the blasting section has been emphasized in practice.

In general, this research aims to modify the technical and execution bugs of drilling and blasting operations in Sungun mine and provide the best possible drilling and blasting plan to reduce adverse outcomes arising from drilling and blasting. Moreover, the changes in important parameters resulting from specific charge and special drilling, the status of drilling, and charge placement of the holes during the process of blasting in Sungun mine are studied. Furthermore, the changes in blast hole diameter and height and the general state of the working face are studied, compared, and analyzed. It is worth noting that the present study doesn't focus on presenting relationships between rock mass and blasting parameters using scientific tools.

The rest of the study is structured as follows: In Section 2, the Sungun mine blasting operation is evaluated and analyzed. In Section 3, results are discussed, and the proper recommendations are provided to reduce the negative impacts of blasting. Finally, in Section 4, the conclusions and future research are highlighted.

2. Blasting evaluation and analysis

The Sungun copper ore deposit is located in a part of Gharedagh mountain range with 100 km distance from Tabriz and 25 km from Varzghan Township in the neighborhood of Azerbaijan and Armenia Republics. The region is mountainous with an average height of 2000 m relative to the sea level in a part of the Gharedagh mountain range. The maximum height of the mine area relative to the sea level is 2700 m. The Sungun region geographical coordinates are longitude of 46° and 43′ E and latitude of 38° and 42′ N.

Many factors such as geotechnical conditions, explosive properties, drilling equipment specifications, distribution of particle size after blasting, etc., affect the blasting design in such a way that the change of each of these factors may cause major changes in the patterns. In the Sungun copper mine, detonation fuses and boosters are used, and the main charge is ANFO. The detonation fuse is tied to the end of the booster which has a puncture, and it is dropped to the bottom of the blast holes (Figure 1).

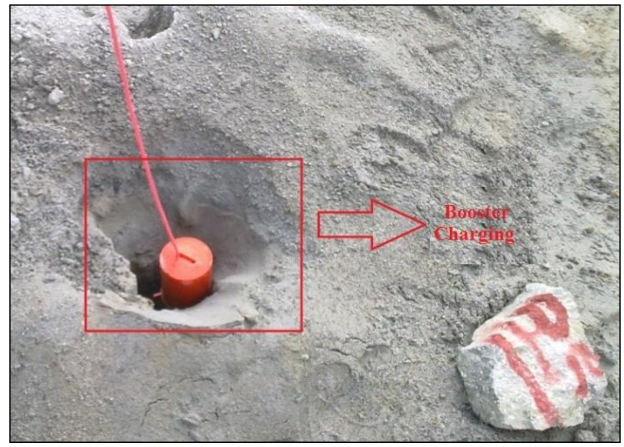

Figure 1. Booster charge placement using detonation fuse in Sungun

Some trial blasts were carried out in porphyry, dyke, and trachyte zones to improve the outcomes induced from the Sungun mine blasts. For this purpose, the main technical points and experiences from the literature and similar case studies were investigated. Field acquisition of operational and technical components for the current blasting plans in Sungun was performed, and all field observations and studies were recorded. The technical problems of more than 100 blasts in the mine site were extracted, and the current drilling and blasting operations were studied and analyzed by considering a variety of technical factors and data. Drilling network, factors affecting ground vibration, delay time, the charge per delay, the distance of blasting location to infrastructures, specific charge, type of rock and explosives, charge length, stemming length, geological conditions, rock mass characteristics, geometric characteristics of blasting, blasting method, climatic conditions, flyrock distance, and explosion sequence were among the technical factors.

2.1. Blast hole diameter

Given the request of the Mine & Contractors Affairs, the designed blasting pattern was executed using the slanted method for 127 mm diameter in the porphyry and dyke zones and the vertical method for 165 mm diameter in the trachyte zone. An example of blast holes drilled in the Sungun mine is shown in Figure 2.

Figure 2. A blast hole in Sungun copper mine

2.2. Blasting parameters in different zones

According to the current blasting scheme in Sungun, some of the most important information for each of the zones include a bench height of 12.5 m, blasting-fuse type system, 50 ms delay between the rows, ANFO with a density of 850 kg/m^3, and an ore density of 2500 kg/m^3. The blasting pattern results using the Nitro Nobel relations based on ANFO are summarized in Table 1 for all three zones.

Table 1. The information of current blasting patterns in three types of Sungun rock zones

Rock type	Burden (m)	Spacing (m)	Stemming (m)			Under drilling (m)	Hole length (m)	Charge per hole (kg)			Specific charge (kg/ton)
			First row	Second row	Third row			First row	Second row	Third row	
Porphyry	4	5	4	5.5	-	1.5	14.5	113	97	-	0.168
Diorite Dyke	3.2	4.5	3.5	4.5	-	1.5	14.5	118	108	-	0.25
Trachyte	3.5	4.5	6	4	4.5	1.5	14	145	181	173	0.43

In the porphyry and diorite dyke zones, blast holes were drilled in two rows as a regular diamond-shaped network with 10 slanted blast holes with a diameter of 127 mm in each row. In the trachyte zone, blast holes were vertically drilled with a diameter of 165 mm in rows. Three rows with 10 holes in each row were drilled, such that the blasting pattern included 30 blast holes. Based on the geomechanical nature, the porphyry and diorite dyke zones are soft and medium, respectively. In the trachyte zone, the burden of the first row was zero based on a bench slope of 70 degrees. Given that drilling of blast holes at the bench edge was not precisely possible, a maximum burden of 0.5 m was considered for the first row. In this case, stemming in the first row was technically recommended to be increased. In the last row, the average length of stemming was 4 m to decrease the number of coarse fragments and boulders in the second row. The stemming should be slightly increased to 4.5 m compared to the middle row. Given a different burden at the top and bottom of blast holes, an average burden of 2.75 m and a specific charge of 0.364 kg/ton were calculated for the first row. The blast hole length in both the porphyry and diorite dyke zones was approximately 14.5 m based on the blast hole dip of about 63 degrees. The factors that affected undesirable blast-induced outcomes were studied in two categories of drilling and blasting components by considering the acquisitions and information collected from the Sungun blasting sites.

2.2.1. Drilling-based factors

Blast holes were vertically drilled in all Sungun blasting sites without any slope. Therefore, blasting site preparations in the form of leveling, ripping, and cleaning up were needed to avoid large size fragments due to hole deviations, non-uniformity in toes, and flyrocks. According to the observations and records at Sungun mine, the blast hole services and preparation of the site before drilling were not carried out. In the Sungun copper mine drilling sites, incorrect positioning of the drilling rig, and the deviation inside the blast holes caused by inappropriate geological conditions resulted in undesirable blasting outcomes.

One of the most important factors affecting blasting results during the preparation of the drilling site was the exact location of the blast holes in the working face and the availability of the required drill holes for the uniform charge distribution in the rocky blocks. In the Sungun copper mine, these cases were left to the whim of the operators. On the other hand, there wasn't enough precision in controlling the depth of the blast holes and servicing the blast holes during the drilling operation. Moreover, the drilling debris didn't extract from the blast holes by operators, which resulted in shortening blast holes or the defective placing of the charges. This issue may cause backbreaking, non-uniformity in the bench toe, coarse fragments, flyrock, and inappropriate mucking. Paying attention to all these points is necessary for accurate primer charge placing, accurate cutting of the block floor, and preventing non-uniformity in toe and roughness at the lower levels, which have not been perfectly adhered to in the mine under investigation.

2.2.2. Blasting-based factors

Burden, as the most critical variable in blasting design, is in direct relationship with other blasting factors. Failing to accurately determine a burden considerably affects the blast-induced outcomes [17]. The executed patterns in Sungun showed over 40% error and deviation according to the study of checklists resulting from field acquisitions and irregularities of drilling networks, especially inaccurate locating the blast holes. The information obtained from the acquisitions and observing the blasting results indicated that about 10% of the current blasts had similar results based on deviations from the current drilling pattern. The lesser hole spacing caused extreme fragmentation, and discontinuities were expanded in the direction of blast hole drilling instead of the working face. This issue resulted in the creation of toe irregularity, air overpressure, noise, and flyrock. However, the face surface was smooth after blasting. If the spacing is more than optimum, it may result in high rock crushing around blast holes, production of large size fragments, toe irregularity, defective breaks between the blast holes, and ragged face surface after blasting.

According to the field acquisitions, short bench height which is not in accordance with hole diameter causes intense vibration, flyrock, and backbreak. In many cases, the use of blast holes with less diameter and a length less than the height of 12.5 m benches resulted in doubling the blasting process in the mine benches. The damages caused by the first phase of the blasting led to drilling and blasting problems at the later stage. In the mine, stemming was about one-third of the blast hole height. The stemming material was a combination of gravel produced by drilling and some wet clay compressed by ramming. Any change in the blast hole height led to anomalies in the distribution of charge. Given the information obtained from the blast sites in Sungun, observations and recorded results were the most important factors in producing the undesirable outcomes.

The maximum acceptable size of fragmentation was 1 m by considering the 1.2-m diameter of the primary crusher (gyrator) opening in the Sungun mine. Larger fragments led to an increase in the cost of blasting and secondary blasting, in which higher fragmentation led to wasting the crusher energy and the loss of the related costs. Changes in burden along the vertical blast holes resulted in non-uniform fragmentation, flyrock, and ground vibration in Sungun.

2.2.3. Results of the field investigations

After finishing the drilling operation and before charging the blast holes, the geometric parameters of the current blasting pattern were carefully reviewed to ensure the accuracy of the drilling operation. The following points were achieved accordingly:

- The designed burden and spacing were often correct with negligible error margins.
- The recommended depth of blast holes in Sungun porphyry and dyke was 14.5 m while the maximum drilled depth was 11.5 m which was even 1 m less than the bench height. With such drilling depth, there is no chance of good fragmentation at the base of the benches and the probability of irregularity in the toe is very high.
- In the case of the proposed pattern for trachyte, a 14 m depth has been recommended for the blast holes; the measured depths were often 13.5-14 m which is a relatively acceptable depth. A limited number of blast holes had a depth of 10-12 m. In this case, it was observed that due to the hardness of the rock, drilling deeper holes with the current equipment was not possible.
- The holes drilled in the porphyry and dyke zones, based on the conditions of the current contractors' drilling equipment; were often drilled with a slope more than the bench slope (70 degrees) and mostly had nearly vertical slopes. Therefore, regardless of the observance of the burden in the hole opening (collar), the real amount of burden at the bottom of the hole was much more than the designed burden. This issue affected the amount of rock fragmentation at the base of the bench and blast-induced outcomes.
- Among the studied patterns, only the pattern designed for the trachyte zone was approximately drilled in accordance with the current plan, and the other two patterns had considerable differences from other design patterns. It became obvious that

these problems are related to the existing drilling equipment and their operators especially when drilling slanted blast holes.

Ground vibration, fragmentation, mucking and displacement of the working face, flyrock, and backbreak were studied after monitoring the charge placement operation. The following results were achieved accordingly:

- Rock fragmentation in the porphyry zone was appropriate (Figure 3).
- Increasing stemming length at the front row of the working face was effective in preventing flyrock.
- Rock fragmentation in the diorite dyke zone was acceptable at the crest of the benches. However, as expected, a toe with approximately 2 m height was emerged due to the high burden in vertical drilling.
- Rock fragmentation in the trachyte zone was unacceptable, in which many large sizes of fragments were produced. The essential information, particularly about joints and discontinuities of the blocks, was limited.
- Backbreak in some cases can be reduced by a slight modification of the current pattern in case of using different methods for charging and reducing the amount of charge in the last row.
- In many cases, the mentioned problems during the drilling and blasting operations resulted in increasing the amount of specific charge from 165 g/ton for porphyry and 229 g/ton for dyke to more than 500 g/ton.
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Figure 3. Fragment dimensions resulting from blasting the porphyry zone

3. Results, Discussions, and Recommendations

The most important results and recommendations for the optimization of the drilling and blasting operations with an emphasis on minimizing the undesirable blast-induced outcomes in Sungun mine are stated as follows. They are the most important approaches of the research. The effects of geomechanical and annoying parameters, such as in-situ stress, specific gravity, topography, and local slopes should be studied and analyzed in the blasting plan design and undesirable outcome considerations. Furthermore, these parameters had indirect impacts on copper extraction, separation, milling, and processing.

The current methods of drilling and the speed and capacity of available drilling equipment did not meet the needs and conditions existing in the Sungun copper mine and they, along with the blasting operation process methods, must be modified. Site preparation wasn't carried out before drilling to maintain the alignment of the holes in Sungun. Given that vertical holes were drilled and slanted holes were failed to be drilled at present, site preparation in terms of leveling, ripping, and clearing plays a prominent role in preventing the diversion of blast holes to their flanks. Moreover, large fragmentation due to blast hole diversion, non-uniform fragmentation, non-uniformity in toes, and flyrock can be prevented. The use of the DTH and Coprod drilling methods was effective to reduce diversion in deep holes and inappropriate geological conditions. It is worth noting that the impact of geological conditions in the diversion of the blast holes couldn't be eliminated.

The hole diameter of 200 mm (8 inches) was the minimum diameter that was used based on the compressive strength of the three rock zones in the Sungun mine. However, the 200-mm diameter holes cannot be drilled in the meantime due to technical problems existing in the mine. Therefore, the components of the drilling and blasting operations must be strengthened to supply 14 million tonnes of feed for Phases 1 and 2 of the processing plants at Sungun copper mine. Because of increased production in Sungun from 7 million tonnes to 14 million tonnes since January 2015, it is important to change the current drilling fleet and use larger-scale drilling equipment. The Coprod drilling method should be used, and slanted holes with greater diameters should be drilled instead of vertical holes to reduce blast-induced ground vibration. Furthermore, the accurate delay time, the accurate charge placement method, and the maximum charge per delay should be determined. The mine should move toward the mentioned use of drilling equipment and procedures to reduce the chances of unfavorable blasting outcomes. The most important fixed general information for each of three rocky zones was a bench height of 12.5 m, the blasting-fuse system, 50-ms delay between rows, ANFO with a density of 850 kg/m^3, and a density of approximately 2500 kg/m^3 for the ore. The results of the proposed blasting pattern using the 200-mm blast hole diameter are summarized in Table 2 based on the Nitro Nobel relations for the three zones.

Notably, the calculated burden in the trachyte zone must be observed all along the hole's length. For the first row, the burden will not be consistent along the hole due to the slope of the benches. Therefore, the distance between the hole collars of the first row to the crest of the benches should be corrected according to the bench slope of 70 degrees. The modified burden for the first row was approximately zero based on the bench slope. In a slope of 70 degrees, the first row must be drilled on the crest of the benches as much as possible. In any case, the length of the first row's stemming must be increased for the sloped benches. Stemming in the first row should be increased concerning the bench slope and a lower burden of the first row at the higher parts of the blast hole. In the last row, the average stemming length was considered to be equal to the burden (4 m) to decrease large size fragments in the second row. Stemming should be increased in the middle row to reduce the backbreak in the last row.

The results of image analysis of various Sungun rock types revealed that D_{80} of every three types of fragmented ore was 15 to 20 cm. Based on the current blasting pattern, only 20% of the raw ore required initial rock crushing and the initial rock crushing cost could be significantly reduced by initial screening using the grizzly type.

Table 2. The results of the proposed blasting pattern based on the 200-mm blast hole diameter

Rock type		Burden (m)	Spacing (m)	Stemming (m)			Under drilling (m)	Hole length (m)	Charge per hole (kg)			Specific charge (kg/ton)
				First row	Second row	Third row			First row	Second row	Third row	
Porphyry		6	7.5	6	5.5	-	2	15.5	254	267	-	0.185
Diorite Dyke		5	6	5	4.5	-	2.5	15	267	280	-	0.292
Trachyte	Ver	4	5	6	4	5	1.5	14	214	267	240	0.385
	Dip	4	5	6	4	5	1.5	15	240	294	267	0.427

One of the factors affecting the result of blasting is the accurate location of the blast hole. In this case, holes should be accurately arranged on the working face to provide the uniform distribution of the charge in benches. This was ignored and left to the whim of the operators in the Sungun copper mine. Blast holes at blasting sites should be divided into auxiliary, production, buffer, and control holes. There is no sufficient accuracy in controlling the depth of blast holes, and servicing (cleaning) the holes from drilling debris was not performed properly. Therefore, it is either the blast holes were closed, or the charge placement was defective, and both cases led to backbreaking, non-uniformity in the toe, large size fragments, flyrock, and inappropriate mucking. The blast hole depth in the three rock zones was 14-14.5 m, while in practice, the depth of drilled holes was less than 12 m at the porphyry and dyke zones, which led to non-uniformity in the toe. Therefore, the contractor must be provided for the possibility of drilling 14-m holes by supplying proper equipment as soon as possible. Even after monitoring to correctly implement patterns, especially during the drilling operation, a backbreak up to 2 m was created. The backbreak can be reduced by modifying the pattern that necessarily included the charge reduction in the last row.

Inappropriate blasting patterns in the Sungun copper mine resulted in undesirable rock fragmentation, especially in the trachyte zone, and considerable backbreak after each blasting round. In some cases, flyrock and uneven bench surfaces occurred as well. A secondary blasting is needed and the specific charge would be more than the nominal value to improve undesirable fragmentation. Given the production of the high tonnage of ore and waste at the Sungun copper mine (approximately 40 million tonnes per year), the amount of consumed specific charge should be reduced to decrease the selling cost of the ores and their quality. PVC or at least plastic tubes should be used in the holes and the charge placement method should be inconsistent to keep charge along the length of the blast hole due to discontinuities in the trachyte zone. According to the modified plan, the specific charge will be reduced from the current value that is more than 500 g/ton to 168 g/ton for Sungun porphyry and 229 g/ton for diorite dykes.

In general, it seems that the proposed pattern is appropriate for the porphyry and dyke zones. If drilling slanted blast holes aren't possible, this pattern may be utilized for vertical holes as well. The first row must be drilled near the crest of the benches at a distance of 0.5 m and other rows must be drilled according to the pattern while observing the recommended burden to reduce the burden at the bottom of the holes. The shorter spacing and blast timing (immediate and delayed) resulted in too much fragmentation, non-uniformity in toe, air vibration, noise, and flyrock.

The main reasons for the occurrence of the flyrock phenomenon in Sungun are the lack of a comprehensive blasting pattern and proper management in execution, faults, discontinuities, and weak areas that locally reduce the strength of rock mass. The maximum flyrock was obtained when the ratio of stemming to blast hole diameter was about 10. Flyrock was reduced with an increase in this ratio up to critical depth. Delays more than 100 ms between the parallel blast holes should not be utilized in designing the starting pattern of the blast. When delays were more pronounced, the rocks thrown by the blasting of the first blast hole row were thrown out to further distances. In this case, they did not cover up for the next rows. Therefore, the rocks that emerged by the next rows were thrown out and exacerbated the flyrock phenomenon.

The most effective factor in the blast-induced ground vibration in Sungun mine was the maximum charge per delay. Based on the results of the present research using the field acquisitions of the mining site, the blasting plan was limited to three rows and five holes in any delay. However, practically, the extent of charge placement is between 500 to 8000 kg, and the number of blast holes in the rows didn't limit. Besides, the number of rows was 2 to 4, depending on the size of the working face. In this mine, to control the ground vibration, particularly at the trachyte working faces, the Nonel system should be utilized. Moreover, by specifying the appropriately delayed relays, isolated blasting of the holes, reducing charges in each delay period by delayed relays, and creating an effective delay, the amount and impact of the vibration due to blasting consecutive blast holes can be reduced. Natural joints and discontinuities as well as the discontinuities created by controlled blasting (pre-splitting) greatly reduce ground vibrations. In the Sungun copper mine, despite the joints and discontinuities of the trachyte block, the distance of the ground vibration impact was less than that in other regions.

4. Conclusion

Given the importance of blasting results in the working faces near infrastructures and inhabited areas and ecosystems, adverse blast-induced outcomes were focused on in the present research. The adverse outcomes, as well as reduction solutions, are significant matters that should be investigated to optimize a blasting plan, especially in surface mines. As part of the research, a total number of 100 blasting cases at porphyry, diorite dyke, and trachyte zones were practically investigated and analyzed in a surface copper mine. The simultaneous investigation of blast-induced phenomena to provide a practical framework is the main technical point of the present research. The impacts of blast hole diameter and height, specific charge and special drilling, drilling status, the charge placement in the holes, and the general state of the working face were studied and analyzed to optimize the mine blasting operation. Investigating and Recording times after each blasting round were the main challenges and limitations for the research team because the loading and hauling operations were commenced a short time after blasting. Ignoring the predesigned drilling and blasting patterns was another limitation of the research. Investigations indicated that the most critical adverse outcomes of the mine blasts were due to the ground vibration and flyrock phenomena. However, the blast-induced dust and gaseous outcomes should be considered because the mine is located close to a protected ecosystem area. The factors inducing the occurrence of undesirable outcomes were also studied in the form of observation, acquisition, and complete field studies. Checklists, specification forms, and recorded observations were other tools for collecting data. The field investigations and analyses resulted in an improved blasting plan with the allowable limits of the adverse prominent outcomes. This research can afford significant benefits and make an acceptable contribution to solving this problem based on practical points adequately. For future works, it is suggested to apply a multi-objective programming model based on all critical adverse blast-induced outcomes, in order to integrate the mathematical programming advantages and the results of field investigations and solutions. In this case, the mathematical model can be justified based on practical results. Moreover, the impacts of the adverse blast-induced outcomes on the subsequent operations, such as loading, hauling, and crushing can be analyzed in practice. A monitoring approach using precise instruments is recommended to investigate the blasting outcomes.

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