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GEOMECHANICS

Transportation Costs: A Tool for Evaluating the Effect of Rock Mass Mechanical Parameters on Blasting Results in Open Pit Mining[1]

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Abstract—Blasting is one of the most important stages of open pit mines extraction which plays an essential role in changing the extraction costs. Mechanical parameters of rock mass as fixed parameters are results of effective blasting. In this paper, the costs of transportation have been introduced as a tool for determining the blasting quality and transportation operation in open pit mine of Angouran (the largest lead and zinc mine in the Middle East) has been discussed. Approximately, 55 percent of the piles from blasting conducted in Angouran mine are appropriate for loading by hydraulic shovel and the rest of the piles are not appropriate for loading by most machines. This has led to a significant change in transportation costs caused by blasting quality. First, the mechanical parameters of the rock mass (compression strength of intact rock, RQD, discontinuity conditions, the angle between the joints and direction of drilling and slope discontinuities) as well as all transportation costs (total cost of loading, hauling, and bulldozers work) in the 104 blocks of extractive mining of Angouran were surveyed. Regarding blasting pattern which is constant approximately in studied blocks, an equation was proposed to determine the relation of geotechnical parameters associated with the transportation costs. Ultimately by conducting a sensitivity analysis it was determined that uniaxial compressive strength of rock and difference of bench face dip and joint dip have the greatest impact on the quality of fragmentation and thus changes in the cost of transportation in Angouran mine

Keywords: Geotechnical parameters, rock mass classification, transportation, height and displacement of piles, Angouran mine.

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INTRODUCTION

Blasting as the most important step of mining operation of open pit mines plays an essential role in the long-term and short-term production efficiency, cost and environmental issues. Many factors affect the design flow and effective parameters which are divided into two sets of non controllable parameters (Fixed) and controllable (variables). Fixed parameters include properties related to material and rock mass and variable parameters include technical and geometrical properties of the explosion pattern.

Once the blast has been carried out, it is necessary to analyze the effective parameters, as their interpretation will give the successive modifications of the design parameters for the following rounds and trench geometry. This is the basis for the optimization process. Investigation the fragmentation and swelling of the muck pile is a basic step to achieve a global evaluation. The classification of size distribution and screening of the muck pile in treatment plants are useful methods for a quantitative evaluation of fragmentation. Size distribution is the basic tool within the optimization process of blasting, as it is the only means of comparing the fragmentation obtained when a study is to be done on the sensitivity of the design parameters.

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Qualitative visual analysis, Photographic and photogrammetry methods, bridging delays at the crusher, partial screening, volume of material that requires secondary blasting and image analysis by computer are commonly used to analyze the fragmentation and the blasting quality [1–5].

Several studies have been conducted regarding the impact of variable parameters on the result of explosion but any considerable research about focuses on fixed parameters is not found. Da Gamma [6] encouraged for blast prediction to engineers understanding the role of in-situ rock mass geometry in terms of block sizes in mine production. Estimating equations of the undersize fragment percentage were developed by Da Gamma and Jimeno [7, 8]. Jurgensen and Chung (1987) [9] and Singh (1991) [10] also opined that the blast results were influenced directly by the overall formational strength of rock. Hagan (1995) [11] concluded that the results of rock blasting were affected more by rock properties than by any other variables.

Pal Roy and Dhār (1996) [12] proposed a fragmentation prediction scale based on the joint orientation with respect to bench face. Scott (1996) [13] reported that the blast-controlling rock mass properties include the strength parameters, the mechanical properties like modulus of elasticity, Poison's ratio, shock wave transmission capability, the size and the shape of the natural block and the required fragment size reduction by blasting. Chakraborty et al. (2002) [14] found the joint orientations can considerably influence the average fragment size and shape. Thornton et al. (2002) [15] categorized the parameters influencing fragmentation in three groups like; (i) rock mass properties, (ii) blast geometry and (iii) explosive properties. Hamdi and Mouza (2005) [16] studied a methodology for rock mass characterization and classification to improve blast results. They aimed the characterization of the two rock mass components which are discontinuity network and rock matrix.

Studies of loading and hauling equipment productivity can reflect the fragmentation quality also. This technique of fragmentation evaluation is based upon the assumption that the digging rates are an inverse function of the coarseness of the muck pile and a direct function of the swelling of the same. The presence of oversize, reduced swelling and poor toe condition will be immediately reflected in productivity. If the technique is applied correctly, a precise evaluation can be obtained.

Since geotechnical parameters have a huge effect on the results of the blasting and later steps of mining operations, particularly in transportation, thus in this paper, the influence of geotechnical parameters on result of blasting quality by review of its downstream operations cost is considered. For this purpose, the operating cost of 104 blasted bench faces calculated, separately for each step of loading, hauling and bulldozers work in waste rocks of lead and zinc mine of Angouran that formed from schist and limestone. Then, according to the results, the effect of geotechnical parameters and engineering properties of rock mass on the cost of transportation is investigated.

1. ANGOURAN MINE, GEOTECHNICAL PROPERTIES

Angouran lead and zinc open-pit mine with production capacity of 800 thousand tons per year and the remaining amount potential over 12 Mt with the average grade 3–6% of lead and the average grade 25–30% of zinc is one of the largest metal mines in Iran [17]. Angouran mine is located in Zanjan province, 125 km South West of Zanjan, and in a region with an average altitude of 3000 m. The geographical location of Angouran mine has been shown in Fig. 1. The ore body is located between a limestone layer as hanging-wall and on a thick layer of schist as foot-wall. The mine was designed with an overall slope dip angle about 45° in waste and 35° in the ore zone [17]. In Angouran mine, rocks in foot-wall are collections of metamorphic schist with an approximately thickness of 1000 m that mostly these collections have extended in the west of the mine, while rocks in hanging-wall are collections of semi-metamorphic limestone with an approximately 200 m thickness that the most extension of these collections are in the east of the mine [18].

Fig. 1. View of Angouran zinc and lead mine.

According to the mining experts and geologists' reports, geological formation containing the zinc and lead Angouran mine is Sanandaj-Sirjan belt formation. This formation was originally part of Central Iran and this formation called to the various titles such as Oromieh-Esfandaghe zone, Interior's Zagros, and finally Sanandaj-Sirjan belt.

Blast holes with an average diameter of 4.5 inches are drilled in Angouran mine and drilled networks typically have dimensions of 3.5×4.5 meters. The most explosive substance in this mine and its special funds medium are Ammonium-Nitrate-Fuel Oil (ANFO) and 565 g/m^3 respectively. Loading in Angouran mine mainly is done using excavator. Each device on average 160 cubic meters per hour loads the waste. The fleet of mine transportation consists of 34 dump trucks with capacities from 32 to 60 tons.

1.1 Geotechnical Characteristics of Rock Mass in Angouran Mine

Rock mass comprises several different rock types and is affected by different degrees of fracturing in varying stress condition. A number of rock mass classifications have been developed for Geo-technical purposes like Q-Index (NGIQ; Barton et al 1974) [20], Rock Mass Rating (RMR; Bieniawski et al 1973) [21], etc. The rock mass rating system (RMR) was presented by Bieniawski. The purpose of this system is determining the engineering properties of the rocks in the shallow tunnel that was excavated in sedimentary rocks. The rock mass classification system is one of the best ways to investigate stability and determine the support system in open pit mines. In addition, in 1974, the system of rock mass quality (Q), by Barton et al was presented for the classification of hard rock tunnels and Caverns with curved roof has been recommended and used for the design and maintenance of underground excavation [19].

In 1985, Romana introduced slope mass rating (SMR), for evaluating rock slope stability [22]. In 1989, Bieniawski presented the modified classification of the rock mass rating (MRMR), with changes in RMR system. Geological strength index (GSI) presented by Hook and Brown (1997) that was the classification of the rock mass as an observation takes place and Usage gradients and is designed excavating in rock [23].

In order to accomplish the aim of the article, 104 extractive blocks which major mining activities including drilling, blasting, loading and hauling are done in them were selected. Studied blocks are shown in Fig. 2. These blocks are located within mine waste area which are formed from schistose rocks (Schist of Footwall) and limestone (hanging wall limestone).

According to deductions which were taken in Angouran mine a layered plate and two principal joint sets can be identified. Table 1 shows the characteristics of discontinuities in Angouran mine.

Considering the methods offered in the classification of rock masses in open pit mines and limitations in their surveying in Angouran mine, in this paper, uniaxial compressive strength (UCS), rock quality description (RQD), spacing of discontinuities (Sp), difference of dip direction and bench face direction (A), difference of dip joints and dip of bench face (B) parameters are determined in order to study the effect of mechanical parameters of rock mass on the efficiency of blasting.

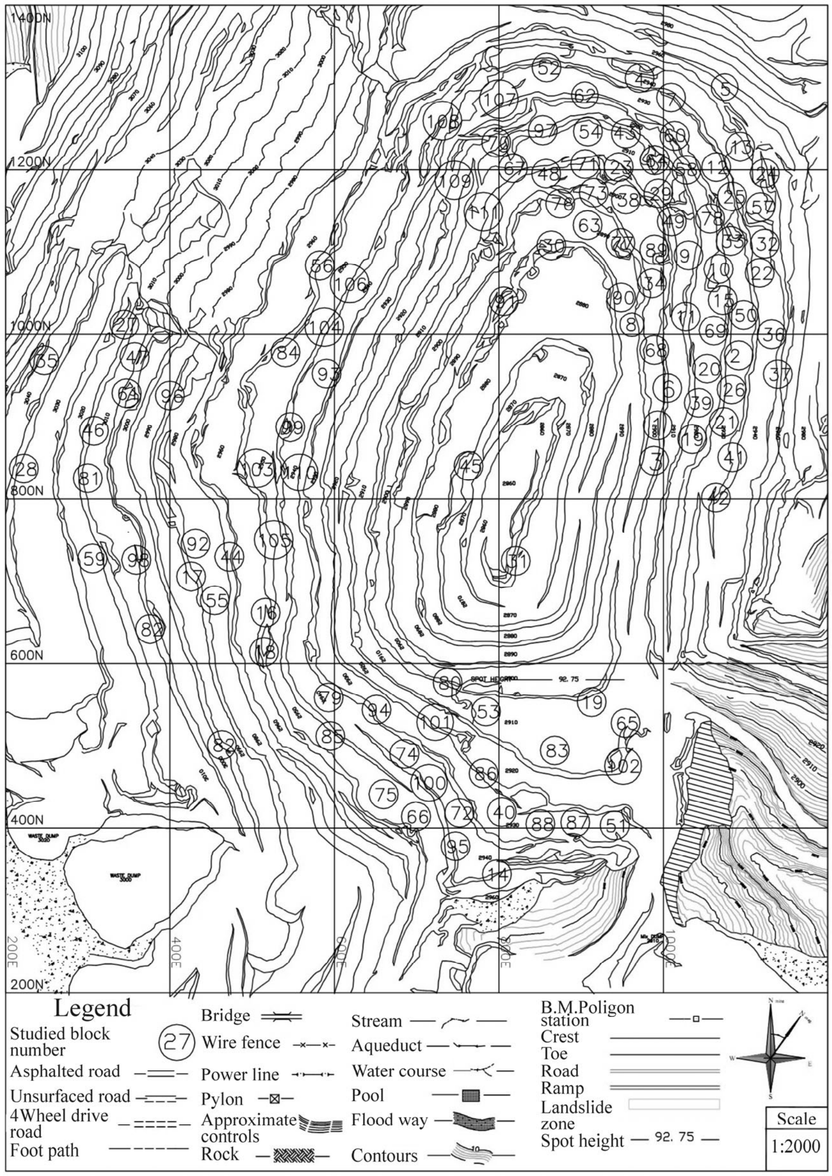


Fig. 2. The position of 104 studied blocks in Zinc-lead Angouran mine.

Table 1. Characteristics of discontinuities in Angouran mine

Discontinuity	Dip, deg	Azimuth,	Slope orientation	Joint spacing, cm	Mudium separation, cm
Bedding	10-15	N14W	To the east	40	locally
Joint set 1	75	N55E	To the southeast	35	1
Joint set 2	75	N18W	To the west	25	2

Using field studies, mechanical parameters and rock mass joint system of Angouran mine (uniaxial compressive strength, rock quality description, spacing of discontinuities, difference of dip direction and bench face direction, difference of dip joints and dip of blasted bench face) from mining studied blocks are surveyed (Fig. 2). Table 2 shows surveyed parameters for some samples of studied blocks.

Hanging wall limestone are a metamorphic thick limestone layer which cover ore of Angouran and are developed from north and eastern north to western south of mine. Footwall of Angouran is kind of green schist which due to containing a large amount of group minerals of mica is called mica schist. These rocks are mainly formed of quartz, feldspar and mica. This schist is the lowest part of the ore deposits. Ore deposit Zone is enclosed between the two sections of limestone hanging wall and footwall zones of schistose material.

Table 2. Table of values of obtained parameters for 104 blasted bench faces in Angouran mine

Block no.	UCS	RQD	Sp	A	B
1	66	77	85.8	8	2
2	66	69	60.8	3.5	-4
3	12	49	50	49.5	25
4	12	49	61.7	166.5	-54
5	51	49	48.3	-20.5	-4
6	51	49	48.3	6.5	1
7	51	49	48.3	-13.5	-1.5
8	12	49	55	-30.5	0
9	12	49	80.8	-44.5	-3
10	66	24	31.7	86.5	-6.5

Hanging wall limestone are a metamorphic thick limestone layer which cover ore of Angouran and are developed from north and eastern north to western south of mine. Footwall of Angouran is kind of green schist which due to containing a large amount of group minerals of mica is called mica schist. These rocks are mainly formed of quartz, feldspar and mica. This schist is the lowest part of the ore deposits. Ore deposit Zone is enclosed between the two sections of limestone hanging wall and footwall zones of schistose material.

2. TRANSPORTATION

Transportation is the major part of mining operations and has the most cost in it. Furthermore the performance evaluation of this step as much of the mining operations is essential to allow the strengths, weaknesses, problems and barriers to be found out. The most important and influential step of mining operations is blasting or explosion which has a direct impact on the efficiency of transportation.

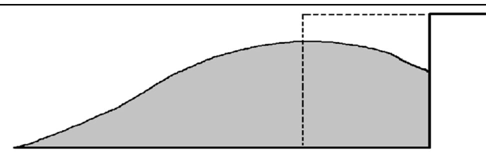
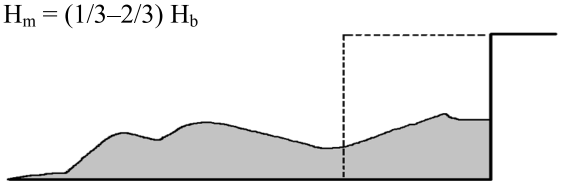
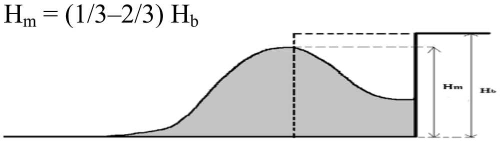
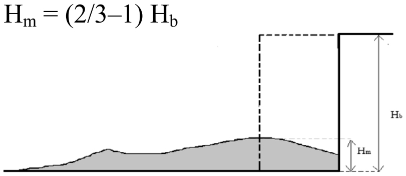
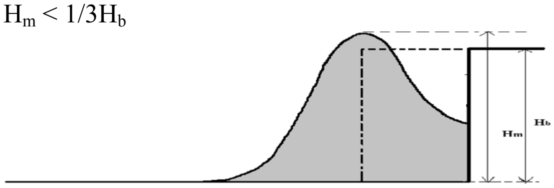
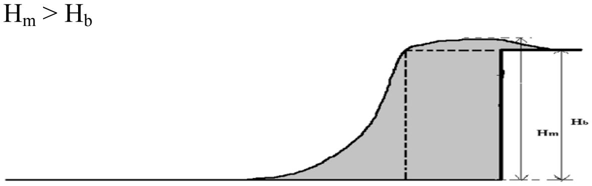
Blasting results according to the size distribution of rock (obtained from it) and the amount of swelling and muck pile geometry can influence the efficiency of loading equipment. Studying of loading machines efficiency is based on the assumption that the rate of loading has an inverse relationship with oversize fragments and a direct relationship with muck pile swelling obtained from explosion. Existence of large parts, low swelling and bad conditions of toe will be reflected immediately in the performance of loading machines. Accurate surveying and correct implementation of this method can provide an accurate assessment. For example, wasted times such as waiting for arrival of a truck, a malfunctioning of a device, relocating of hydraulic shovel, cleaning stairs and pushing load forward by bulldozers and hydraulic shovels should be considered.

Optimized shapes of piles in different mines are different and depend on loading and hauling machines in each mine. Classification of crushed rock muck pile using different sources is presented in Table 3 [8].

Figures 3 and 4 show frequency of height and displacement of piles which are obtained from recorded explosions in Angouran mine. As is depicted in these figures approximately 39.8% of piles height is less than 7 meters, 51.5% of them are between 8 to 10 meters and 8.7% are more than 10 meters.

Considering both parameters of height and displacement and according to Table 3 frequency chart of muck pile shape rankings from blasting is shown in Fig. 5. According to this graph, about 55 percent of explosions carried out in the third category, which according to Table 3, an average cleaning tasks in the bench faces are needed after each explosion. Hydraulic shovels in Angouran mine have appropriate performance in bench faces and their safety of loading is high. But as regards loading fleet in the mine often contains an excavator, in more bench faces excavators make a platform from load and step on it to start loading. Furthermore 14.5% of explosions carried out in the mine, piles are not appropriate for loading by most loading machines in the mine due to their shapes. About 30.5% of the rest are not suitable to load by hydraulic shovels and excavators in the mine and cause the extra transportation cost.

Table 3. Classification of muck pile of crushed rock mass [8]

Section code	Description	
1	 $H_m = (1/3–2/3)\ H_b$	Excessive clean-up Low shovel productivity Very safe for hauling Relatively easy for loading operation (excavator, loader)
2	 $H_m = (1/3–2/3)\ H_b$	Irregular sections Excessive clean-up Low shovel productivity Good Safe
3	 $H_m = (2/3–1)\ H_b$	Middle(average) clean-up Good shovel productivity Good Safe
4	 $H_m < 1/3H_b$	Excessive clean-up Very low shovel productivity Very good Safe
5	 $H_m > H_b$	Little clean-up High shovel productivity Dangerous
6	 $H_m > H_b$	Low displacement of pile Hard clean-up of pit walls Dangerous

H_m—muck pile height, H_b—bench height

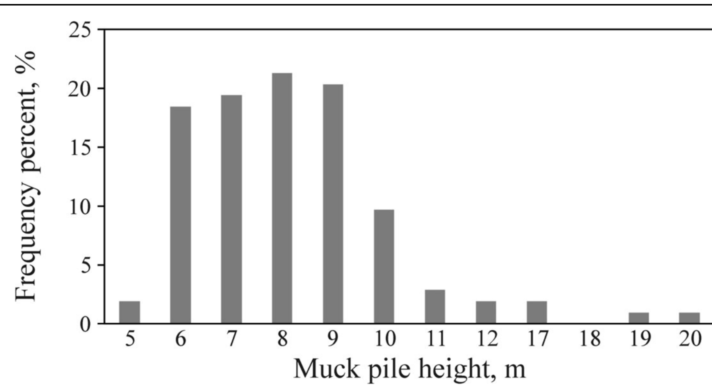


Fig. 3. Frequency of muck pile height of blasting.

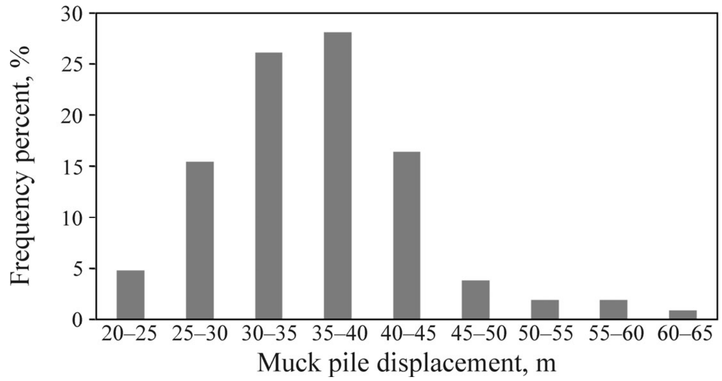


Fig. 4. Frequency percent of muck pile displacement of blasting.

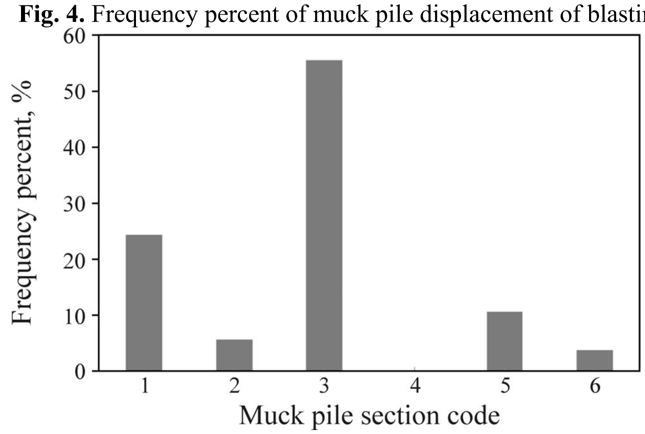


Fig. 5. Frequency percent of muck pile classification after the explosion.

Considering both parameters of height and displacement and according to Table 3 frequency chart of muck pile shape rankings from blasting is shown in Fig. 5. According to this graph, about 55% of explosions carried out in the third category, which according to Table 3, an average cleaning tasks in the bench faces are needed after each explosion. Hydraulic shovels in Angouran mine have appropriate performance in bench faces and their safety of loading is high. But as regards loading fleet in the mine often contains an excavator, in more bench faces excavators make a platform from load and step on it to start loading. Furthermore 14.5% of explosions carried out in the mine, piles are not appropriate for loading by most loading machines in the mine due to their shapes. About 30.5 percent of the rest are not suitable to load by hydraulic shovels and excavators in the mine and cause the extra transportation cost.

Using qualitative analysis and visual images taken from several bench faces, which are evident in Fig. 6, we can say that the quality of rock fragmentation in bench faces in east, south and southwest of the mine is suitable. It covers several areas with different geotechnical properties. East region has stone blocks with dimensions of 0.1 to 1 meters and the southeast contains fragmented rock blocks or small limestone blocks with dimensions of 0.05 to 0.3 meters. South and southwest regions have average size of stone blocks. In this area due to intense tectonic activity occurred, slight anticlines and synclines can be seen which disrupted joint systems in the region.

On the other hand, in the east and south Angouran mine, space of discontinuities are close together and RQD value in these regions is low. Also the joint separation between the discontinuities is not impressive (low escape of gas in this section). Thus the efficiency of transportation in these areas is higher than the other areas of the mine. In the northwest part because of the layers of schist and integrity of this section, the efficiency of blasting operations is acceptable and fragmentation quality is appropriate. However, according to presence of underground water, loss in the schist due to incorrect design of dip of bench towards the slope of the layers, the efficiency of transportation in these areas greatly reduces. Furthermore, pro-fragmentation in majority of bench faces can be seen which its amount in northern and schist bench faces is more than other areas.

(a) (b)

(c) (d)

Fig. 6. Blasting results from the different areas of Angouran mine (fragmentation status, shape and height of the piles): (a) created oversize in the north and northeast Angouran mine; (b) working face in the west of the mine (over size creation); (c) working face in the south of the mine (good fragmentation); (d) schist areas of north and north west (good fragmentation, high density).

However, the explosion in the west, north and north east of the mine involves large pieces of rock and heavy back break which hydraulic hammers used to break large pieces of rock. As section contains large block of limestone with dimension of 0.3 to 1.5 meters filling by schist and clay, there is the risk of landslides of large blocks during rainfall. RQD values in this region are high and spacing of discontinuities between the joints is so much. Surface of discontinuities is smooth and their joint separation is too large (high escape of gas in this section).

Because of large pieces of rocks and along with low swelling of pile, loading rate is reduced and period of time required for one cycle of loading increased in bench faces of north, northeast and west (Fig. 7). On the other hand in majority of explosions conducted in these regions, presence of toe due to slow loading of nails and occasionally breaking them and its raising depreciation causes reducing the efficiency of loading operation (Fig. 8).

Fig. 7. An example of waiting time for loading trucks.

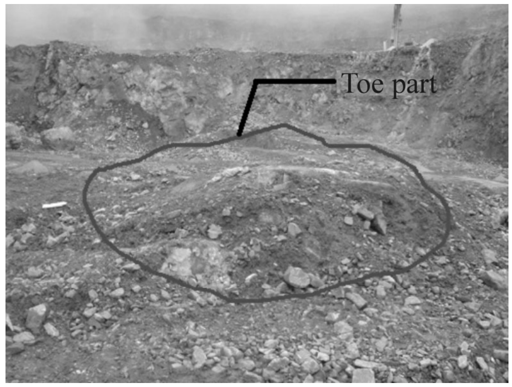


Fig. 8. Create toe in the north and northeast of the mine -2900 bench.

The presence of large pieces of rock has also negatively affects on efficiency of trucks. This means that sometimes it is just a great piece on the truck which does not fill its real capacity and decreases the efficiency of the transportation (Fig. 9). Besides the presence of large pieces of rocks, high toes and low swelling in the bench faces of these regions increases the period of one cycle loading time causing the queue waiting time to increase and reduce the efficiency of the loading and hauling cargo. However it is sometimes seen there are waste times for arrival of trucks and usually cleaning operation of steps is required.

According to presence of water in the layers of schist in the north, northwest and west Angouran mine, though the fragmentation quality in these areas due to integration of layers of schist and no escaping gas is appropriate, it is sometimes the cargo from explosions causes transportation trucks to sink in the mud due to presence of groundwater and thus causes disorder of transportation system of mine. This is clearly depicted in Fig. 10.

(a) (b)

Fig. 9. Effect of rock fragmentation quality on transport operations efficiency: (a) Loading oversize of rock mass (north to the east); (b) loading of good fragmentation rock and efficient use of a capacity of the excavator and truck (south west).

Fig. 10. Truck stuck in schist, inability to transfer load of the schist working space.

Due to transportations, we can realize that the quality of this operation is greatly affected by the geotechnical parameters of rock mass and results of explosions carried out in the mine. In the next section the influence of mechanical parameters are outlined and discontinuities systems have been picked from Angouran mine and extent of changes in transportation cost are discussed.

2.1. Calculation of the Transportation Cost at The Blasted Blocks

There are different methods used to assess the quality of fragmentation. In this article the evaluation was measured by studying of loading machines efficiency at different stages in which the cost of transportation, particularly the loading was calculated.

Equation (1) is used to calculate the transportation cost for each extractive block:

$$C_{Ti} = C_{Ii} + C_{bi} + C_H \,, \tag{1}$$

where C_{Ti} is the transportation cost on the number i of bench face by USD per cubic meter, which is sum of the loading cost C_{Ii}, bulldozers works cost C_{bi}, hauling cost C_H, respectively, to transfer a cubic meter of rock in the bench face. For example, the results of calculations for 10 blocks are reported in Table 4.

3. INVESTIGATION OF GEOTECHNICAL FACTORS INFLUENCE ON THE COST OF EXTRACTING

To describe the relationship between the geotechnical parameters and transportation costs, according to Eq. (2) multivariate linear regression was used:

$$\begin{bmatrix} y_0 \\ y_1 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_{11} \cdots x_{1k} \\ 1 & x_{21} \cdots x_{2k} \\ \vdots \square & \vdots \quad \cdots \vdots \\ 1 & x_{n1} \cdots x_{nk} \end{bmatrix} \cdot \begin{bmatrix} \square \\ \square_1 \\ \vdots \\ \square_k \end{bmatrix}, \tag{2}$$

Here, x is matrix values point for each geotechnical variable, $\square$ is matrices geotechnical variables, and y is the matrix of the transportation cost of the extracted blocks.

The variables used in this equation are the most important geomechanical and geotechnical parameters of rock mass (uniaxial compressive strength-UCS, rock quality description-RQD, spacing of discontinuities-Sp, difference of dip direction and bench face direction-A, difference of dip joints and dip of bench face-B) which are often in all classifications of rock mass in terms of open pit mines and are the most important variables to determine the results from blasting. A sample of this data used as an input data in Equation (2) is shown in Table 2. Therefore input matrix contains: UCS, RQD, Sp, A, B, respectively.

Table 4. The results of transportation steps cost for 104 blasted bench face

The cost of the various stages of transportation operations for each studied blocks (USD per in situ cubic meter)				
Block no.	Loading	Hauling	Bulldozers work	Transportation cost
1	1.73	3.02	0.31	5.07
2	1.05	1.86	0	2.92
3	1.26	1.41	0.198	2.87
4	0.65	1.62	0.131	2.4
5	0.34	0.63	0	0.96
6	0.3	0.47	0.027	0.79
7	0.34	0.65	0.03	1.02
8	0.48	1.31	0.166	1.96
9	0.32	0.66	0.069	1.05
10	0.57	0.75	0.022	1.34

The output of the above equation includes the total cost of loading operation, bulldozer works and freight for transfer of a cubic meter of rock mass (Table 4). It should be noted that the geotechnical properties and transportation cost of block 104 studying in the mine (Figure 2) have been used in the input and output of Equation (2) that Table 2 and Table 4 shows all the details of 104 blocks.

3.1. Relationship between Extraction Cost and Geotechnical Characteristics

By solving Eq. (2), the cost of extractive mining blocks are calculated from Eq. (3):

$$COST = -1.568 + 0.0125 \cdot R_{USC} + 0.025 \cdot R_{RQD} + 0.035 \cdot R_{Sp} + 0.004 \cdot R_A + 0.009 \cdot R_B, \qquad (3)$$

where $COST$ is transportation cost in waste region (USD per cubic meter), R_{UCS} is the uniaxial compressive strength value, R_{RQD} is the rock quality description value, R_{Sp} is the spacing of discontinuities value, R_A is the azimuth difference between discontinuities and bench face parameter (A) and R_B is the dip joints parameter point (B)

Figure 11 shows the actual cost of transportation against the estimated costs by multiple linear regressions. Since the correlation coefficient between estimated values and actual values is 0.7013 and much of estimated parameters are in range of ±20% from actual values then it can be concluded that there is an acceptable relationship between geotechnical parameters and amount of transportation cost.

According to Eq. (3), the coefficients of all studied parameters are positive. Increasing of UCS, RQD and SP parameters means the integrity and greater resistance of the rock mass against fragmentation operation and thus higher costs in the later stages of the mining operation.

According to Eq. (3), the influence of spacing of discontinuities, difference of dip direction and bench face direction (A), difference of dip of joints and dip of bench face (B), on the amount of transportation cost is positive. Increasing in spacing of discontinuities value means the integrity and greater resistance of the rock mass against fragmentation operation and thus higher costs in the later stages of the mining operation. Increasing of A parameter causes the increase of probability of discontinuity outcrop at bench face.

This fact is a factor in the loss of blasting gas, the weak fragmentation and the resulting increase in the cost of transportation in the discontinuities. Eventually increasing B parameter leads to orientation of discontinuities direction to inward of bench face and thus reducing of the fragmentation ability as Lily (1976) and Mumivand (2006) have pointed out. Decreasing in fragmentation ability and its negative impact on the subsequent mining operations, lead to increasing of transportation costs which is validated in Eq. (3).

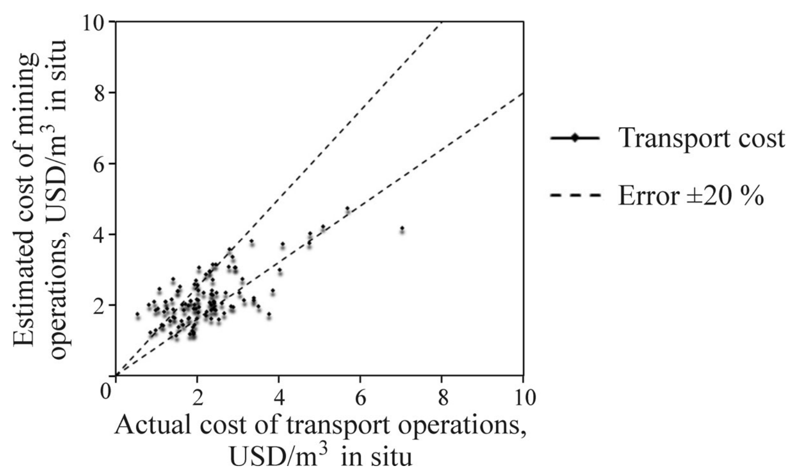


Fig. 11. Actual and estimated costs of mining operation in Angouran mine.

3.2. Sensitivity Analysis of Transportation Cost Variation in Compare of Geotechnical Parameters

In this subsection, the amount of change in the exploitation costs versus change of every single geotechnical parameters is studied and therefore the parameters effect is evaluated. Equation (4) is used for sensitivity analysis on effects of geotechnical parameters in mining operations at zinc and lead Angouran mine [24]:

$$\Delta C_E = \frac{(C_{T\max} - C_{med})/C_{med}}{(R_{\max} - R_{med})/R_{med}}, \tag{4}$$

where ΔC_E, $C_{T\max}$, C_{med}, $R_{\max}$ and R_{med} are the percentage change in average cost of exploitation for the parameter change, total cost of exploitation for the maximum value of the parameter of the cost (other geotechnical parameters remain in the average value), the cost for the average value of the parameters, the maximum value of the parameter of the cost, average value of the parameter, respectively.

According to calculations, the maximum (greatest) effect on increasing of mining operations costs is relevant to spacing of discontinuities parameter of rock. After this parameter other important variables are as follows, respectively: rock quality description, uniaxial compressive strength, difference of dip joints and dip of bench face, difference angle of dip joints direction and dip direction of bench face.

CONCLUSIONS

In order to evaluate the performance of the blasting unit in Angouran mine the results from transportation noted and investigated. The blasting results due to the size distributions of rocks from blasting and also the amount of swelling and geometry of piles caused by geotechnical parameters can influence the efficiency of loading equipment.

According to the results of the mine about 39.8% of piles are less than 7 m in height and about 51.5% of them are between 8 to 10 m in height and 8.7% of the rest are above 10 m. Hydraulic shovels in Angouran mine have a desirable performance at 55% of explosions conducted in the mine with high loading safety. However, according to loading system in the mine often includes excavators, in most bench faces they have to make a stage from rocks before loading the piles. Besides about 14.5% of explosions conducted in the mine are not suitable for loading by most loading machines due to piles shapes and about 30.5% of the rest are not suitable by hydraulic shovels and excavators of the mine. This has caused considerable changes in transportation costs and provided adequate background to investigate effect of mechanical parameters of the rock mass as a result of studied blasting by inspiration of these changes.

Geotechnical parameters of ores in Angouran mine, which somehow affect the performance of transportation machines, were survey at 104 regions of the mine. To evaluate the effect of these parameters on final performance (marginal cost) of transportation unit, an equation to determine the correlation between geotechnical parameters and the final transportation cost using multivariate linear regression proposed. Correlation coefficient of the equation and what actually takes place is 0.703 which represents a reasonable relationship between geotechnical parameters and amount of transportation costs.

In order to determine the amount of geotechnical parameters effect on the final cost sensitivity analysis based on the percentage change in price for each parameter change was conducted. The results show significant effect of spacing of discontinuities, rock quality description and uniaxial compressive strength on the final performance of transportation.

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