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Numerical Modeling of Discontinuities to Determine Optimal Direction of Dimension Stone Extraction (Case Study: Melika Kerman Marble Quarry, Central Iran)

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Abstract

One of the most significant risks for investors in the dimension stone industry is the presence of natural discontinuities in the rock mass, which affect the quality of the extracted stone blocks. These discontinuities not only reduce extraction efficiency but also hinder the optimal utilization of the quarry. Therefore, it is essential to identify and analyze discontinuities in the rock before initiating any extraction activities and to assess the optimization of the extraction direction in dimension stone quarries. This study examines the key characteristics of discontinuities and joint sets, including their coordinates, strike, dip, spacing and aperture, in the Melika marble dimension stone quarry in Kerman. The collected data are then analyzed using 3DEC software to construct a quarry block model. Additionally, the azimuth rotation of different joint sets is investigated in four categories. The results obtained from the modeling indicate that, to achieve maximum blocking, the current extraction direction should be shifted 70° westward. This adjustment increases the number of blocks to 14,550, the average block volume to 5.5 m³, and the total volume of extracted stone to 79,918.9 m³. These changes are projected to generate approximately $3,180,000 in revenue for the quarry. The study highlights a practical optimization strategy that can significantly enhance the efficiency and profitability of dimension stone quarries by improving extraction direction based on discontinuity analysis.

1. Introduction

One of the key pieces of information required by the owners of dimension stone quarries is the amount of extractable and profitable stone blocks [1]. Joint systems, in particular, play an important role in the extraction of stone blocks [2,3,4]. The market for dimension stones will continue to grow exponentially in the coming decades. This great demand has led to major improvements in the extraction and processing of natural building stones [1]. According to the world ranking of dimension stone reserves, Iran ranks fourth, but due to technical weaknesses in the technology of extraction and processing of dimension stone, it has not been able to gain a significant share of the export market for this mineral. Activities and investments in the dimension stone industry always face high risks, and can result in heavy losses for stakeholders in this sector. One of the most important of these risks is the presence of fractures and various joints in the areas and quarries of dimension stones. The presence of these fractures significantly reduces the compaction capacity and optimal dimensions of the stone blocks that can be extracted, and during the cutting and preparation of the stone slabs in the factory, it causes the stone piles to break. Therefore, the extraction direction should be determined in such a way that the production of stone blocks is maximized. Having enough information about the discontinuity plates and recognizing the blocks enclosed between them

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makes it possible to identify more acceptable blocks for extraction, significantly reducing the amount of waste. On the other hand, the stability of the extraction steps in dimension stone quarries is strongly dependent on the characteristics of these discontinuities including slope, dip direction, aperture, spacing, opening, filling, and continuity. The presence of discontinuities always reduces the safety factor of the extraction steps, and presents life risks. Therefore, studying discontinuities in dimension stone quarries is of great importance both economically and safely. Various studies have been conducted in this regard. [5] used a genetic algorithm to introduce a new indicator to determine the extraction of dimension stone quarries and find the optimal extraction direction. [6] studied rock quality charts for log-normally distributed block sizes. [7] investigated block sizes for rock masses, and estimated block sizes for rock masses with non-persistent joints. [8] evaluated joints in granitic outcrops for dimension stone exploitation. [9] studied the determination of optimized extraction of dimension stone blocks. [10] developed a new method to estimate in-situ block size distribution. [11] investigated the effect of fractures on rock fragmentation efficiency in Kopec granite quarries located in Southwestern Nigeria. [12] developed a 2D computer program to determine the geometry of rock mass blocks. [13] investigated appropriate methods to identify the geometry of in-situ rock blocks in dimension stones. Also, [14] developed a Matlab code to determine the geometry of rock mass blocks and its applications in mining and rock mechanics engineering. [15] studied the optimized dimension stone extraction direction using block analysis in the Dingle Kahriz travertine quarry located in Iran. [16] developed discontinuity modeling and rock block geometry identification to optimize production in dimension stone quarries. [17] developed 2D and 3D computational algorithms for discontinuity structural geometry identification using artificial intelligence based on image processing techniques. [18] studied the optimal extraction direction to maximize dimension stone excavation by modeling discontinuities in the capitol travertine quarry located in Iran. The resulting changes will lead to high revenue for the quarry.

In addition to the aforementioned studies, more recent research includes the following: the dimension stone extraction method was reviewed by [19]. The determination of the size and shape of a dimension stone block, considering joint sets, was investigated by [20]. Fracture analysis for optimizing site selection and quarrying of natural stone was studied by [21]. Additionally, [22] surveyed the effects of discontinuities on the rock block geometry in dimension stone quarries, while [23] analyzed the discontinuities and rock mass blocks in dimension stone quarries.

2. Melika Marble Quarry in Kerman

The Melika Nescafe marble quarry is located in Ravar city, Kerman province, 3 km away from Tarz village and Ravar city. The location of the studied area, the Melika Kerman marble quarry, is shown in Figure 1. The relationship between fractures and active tectonics in the Central Iran basin has been investigated by several researchers.

Nucleation is one of the most important and fundamental steps during the exploration phase of the quarry. It not only provides information about the amount and volume of rock in the quarry area but also, through the use of an appropriate drilling plan and suggesting an optimal drilling depth, helps track the fractures and joints that appear on the surface and in trenches dug at the start of exploration. This approach allows for understanding the general performance, processes, and movement direction of joints and fractures in the studied area.

At the Melika marble quarry, according to the excavations, the scales have increased during drilling at depths from 0 to 10 meters without fossil evidence and with a light color. At a depth of 10 to 16 meters, the stone gradually discolored, and scattered fossil evidence decreased. Between 16 and 25 meters, the rock color darkened and became opaque, and the drilling speed slowed to one-third of the initial rate. The power of the drilling rig decreased at lower depths, indicating an increase in the integrity of the rock in terms of seams and cracks at these depths.

Studies have shown that two groups of discontinuities are visible in the studied area, which have a direct orientation and intersect vertically. To better analyze the situation of breast augmentation, it has been studied. The leveling and segmentation of the quarry based on production steps, for the removal of joints and fractures, is shown in Figure 2.

Surveys of the quarry's steps have shown that the direction of the joints is nearly N-S. The collected data required for modeling and optimization of the quarry are provided in Table 1.

Figure 1. Location of the studied area, the Melika marble quarry, Kerman.

Figure 2. Leveling and segmentation of the quarry based on production steps to remove joints and fractures.

Table 1. Specifications of the discontinuities.

Discontinuities	Strike and dip	Spacing of discontinuities	Aperture	Description
1	195, 65 SE	5.3	Open	Oblique to bedding plane
2	135, 23 NE		Close	Bedding plane

3. Materials and Methods

3.1. Preparation of discontinuity model

After identifying the joint system in the Melika quarry area, the rock mass discontinuity model was created based on the collected characteristics. In this research work, the trend shown in Figure 3 was applied to model the discontinuities in the rock mass.

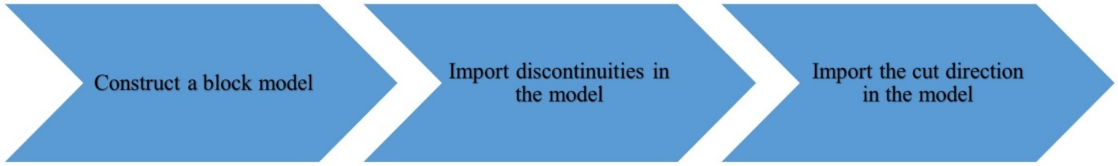

Figure 3. Stages of modeling discontinuities in the dimension stone quarry.

3.2. Building a block model

Creating a block model in the 3DEC software can be done in two ways: a) by cutting a polygon into separate polygons, and b) by constructing separate polygons and connecting them together.

In this research work, by constructing separate polyhedra and connecting them to each other, a quarry block model was created (Figure 4).

3.3. Inserting discontinuities into the model

In the 3DEC software, discontinuities can be inserted in two different ways: a) by defining the properties of joints using keywords. In this case, the command creates a page that cuts the model with the specified geometry; b) randomly. In this method, by inputting the geometric properties and statistically defined properties, the heterogeneous nature of the rock joints is represented as a discrete element using a three-dimensional representation of the joint network. In the present study, the discontinuities were manually defined for the software according to the field data collected in the Melika quarry's frontal harvesting form (Figure 5).

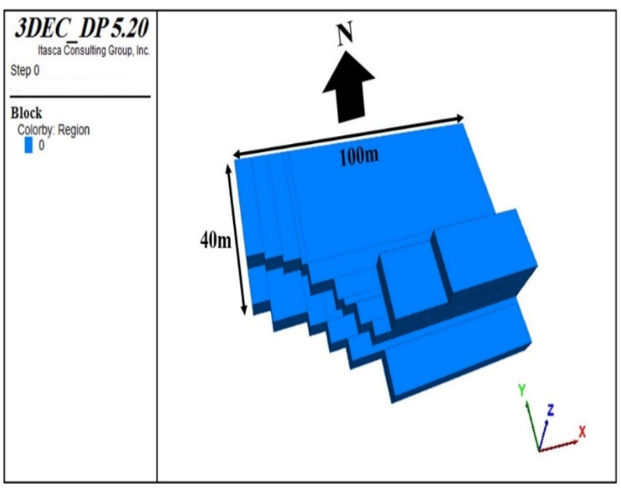

Figure 4. Block model of the Melika marble quarry in the 3DEC software.

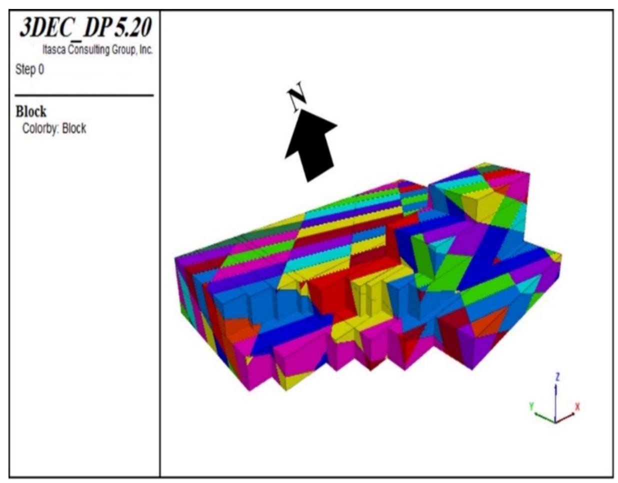

Figure 5. Joint block model of the Melika marble quarry.

3.4. Inserting cuts from cutting wire into numerical model

The boundaries of the model correspond to the cuts made by the cutting wire. Each of the cut lines is applied to the model as a single seam. The dimensions of the cut blocks in this quarry are usually 2 m × 3 m × 2 m. Therefore, shear lines can be considered as three single joints perpendicular to each other.
The first joint consists of transverse shear lines with a slope of 90°, in the current direction of progress (north-south), i.e. zero to the north, with a distance of 3 meters. The second joint includes longitudinal shear lines with a slope of 90°, perpendicular to the first shear lines, extending 90° to the north and a distance of 2 meters. The third joint consists of shear lines used to slate the cut block, which can be considered as a joint with a slope of zero and a distance of 2 meters (Figure 6).

3.5. Determining on-site quarry blocks

After modeling the joint system in the area and replacing the cutting lines with two single joints in the rock mass, the volume and tonnage of the blocks created by these joints at each stage are calculated.

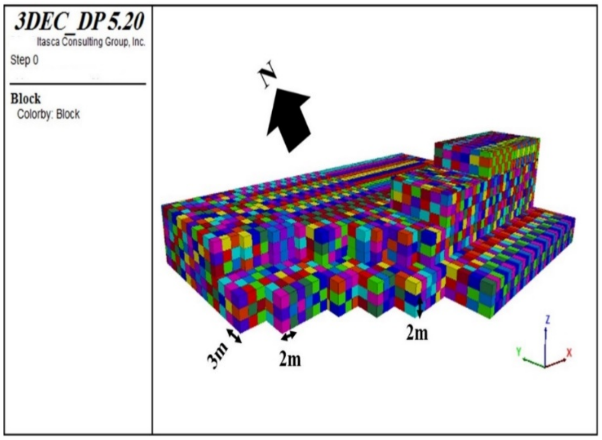

Figure 6. Application of the cuts from the cutting wire in the numerical model.

In this quarry, blocks with a volume of less than one cubic meter (or an approximate tonnage of less than 2.5 tons) are considered tailings. The volume considered waste depends on the type and price of the stone. The higher the price of dimension stone, the lower the waste volume. For example, in a marble quarry, this value may be 0.5 cubic meters.

Taking into account the value and volume of blocks and consulting with mining engineers, four categories have been suggested for grading large blocks, as shown in Table 2.

Considering the size factor, category 1 includes blocks with a volume of more than 12 m³, category 2 includes blocks with a volume between 2 and 12 m³, category 3 includes blocks with a volume between 1 and 2 m³, and category 4 includes waste blocks with a volume of less than 1 m³.

Table 2. Classes designated for grading blocks.

Class number	1	2	3	4 (Waste)
Extraction block volume (V)	12 m^3	2 m^3 < V < 12 m^3	1 m^3 < V < 2 m^3	< 1 m^3

4. Results and Discussion

To extract the stone, depending on the variety of devices used, holes are drilled with a horizontal distance of 15 to 20 meters. This distance is then divided into holes at intervals of 1.8 meters, which corresponds to the width of the initial blocks. The 1.8-meter distance is determined based on the width of the truck used to carry the block. Therefore, the maximum cutting width cannot be altered, but the cutting depth can be optimized. In this process, after selecting the optimal extraction direction, the cutting depth is determined based on the dominant discontinuity distance. Since advancing in two opposite directions will yield the same results, a 180° rotation is sufficient to analyze the direction of advancement. Instead of changing the extraction direction in the block model, the azimuth of the model joints can be rotated by 10° at each stage of modeling. The value of the azimuth rotation, α°, in a clockwise direction is equivalent to changing the extraction direction by an amount of α° in a counterclockwise direction. The azimuth rotation of the joints is altered in 10° increments to identify the best extraction direction in the counterclockwise direction.

The results of these studies are presented in Table 3, which shows the volume of blocks that can be sold in exchange for azimuth rotation of joints in different categories.

Table 3. The volume of blocks that can be sold in azimuths of different joints.

Azimuth of extraction	Total volume (m^3)			
	Class 1	Class 2	Class 3	Waste
0	1967.9	74528	2118.6	1304.8
10	1943.5	74443	2223	1310.7
20	1835.8	74503	2246.7	1334.3
30	1959.2	74363	2221.6	1375.7
40	2070.4	74309	2190.2	1350.3
50	2215.5	74240	2174.4	1288.9
60	2461.8	74301	1984.3	1172.3
70	2618.5	74179	2014.6	1106.8
80	2379.9	74451	1954.6	1134
90	2310.7	74488	1899.7	1221

Figures 7 to 9 show the volume of blocks that can be sold in three different rotations. In Figure 7; the blocking volume in the initial state (current progress) is shown; in Figure 8, the best extraction direction is shown; and in Figure 9, the worst extraction direction is shown.

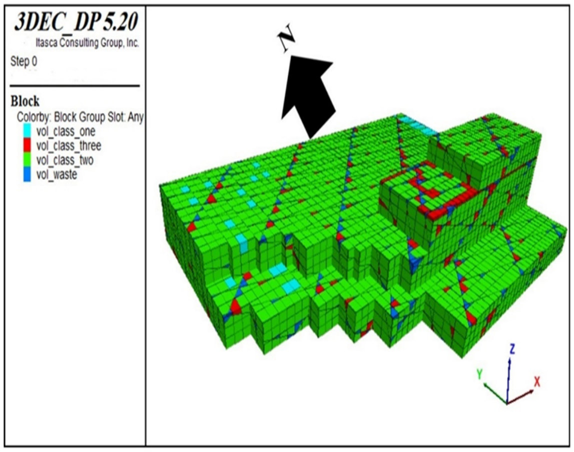

Figure 7. Blocks created in the north and northwest direction (current progress).

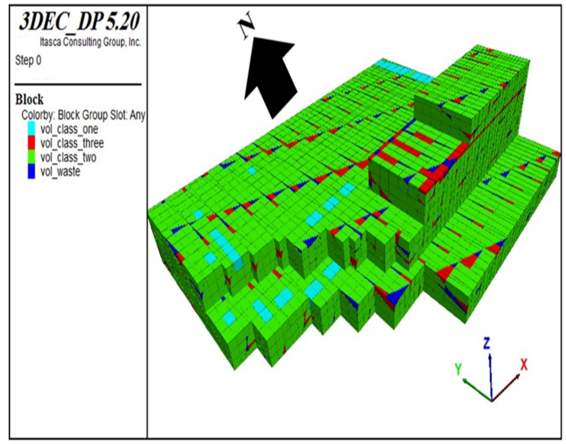

Figure 8. Blocks created by rotating the 70° joint azimuth (the best extraction direction).

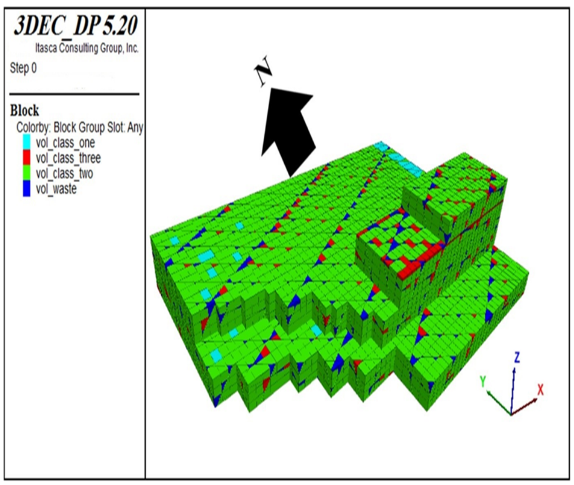

Figure 9. Blocks created by rotating the 20° joint azimuth (the worst extraction direction).

With the identification of four categories for grading blocks, the value of each category is as follows:

Category 1: Blocks with a volume of more than 12 m^3, valued at $28.

Category 2: Blocks with a volume between 2 and 12 m^3, valued at $16.

Category 3: Blocks with a volume between 1 and 2 m^3, valued at $6.

Category 4: Blocks with a volume of less than 1 m^3, which are considered waste.

In this way, the relative value of each category and the total value for different directions of extraction are calculated using Equation (1). By calculating the amount of blocks that can be sold in each category, the income and economic feasibility of the quarry can be estimated at the feasibility stage. This is a crucial factor in deciding whether to proceed with quarrying or attract an investor. On the other hand, this also provides a suitable criterion for mining planning and determining the quarry extraction sequences.

In this regard, (insert source of the relationship):

$$I = AMC \times \rho \times P \quad (1)$$

AMC: Amount of marketable cuboid.

ρ: Rock density (Tons per cubic meter)

P: The selling price of each ton of raw block in the quarry

I: Value (income) from the sale of mining compartments

Finally, by calculating the value of each category, the values of all four categories are summed, and the highest value is selected as the best and most appropriate counter-clockwise direction for extraction. The results are provided in Table 4 and Figure 10.

Table 4. Results of the study of blocks formed in different directions.

Rotation of joints azimuth	Production specifications	Class 1	Class 2	Class 3	Waste	Total
0	Number of blocks	114	9962	1438	4632	16146
	Total volume (m^3)	1967.9	74528	2118.6	1304.8	79919.3
	Av. volume (m^3)	17.3	7.5	1.5	0.3	4.9
	Value ($)	137,753	2,981,120	31,779	0	3,150,652
10	Number of blocks	112	9861	1502	4855	16330
	Total volume (m^3)	1943.5	74443	2223	1310.7	79920.2
	Av. volume (m^3)	17.4	7.6	1.5	0.3	4.9
	Value ($)	136,045	2,977,720	33,345	0	3,147,110
20	Number of blocks	105	9754	1540	4922	16321
	Total volume (m^3)	1835.8	74503	2246.7	1334.3	79919.8
	Av. volume (m^3)	17.5	7.6	1.5	0.27	4.9
	Value ($)	128,506	2,980,120	33,701	0	3,142,327
30	Number of blocks	116	9635	1510	4923	16184
	Total volume (m^3)	1959.2	74363	2221.6	1375.7	79919.5
	Av. volume (m^3)	16.9	7.7	1.5	0.3	4.9
	Value ($)	137,144	2,974,520	33,324	0	3,144,988
40	Number of blocks	126	9545	1489	4664	15824
	Total volume (m^3)	2070.4	74309	2190.2	1350.3	79919.9
	Av. volume (m^3)	16.4	7.8	1.5	0.3	5.1
	Value ($)	144,928	2,972,360	32,853	0	3,150,141
50	Number of blocks	142	9413	1465	4393	15413
	Total volume (m^3)	2215.5	74240	2174.4	1288.9	79918.8
	Av. volume (m^3)	15.6	7.9	1.5	0.3	5.2
	Value ($)	155,085	2,969,600	32,616	0	3,157,301
60	Number of blocks	162	9392	1379	4017	14950
	Total volume (m^3)	2461.8	74301	1984.3	1172.3	79919.4
	Av. volume (m^3)	15.2	7.9	1.4	0.3	5.4
	Value ($)	172,326	2,972,040	29,765	0	3,174,131
70	Number of blocks	174	9342	1364	3670	14550
	Total volume (m^3)	2618.5	74179	2014.6	1106.8	79918.9
	Av. volume (m^3)	15.1	7.9	1.5	0.3	5.5
	Value ($)	183,295	2,967,160	30,219	0	3,180,674
80	Number of blocks	164	9357	1327	3844	14692
	Total volume (m^3)	2379.9	74451	1954.6	1134	79919.5
	Av. volume (m^3)	14.5	8	1.5	0.3	5.4
	Value ($)	166,593	2,978,040	29,319	0	3,173,952
90	Number of blocks	149	9389	1306	4505	15349
	Total volume (m^3)	2310.7	74488	1899.7	1221	79919.4
	Av. volume (m^3)	15.5	7.9	1.5	0.3	5.2
	Value ($)	161,749	2,979,520	28,496	0	3,169,765

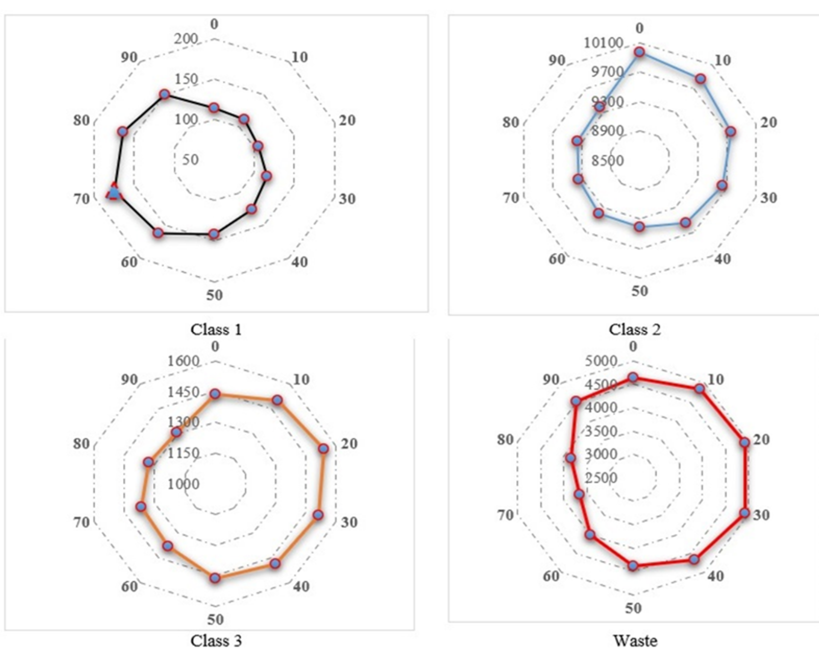

Figure 10. The number of blocks in classes 1 to 3 and waste for different directions.

To determine the optimal extraction direction, the total value of the blocks for the azimuth rotation of various joints was compared. The comparison of the total value of blocks for the azimuth rotation of different joints in the Melika quarry is shown in Figure 11. In this graph, the x-axis represents the azimuth rotation of the joints, and the y-axis represents the value (income). Among the azimuth rotations of the joints, the azimuth that yields the highest overall value is considered the best direction (extension) for the optimal counterclockwise extraction.

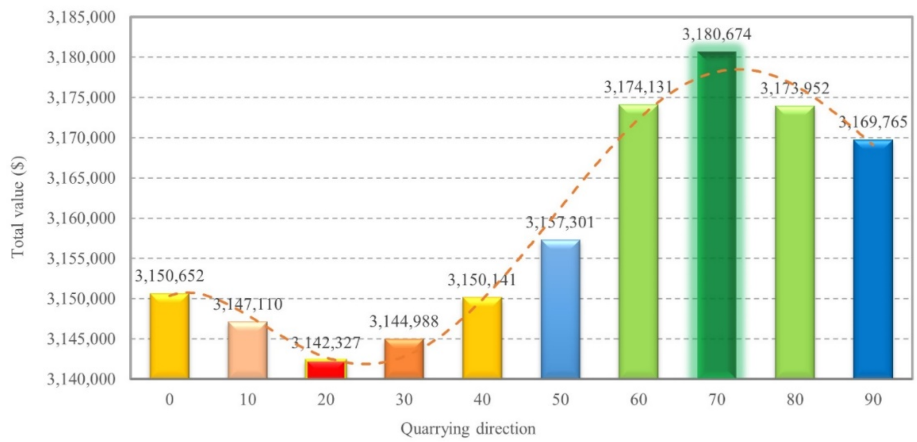

Figure 11. Comparison of the total extraction value for different directions in the Melika quarry.

According to Figure 11, the maximum value (income) is obtained at azimuth rotations of 50°, 60°, 70°, and 80°. On the other hand, based on the conditions of the joints in the studied quarry, and by changing the azimuth rotation of the joints by 70° in a clockwise direction, this is equivalent to changing the extraction direction by 70° in a counterclockwise direction. Therefore, the 70° counterclockwise direction is selected as the best direction for extraction.

The extractable reserves of this quarry, after applying the 70° counterclockwise rotation for the extraction direction, are as follows:

Category 1: 1967.9 m³

Category 2: 74528 m³

Category 3: 21116.6 m³

Category 4 (waste): 1304.8 m³ (as shown in Table 4).

The income from the sale of stones from this quarry, according to Equation (1), is $3,180,674.

As shown in Figure 11, if the quarry changes its extraction direction by 70° to the west, it will yield a profit of $3,180,000. This means that by changing the extraction direction of the quarry by 70° counterclockwise, the highest amount of mining is achieved with the least amount of waste, resulting in greater income.

According to the modeling carried out for a section of the Melika mine, the efficiency of the modeled block has been calculated according to the different directions of mining progression. The highest efficiency is related to the south-north direction and the lowest is related to the east-west direction. Investigating the optimal mining direction in different directions allows planning the location of the ramps and other facilities in the mine area to be selected with greater freedom of action.

The 3DEC software also allows for estimating the mine's efficiency at varying mining depths. To test this method, the efficiency of the Melika mine was examined at depths of 6, 10, 15, 20, 22, and 25 meters for both west-east and east-west directions.

Based on the conducted modeling and considering the previous angles of the extraction benches, after consulting with the client and taking into account the extraction costs and the topographic constraints of the region, it was decided that the overall angles of the mine should be adjusted in a single direction. By relocating the equipment and changing the direction of advancement, as well as modifying the angles of the extraction benches, and with the acceptance of financial risk and a temporary reduction in production, after six months of adjustments and bearing the extraction of 4,000 tons of waste material, the mine's advancement axis was finally aligned with the desired angle.

Subsequently, by comparing the periodic monthly reports provided by the on-site mining engineers—including studies conducted on aerial photographs, production tonnage, and the quality of produced blocks at the modeled angle—with the reports prior to these changes in the mining benches, the technical team observed a gradual increase in efficiency within the area. Consequently, over a three-month period and with an error margin of less than 2% compared to the modeling, there was a significant reduction in fractures within the production blocks. Based on the decision of the technical team, the same path was confirmed as the primary advancement front for continued production. Therefore, with the verification and practical feasibility of the study, the necessity of applying this modeling to other areas and benches for economic production was communicated to the production team.

Thus, using numerical modeling based on joint and layering attitudes in ore extraction offers several advantages that enhance efficiency, reduce costs, and improve safety in mining operations. Some of the key benefits of this method include:

1. Optimization of Extraction Design

- Ability to predict rock behavior based on geological structures such as joints, faults [24], active faults [25], layering and topography [26].
- Reduction of unwanted fractures in the rock, improving the quality of extracted blocks.
- Optimization of bench angles and excavation direction to enhance mining efficiency.

2. Increased Safety in Mining Operations

- Identification and prediction of high-risk areas such as slope instabilities and potential collapses.
- Optimization of support and reinforcement placement to minimize risks.
- Reduction of accidents caused by geomechanical instabilities.

3. Cost Reduction and Increased Efficiency

- Minimization of ore loss by selecting optimal extraction paths.
- Reduction in unnecessary drilling and blasting, leading to lower operational costs.
- Extended lifespan of mining equipment by decreasing unnecessary stress.

4. High Accuracy in Prediction and Decision-Making

- Ability to perform precise simulations to assess rock mass behavior before actual operations.
- Utilizing numerical modeling to enhance managerial decision-making in mining.
- Reduction in reliance on traditional methods and increased accuracy in extraction planning.

5. Improved Environmental Sustainability

- Reduction of waste material generation by selecting optimized extraction routes.
- Minimization of environmental impacts caused by uncontrolled excavation and unstable mine expansion.

5. Conclusions

The presence of discontinuities in dimension stone quarries not only affects the quality of the extracted stone blocks, but also reduces mining efficiency. Additionally, it causes significant economic and safety risks to the actors in this industry. Therefore, the study of discontinuities in dimension stone quarries is vital. In this study, the characteristics of the discontinuities in the Melika quarry were collected using the line method. After modeling the joint rock mass using the 3DEC software and analyzing the results, it was observed that the optimal extraction direction for the quarry forms an angle of 70° with the extension line.

By changing the extraction direction to 70° to the west, it was found that this direction results in the highest mining efficiency and the least amount of waste. A comparison of the current extraction direction and the proposed direction showed that changing the direction to 70° counterclockwise leads to the highest mining yield, reduces waste, and increases overall mining efficiency. This change in direction will ultimately generate a profit of $3,180,000 for the quarry. Novelties are: 1. Introducing a new numerical approach for analyzing discontinuities in dimension stone extraction.2. Improving the accuracy of optimal extraction direction prediction compared to traditional methods.

Advantages are:1. Enhancing efficiency and reducing extraction costs by identifying the optimal cutting direction. 2Improving mining safety by minimizing risks associated with unfavorable discontinuities.

Practical Applications are:1. Implementation in similar quarries to optimize the extraction process. 2. Assisting mining engineers in reducing waste removal and increasing productivity.

Limitations and Future Studies are: 1. Dependence on the quality and accuracy of input data, such as surveyed joints and fractures.2. Future research is suggested using advanced numerical techniques, including machine learning-based methods.3. Investigating the influence of other geological and mechanical factors on the optimal extraction direction.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

We have no conflict of interest to declare. This statement is to certify that all authors have seen and approved the manuscript being submitted. We warrant that the article is the authors' original work. We warrant that the article has not received prior publication and is not under consideration for publication elsewhere.

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کلمات کلیدی

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چکیده

یکی از مهم‌ترین ریسک‌های سرمایه‌گذاران در صنعت سنگ‌های ساختمانی، وجود ناپیوستگی‌های طبیعی در توده سنگ است که بر کیفیت بلوک‌های استخراج‌شده تأثیر می‌گذارد. این ناپیوستگی‌ها نه‌تنها بازدهی استخراج را کاهش می‌دهند، بلکه بهره‌برداری بهینه از معدن را نیز مختل می‌کنند. بنابراین، شناسایی و تحلیل ناپیوستگی‌ها در توده سنگ پیش از آغاز عملیات استخراج و ارزیابی جهت بهینه استخراج در معادن سنگ ساختمانی ضروری است.این مطالعه، ویژگی‌های کلیدی ناپیوستگی‌ها و دسته‌بندی درزه‌ها ازجمله مختصات، امتداد، شیب، فاصله و گشودگی آن‌ها را در معدن سنگ مرمر ملیکا واقع در کرمان بررسی می‌کند. داده‌های جمع‌آوری‌شده با استفاده از نرم‌افزار 3DEC تحلیل شده و یک مدل بلوکی از معدن ایجاد می‌شود. افزون بر این، چرخش آزیموتی دسته‌های مختلف درزه در چهار دسته مورد بررسی قرار می‌گیرد.نتایج مدل‌سازی نشان می‌دهد که برای دستیابی به حداکثر بازدهی در استخراج بلوک‌ها، جهت استخراج فعلی باید ۷۰ درجه به سمت غرب تغییر یابد. این تغییر باعث افزایش تعداد بلوک‌ها به ۱۴,۵۵۰ عدد، افزایش متوسط حجم هر بلوک به 5.5 متر مکعب و افزایش کل حجم سنگ استخراج‌شده به ۷۹,۹۱۸.۹ متر مکعب می‌شود. همچنین، این بهینه‌سازی حدود ۳,۱۸۰,۰۰۰ دلار درآمد برای معدن به همراه خواهد داشت.این مطالعه یک استراتژی عملی برای بهینه‌سازی فرآیند استخراج ارائه می‌دهد که می‌تواند به‌طور قابل‌توجهی بهره‌وری و سودآوری معادن سنگ ساختمانی را از طریق بهبود جهت استخراج بر اساس تحلیل ناپیوستگی‌ها افزایش دهد.

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