http://doi.org/10.29227/IM-2019-02-67 Submission date: 01-06-2019 | Review date: 07-06-2019

Determining for an output capacity of dimension stone exploitation from the computer simulations to generate the fracture network in 3D: case study in some dimensional stone quarries in Vietnam

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Abstract: In dimension stone quarry exploitations such as the marble quarry, a literature review of the existing numerical modelling techniques has been carried out. According to Distinct Element Method, discontinuities have been treated as boundary conditions between blocks and, consequently, an accurate knowledge of joint distribution and orientation was required. The result of analyzing data and simulating in the fracture rock environment, which is applied to a mining condition of the dimensional stone quarries. The research we introduce in the output capacity of the dimension stone quarry from the computer simulations to generate the fracture network in 3D with an aim of evaluating the size of the blocks. The results of numerical models have been used to optimize some of the technical parameters for dimensional stone extraction and ensuring stable bench in the mining operation.

1. Introduction

In dimension stone quarry exploitations such as the quarry, the stability of the slopes can be considered from the aspect of slope cut or from the aspect of a bench or from gallery width. The research we introduce is the result of analysing data and simulating in the fracture rock environment, which applies to a mining condition of the dimensional stone quarries. Structural geologists usually measure and analyze orientation data in rock masses. The orientation of a discontinuity can be described by its dip and dip direction [1]. The combined orientations of discontinuities determine the shape of the individual blocks comprising the rock mass [2]. The properties of discontinuities relative to stability include orientation, persistence, roughness and infilling [3]. They are often found on the weakest structural plans where diverse displacement can develop. We have used advanced tools for analysing the data of joints and simulating the joint sets. Modelling program RESOBLOK was firstly written by LAEGO and INERIS, basing on the theory of Heliot 1988 [4, 5, 6] which is used to simulate cracking rock. The model result has been used to optimize some of the technical parameters for dimensional stone extraction and ensuring stable bench in the mining operation.

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2. Statistical study of the fractures

2.1. Input parameters

Parameters such as discontinuities, the fracture orientation, slope orientation, model dimensions of slope cuts, etc. were considered as inputs to predict number of set, the poles of sets, histogram and statistical of sets, statistical outputs with an aim of evaluating the size of the blocks, then the output capacity of the dimension stone quarry, synthetic indicator of global stability of slope cuts. The complexity of reality does not allow a complete description of the actual field [3,7]. The rock mechanics of rock mass depend mainly on the characteristics of the fracture field. It is therefore necessary to use stochastic models.

Applications are increasingly complex, and some involve a complete description of the fracture field. As fractures are not accessible in their entirety, but only at their intersections with boreholes, outcrops or drifts, one the first steps in the study of a given site is modeling and simulation of the fracture field. Mathematical morphology provides a means of fully characterizing a fracture network. It means stochastic models such as models of fracture systems, we are considering the random set of all the fractures [1, 3]. The knowledge of the functional of models of fracture systems is the random such as the exact equivalence of the spatial law for random functions and any nonrandom set of all the fractures. For any nonrandom set is then unchanged by translation and can be estimated from the sole realization of the fracture network. In practice, it is not possible to consider any nonrandom set of all the fractures. This works, the modeling deals with the scale ranging from tens of centimeters to tens of meters. It means various scales such as metric scale. The method is general and can be transposed to another scale.

2.2. Output parameters

2.2.1. Orientation distribution

The statistical modeling of directional data has been studied for a long time such as Mardia (1972) [1, 8]. The most commonly used models for spherical orientations concerning a fracture set are the truncated Fisher, the Bingham, and the uniform distributions. The expression of these distributions is linked with the reference sphere, is changed is such a way that the “new” North pole coincides with the mean direction of the given fracture set.

2.2.2. Spacing distribution

The intersection of any of the basic models with a line provides a 1D Poisson process [1]. Successive spacing are independent and follow an exponential distribution.

2.2.3. Trace length and fracture size

If fractures cannot be considered as infinite at the scale of the study, the distribution of their size largely determines the frequency of intersection and hence the mechanical behavior of the rock mass. In practice, it is not possible to observe the exact size of a fracture. A 2D survey, however, provides the trace length distribution, which linked with the fracture size distribution. But the experimental histogram of trace length is affected by several biases that have to be corrected.

2.2.4. General network models

All models can be deterministic or stochastic. The first models were deterministic, which is defined by three orthogonal directions of equidistant planes. After this, models with purely random parameters were used, such as the Poisson process. The model presents the advantage of displaying many properties. Stochastic models are considered here, because they are better adapted to usual applications. Their transposition to deterministic models is easy. From a stochastic point view, fracture networks are realization of random sets. The basic models can be found among the random set models, mainly developed by Matérn (1960), Matheron (1967, 1975), Miles (1972) [1], and many others. A comprehensive description from a rock mechanics point of view can be found in Dershowitz (1984), Heliot (1988), Chilès (1989) [1, 4]. All the models described common assumptions: all fractures are planar; all fracture locations are equally probable; all fracture orientations are independent of fracture locations.

3. Methodological

3.1. Design and planning methodology for dimension stone quarry

Methodological approach was pursued, developing and using the following set and sequence of components for modelling of the rock structure mass and discontinuity: interactive geological data base with Mathematica and Dips; visualization tool and interface elements expert with Mathematica, RESOBLOK (and LMGC90/3DEC) (see Fig.1). For the design and planning methodology of dimension stone quarry, 7 following tasks need to be performed:

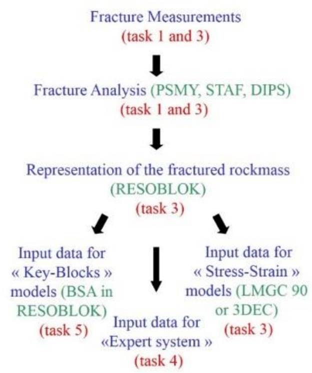


Fig.1. Methodological organization for modelling of the rock mass and discontinuity [7, 8, 9,]: PSMY, STAF and DIPS are the module to analyses the data of joint set; RESOBLOK, BSA in RESOBLOK, LMGC90 and 3DEC are used to simulate cracking rock mass.

Task 1: Site selection, the main objective is to identify the most suitable work sites and experimental layouts considering the geologic conditions.

Task 2: Excavation of the experimental site and installation of the instrumentation system for the collection of the data required in the excavation of experimental quarries.

Task 3: Geomechanical data collection; development of the appropriate 3D rock block models and of the respective geomechanical numerical models.

Task 4: Development and use decision support techniques for predicting cost and quality effective quarry layouts.

Task 5: Numerical analyses of options to predict optimum area openings: determine average block size and shape for each of the quarries; correlation between benches orientations in the fracture network and the recovery and stability of blocks.

The Task 6 and 7 are designing and planning methodology of dimension stone quarry:

Task 6: Field investigation of the exploited block size, quality and value.

Task 7: Design and planning methodology for dimension stone quarry exploitations.

3.2. Analysis of fracture measurements

Fracture measurements had been realised in real sites (Thung Khuoc). The measurements have been done using the scanline method. An analysis has been realised from those measurements with DIPS and PSMY method in order to determine the main sets of orientation and to fit the fracture parameters to statistical laws. The fractures measurements carried out by the operators have been analysed using PSMY method [2, 8]. This data base (orientation, spacing of fractures) was permits to determine which statistical laws adjusted the various fracture sets. The results of this analysis were compared with those established previously from the fracture measurements conducted at large scale in each quarry.

3.3. Realisation of fracture network simulations

The majority of the measured fractures were introduced in the model using the deterministic generator of RESOBLOK. Other fractures were introduced using the statistical generator (the fractures were simulated using the laws established previously) into the zones where no measurement was carried out. As for the other sites, two successive phases are conducted to build the RESOBLOK model: the fracture that have been measured and input the RESOBLOK; then, inside the zones in which the direct observation is not possible (or where no measurements have been done), different sets of discontinuities have been generated using the statistical laws determined previously (PSMY) [2,8].

3.4. Minimum block Size

According to the technical aspect, block size depends mainly on the parameters of mining system, breakability, transport and processing in mine. The minimum size (V_{min}≥0,4) of each recoverable block is taken to follow the size of dimensional stone on the market and current technologies. The blocks which have the size $V_{min} \geq 0,4\ m^3$ usually contain more faults, cracks which requires further processing to complete products from raw dimensional stone. Blocks with the size $V_{min} \geq 1m^3$ will research to recover.

3.5. Mining optimization to recover maximum blocks

Exploiting dimensional stones based on the technological phases of cutting blocks from fracture rock environment. The mining system of horizontal layers, vertical layers, and direct transport on the bench and selective blocks are mined to follow the minimum block size V_{min}.

3.6. Mining Optimization with stabilizing pit slope

Beside mining optimization to recover maximum blocks, we can to determine some technical parameters, the risky problem is caused by bench and pit slope failure in mining operation, which plays an important role in the mining effect for a long time. This study, we choose an assessment method based on limit equilibrium theory to analyze stability slope of quarry. These stiff blocks are analyzed on the basis of stability algorithm including the vector method proposed by Warburton (1981) [12] and Mohr-Coulomb criterion with safety factor F=1, both of which is set up in RESOBLOK.

The distribution of raw block shapes recovered depends on the fracture of rock mass, mining direction and movement of current benches compared with the direction of the main sets. Improving a mining effect means to increase the recovery rate and decrease the risk of unsafe problems. Optimizing the recovery rate of dimensional stones being available on the market are a target function of the technical parameters: angle between mining direction and joint set, bench height, dip angle of the current bench.

4. Applications

4.1. Some dimensional stone quarries in Vietnam

Vietnam has a high potential in marble, magmatic rocks for producing facing stone and use as facing stone. The marble recovery value is controlled by the sale markets and using industries of construction. We present some dimensional stone quarries in Vietnam such as marble resources in Luc Yen area, Yen Bai province (Luc Yen quarry); marble resources in Quy Hop area, Nghe An province (Thung Khuoc quarry); Granite resources in Thua Thien Hue province (Van Xuan quarry, Fig.2); granite resources in Phu Cat area, Binh Dinh procince (Phu Cat quarry, Fig.3); granite resources in Hoa Quan Bac area, Phu Yen province (Hoa Quang Bac quarry, Fig.4); gabbro diorite of Nui Mot area, Ninh Thuan province (Nui Mot quarry); etc. [13, 14].

Fig. 2. Granite Van Xuan quarry, Thua Thien Hue province [14].

Gabbro diorite resources in Nui Mot area has various colours, such as black-grey and black-green gabbro diorite of Nui Mot area; white marble is in Luc Yen area, Quy Hop area; light- to dark-green of Hoa Quang Bac area; black granite of Van Xuan area. The rocks also have the beauty, high mechanical durability and high degree of block recovery. The economic value of the quarries combined the master plan for investigation, exploitation, quarry, processing and rational use of dimensional stone. The economic efficiency of the quarrying enterprise depends on the recovery ratio of dimension stone. They satisfy standards of production of facing stone and have reputation in both domestic and foreign markets.

Fig. 3. Granite Phu Cat quarry, Binh Dinh province [14].

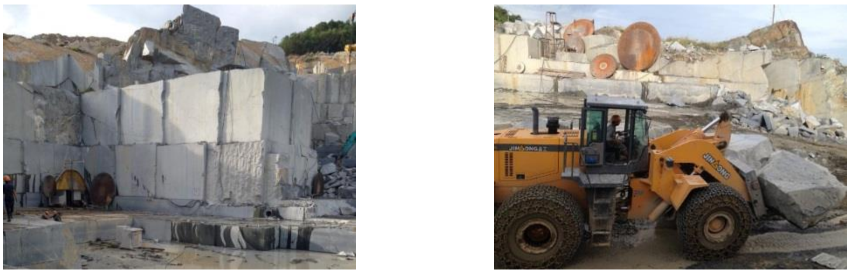


Fig. 4. Granite Hoa Quang Bac quarry, Phu Yen province [14].

4.2. Application for marble Thung Khuoc quarry
4.2.1. Analysis of fracture measurements

In this research, the Thung Khuoc quarry, Nghean province, Vietnam [13] exploits the stone which follows the standard of normal construction materials. The marble stone is able to be used for making various tiles. The dimensional stone products chosen and applied in the calculation and model of the discontinuous rock environment.

Fig. 6. Experiment pit M.01 (a) and 3 main joint sets of the Thung Khuoc quarry, Schmidt grid in hemisphere.

According to the result of the exploration report, the Thung Khuoc quarry has estimated reserves of about 10 046 128 m^3: in which the normal construction material reserve is about 9.593.189 m^3, the reserves producing tiles and dimension stones are 452.939 m^3. The data of joints in the mine are measured by the stations on the surface (8 stations) and joints in drilling cores (5 drilling holes). 3 sets of joints in the mine are identified in Figure 6 and Table 1.

Table 1. Basic parameters of the key sets in the Thung Khuoc quarry

Parameters	Sets		
	Set 1	Set 2	Set 3
Dip-direction angle (α_d, degree)	210÷220	40÷50	170
Dip angle (β_d, degree)	30÷40	70÷75	60÷65
Distributing degree of set (K)	220	995	1876
Distance between the sets: uniform (a; b) with a and b are respectively the minimum and maximum values	(0,1;1,25)	(0,1;1,25)	(0,1;1,25)

4.2.2. Minimum block size

While an average recovery rate of blocks measured with joints on the surface is 20%, in the drill hole is 27,71% and an average rate of joints approached by exploration on the surface and in drill hole is 23,86%. An experiment pit (M.01) is open with aim of quantifying the recoverable rate of different size blocks, in fact, taking samples to discover its engineering characteristics. The mine M.01 has 7 m long, 4,8 m wide and 3,5m in average height; its volume is 117,6 m^3.

The result of the pit M.01 has collected 9 blocks with the sizes $V_{min} \geq 0,4$ m^3, all of which have 5,48 m^3 accounting for 4,7% of the volume of the pit.

4.2.3. Establishing of joint sets and mining orientation

Beginning from the exploratory data in the pit M.01 and the initial results on raw stone volume which are recovered (size, volume and recovery rate) in a typical area of the Thung Khuoc quarry. The model of fracture rock mass in the pit M.01has been chosen to analysis for optimization purpose of the parameters and the mining direction of the mine such as stabilize bench. The open pit slope ensures mining optimization as well as recovering the maximum size of commercial blocks.

Table 2. Effect of an average number of blocks in the model of the experiment pit to relationship between the direction of main joint sets and the pit.

The direction of main sets, degree			the direction of the trial mine, degree	an average number of blocks, blocks
set 1	set 2	set 3		
210÷220	40÷50	170	35	368
			225	382
			350	404

Figure 7 introduces the models of joint sets in RESOBLOK with 3 different mining directions of the trial mine. The results of examinations in each direction considering several various random models are shown in table 3.

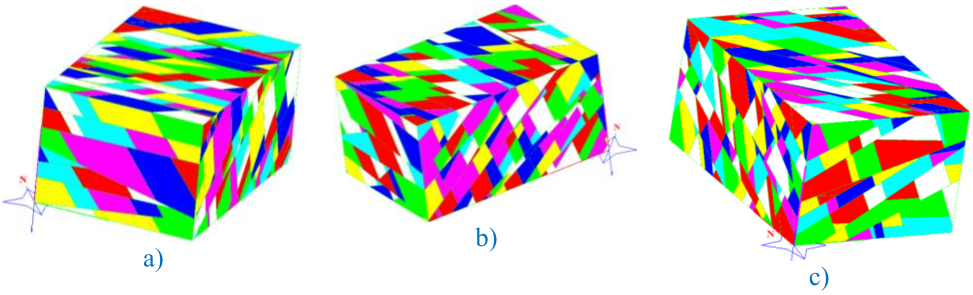


Fig.7. Model of fracture rock mass in the experiment pit M.01: the direction of the model parallels to set 1(a); set 2 (b); set 3 (c).

4.2.4. Determination of mining direction

With a main joint set, the angle of mining bench direction is parallel or perpendicular to the main set, which will allow recovering the maximum volume of commercial blocks (V_{min}). Optimization needs to be tackled when appearing more joint sets in the discontinuous rock mass, the basic parameters in mining bench direction need to be represented properly in order to be able to optimize in the model.

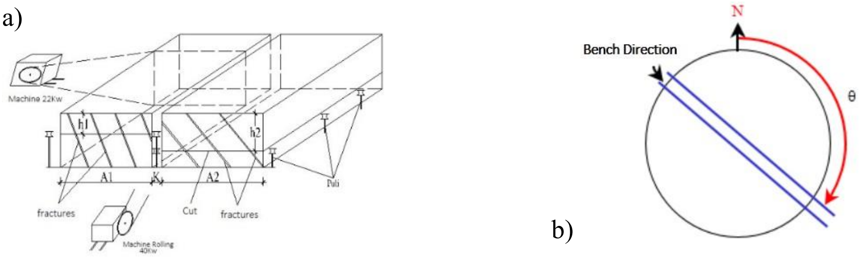


Fig. 8. Plan of mining technology for dimensional stone by wire saw machine and the moving direction of mining benches.

Figure 9 showing the investigating result of 3 typical mining directions is consequently perpendicular to sets 1, 2 and 3. The achievable results are represented on the distributing histogram with a specific order of blocks being equivalent to model volume (in the left column) and the percentage of the volume of the blocks is equivalent to the mining direction of the experiment pit model (in the right column).

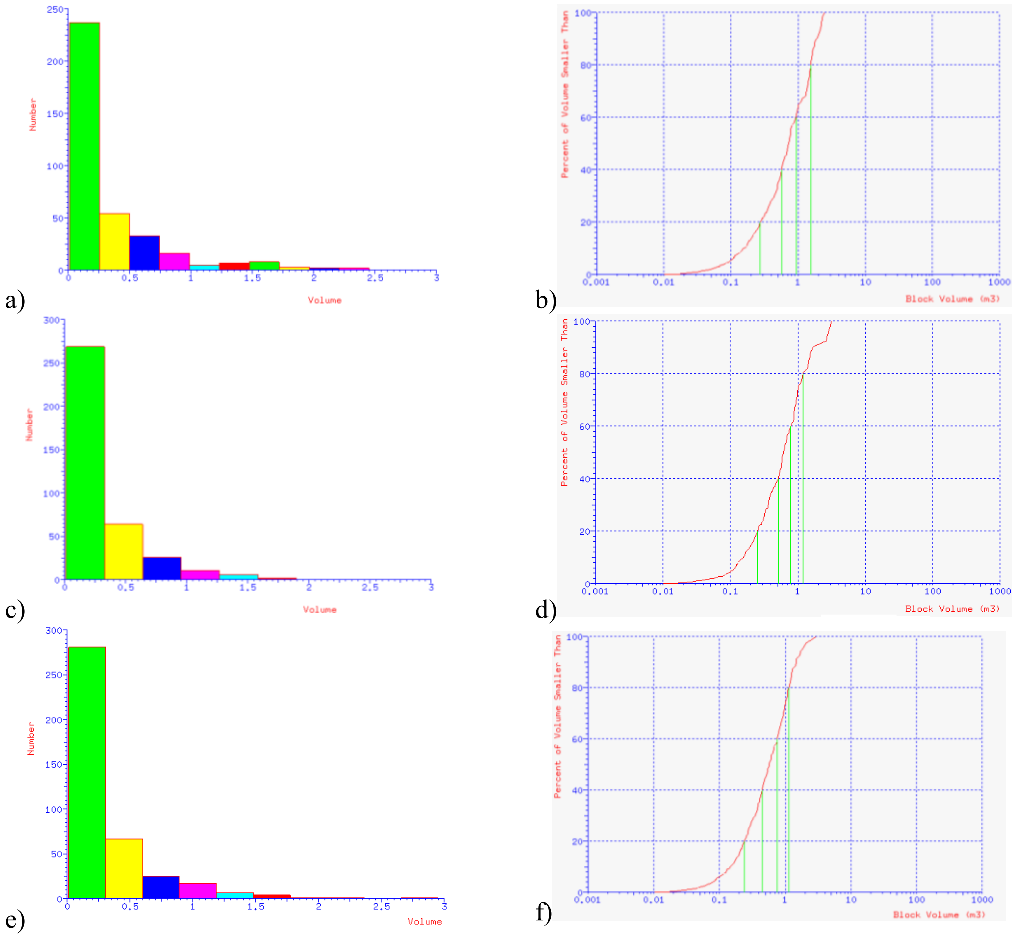


Fig. 9. Histograms distribute a number of blocks with their volumes in the model (in the left columns) and the percentage of blocks with their volumes (in the right column) which are associated with the direction of the pit: (a, b) 35^0 direction; 225^0 direction and (e, f) 355^0 direction.

The direction of the mining benches length where blocks mined relates to the order of new bench opening, the first mining bench position of the mine and the direction of the main joint sets. The data distribution in figure 9 is the distribution of average values collected from a large number of the random statistical model.

- Mining direction of 35^0, the size is with $V_{min} \geq 0,4\ m^3$ accounting for 60% and with $V_{min} \geq 1m^3$ accounting for 36%

- Mining direction of 225^0, the size is with $V_{min} \geq 0,4\ m^3$ accounting for 60% and with $V_{min} \geq 1m^3$ accounting for 25%

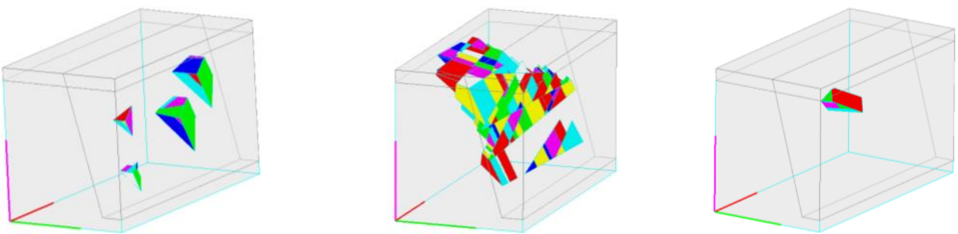
- Mining direction of 350^0, the size is with $V_{min} \geq 0,4\ m^3$ accounting for 60% and with $V_{min} \geq 1m^3$ accounting for 28%.

With the result above, the optimum direction involving in the bench direction of 35^0 parallels or is penpercular to primary set direction 1 (set 1), will be able to be recover the most block rate of $V_{min} \geq 1m^3$ accounting for 36%. Difference in the recoverable rate among the blocks with joint measuring methods on the surface (from 18.75% to 21% and an average of 20%), drillcore (from 25% to 28,7% and an average of 21,71%) and mine opening (14,28%) and the numerical model of the discontinuous environment (40%) with a group of the data from the 3 investigating methods on the surface shows that there are, in fact, a lot of invisible cracks which have not discovered when measuring on the surface. The reason for the difference above is caused by collecting the joint data insufficiently, incomprehensively and accurately. From the results above, the 3 exploratory methods above are not satisfied with the conditions on the numbers, quality of joint data when analyzing and using them for finding out model results.

In this condition, the data collected from the trial mine M01 only hold 2%o of the mine area (about 33,6 m^2 out of the whole area of 16 thousand m^2 with an altitude of from 100 to 230 m^2). Therefore, updating and complementing the number and the exactness of the data is necessary for some the phrases of the mine to improve the quality and certainty of estimated model.

4.2.5. Mining optimization with stabilizing pit slope

Parameters are first applied to compute for numerical model: the mining bench height H=5m, the mining room's width A = 5m, the mining room' length L = 10m, where we examine safety condition with the angle of a bench slope α = 75°. The basically mechanical characteristics of rock and joint: rock density of 2,7 tons/m^3, the joint' fiction angle of 30^0, the joint's cohesion of 0, the 3 bench directions (35^0, 225^0 and 350^0) compared with the North are analysed with the stabilities. The result of computing stability on 3 dimensions model has the weak structure shown in figure 10.



a) b) c)

Fig.10. Distributing model of unstable blocks on the bench is in a bench direction compared with the North, 350 (a) there are 6 unstable blocks with the volume of 1m3; 2250 (b) there are 118 unstable blocks with the volume of 22m3; and 3500 (c) there are an unstable block with the volume of 0,52 m^3.

The analysed results above allow us to select the best mining direction involving recovering and ensuring safe and stability on the bench [9, 11]. When we move the bench with one more mining room, we see that the volume of unstable blocks in the direction of 350^0 being at right angle to joint set 1 is the least, which means that the developing direction of the mine is safe after that it is in the direction of 35^0. The rest direction of 225^0 has the unsafest risk.

4.2.6. Discussion

Beginning with the ability of the dimensional stone's mining and processing technologies with the minimum block V_{min}, we create an order of developing bench in order to recover the rate having size more than V_{min} accounts for the highest. In case, the Thung

Khuoc quarry in the direction of 35^0 compared with the North develops toward 2 sides, which leads to $V_{min} \geq 0.4$ m^3 accounting for 60% of recovery rate and $V_{min} \geq 1$ m^3 accounting for 36% of recovery rate. Moreover, the developing direction of this bench allows the mine to operate relatively safely with $1m^3$ unstable blocks on the 10-length bench.

In the section above, we have already determined the key bench direction of the mine which is perpendicular to the set 1 of 35^0 (set 1) compared with the North. The dip angle of stone layers in set 1 from 30^0 to 40^0. The width and length of mining room are 5m and 10m (some cases depend on particular benches). In some cases of the stable bench, homogeneous rocks are with a dip angle of 90^0. The problem given is to form the target function of specifying reasonable bench height h with certainly geological conditions (including dip angle α and space between two joints L) in order to the most recoverable rate of commercial stones.

5. Conclusions

The article shows the discontinuous model of the rock mass in Thung Khuoc dimensional stone quarry, Nghe An, Vietnam. From the analysing result of the model, we have chosen the developing direction of mining bench optimizing on the recovery rate and safety in the mining operation. This result allows us to calculate the technical parameters being suitable to pit parameters and gallery width as well as the best direction of the bench. Furthermore, we could choose the best mining methods with the aim of increasing mining effect and output, reducing mining expense and needed investment in mining operation, ensuring safety for dimensional stone quarries. Basing on advanced models on the computer, we apply and set up the geometric models of joint sets reliably in the discontinuous environment from the parameters and features of joints. This technology allows predicting the investing expenditure with the most effect and safety in the quarries. Therefore, this could recover the most blocks with the sizes which suit to the market demands.

6. Acknowledgements

The authors wish to thank the 5th International Conference “Scientific-Research Cooperation between Vietnam and Poland” (POL-VIET), and Hanoi University of Mining and Geology, Vietnam to carry out this research is thankfully acknowledged.

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