Dimension-Stone Quarrying Optimization through Integrated Modelling between Joint Sets and Cutting Grid: a Case Study at Tan Long Dimension Stone Quarry in Southcentral Coastal Province of Binh Dinh

PHAM Van Viet[1,2)], NGUYEN Anh Tuan[1,2)], PHAM Van Hoa[1,2)], TRAN Dinh Bao[1,2)]*

[1)] Hanoi University of Mining and Geology, 18 Vien Street, Hanoi, Vietnam
[2)] Innovations for Sustainable and Responsible Mining (ISRM) research group, Hanoi University of Mining and Geology, Hanoi, 100000, Vietnam
* Corresponding author: phamvanviet@humg.edu.vn

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Abstract

Dimension-stone quarrying optimization is significantly important to increase the recovery ratio of dimension stone and to reduce the cutting cost. Due to fracture-existed rock mass, in the mining operation block size and mining direction influences to the recovery ratio and the cutting cost. Therefore, the paper suggests the quarrying optimization for dimension stone to obtain the highest recovery ratio and the lowest cutting cost, based on optimizing block size and mining direction to get a cutting grid of dimension stone. Through developing an integrated modelling between joint set modelling and cutting grid modelling, intact blocks and fractured blocks were generated. From this, block statistics were conducted to get the maximum recovery ratio of dimension stone and the minimum cutting rate between the cutting area and the recovered block volume, which helps to choose an optimizing block size and mining direction. The research was carried out at Tan Long dimension stone quarry where a block size (0.9m x 0.6m x 1.35m) and a mining direction paralleling to joint set 1 will ensure the highest recovery ratio of 13.87% and the lowest cutting rate of 25 m²/m³.

Keywords: *dimension stone, modelling, joint sets, block size, recovery ratio, cutting rate*

1. Introduction

Dimension stone is a natural stone made from intact rock groups of magma, sedimentation, metamorphism without discontinuities and it is quarried and processed to various sizes, shapes, colours and polishes. In stone, there are more joints causing it more difficult to recover more intact blocks [1]. This makes low effectiveness in mining operation due to low recovery ratio and high cutting rate of dimension stone. Collection on joints in stone has been interested in exploration and extraction stages but there are no applications of the collection into optimizing quarrying operation to improve the mining effectiveness [2][3]. Recovering blocks in mining operation is significantly important because it also influences to the following stages as processing activities and quarrying technology and processing technology selections suitable with joint sets to increase the recovery ratio and the low cost. Selecting block size and mining direction are dramatically important because they decide the recovery ratio, the mining cost and mining and processing technologies from joint sets at quarries.

Nowadays, there has been more research on joints in rock mass to calculate recovery ability for dimension stones. Tuan (2019) interested in joint sets to recover valuable blocks of more than 0,4 m^3 based on the modelling of a fracture network in rock mass but block sizes of more than 0,4 m^3 also were not considered their shapes [4]. Mutluturk (2007) showed that beside the quality, dimensional stone also depended on desired size. This would be done by blocks generated from joints in rock mass. The block was put with market blocks (rectangular blocks inside and their sizes of 3 x 2 x1m or 1.5 x 1 x 1) to show how many market blocks [5]. However, the author just showed the way to do, but did not give a result of the method because of lacking fracture modelling ability. Mosch (2011) showed the size and shape of blocks governed by dip direction of joints. The paper showed spatial joint distribution in rock mass navigated three coordination points from the data of joints with window sample and scanline. From calculating pixels in the model to show volume of blocks, the author just established a fracture network for the whole quarries in simple way with three face boundaries of the model [6]. Fernandez-de Arriba (2013) contributed an optimization algorithm on recovery ratio of dimensional stone based on blocks formatted by three joint sets with dip direction angle, dip angle and spacing parameters to divide the blocks into smaller size of 1.5 x 2 x 1.5m. Basing on the mining direction defined from minimum dip direction angle to maximum dip direction angle and mining direction increments determined a mining direction with the maximum recovery ratio, but the paper has not yet to show a change in the volume and the shape of stone blocks with spatial relationship of joint sets [7]. Yarahmadi (2017) also approached into various quarrying direction to optimize the recovery ratio, but the paper showed the intersection of three major joint sets to actual cutting pattern to generate stone blocks with their specific shapes. From

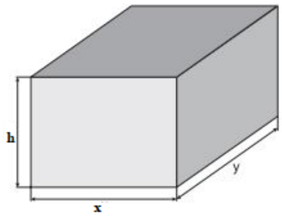

Fig. 1. Dimensions of a minable base block

Tab. 1. Values showing the change in size and area of a minable block

No	Volume, m^3	Height h, m	Cutting area S_0, m^2	x=y, m	k ratio	Length x, m	Width y, m	Area S, m^2	S/S_0
1	0.4	0.6	1.96	0.82	0,1	2.58	0.26	3.41	1.74
2	0.4	0.6	1.96	0.82	0,2	1.83	0.37	2.64	1.35
3	0.4	0.6	1.96	0.82	0,3	1.49	0.45	2.33	1.19
4	0.4	0.6	1.96	0.82	0,4	1.29	0.52	2.17	1.11
5	0.4	0.6	1.96	0.82	0,5	1.15	0.58	2.08	1.06
6	0.4	0.6	1.96	0.82	0,6	1.05	0.63	2.02	1.03
7	0.4	0.6	1.96	0.82	0,7	0.98	0.69	2	1.02
8	0.4	0.6	1.96	0.82	0,8	0.91	0.73	1.97	1.01
9	0.4	0.6	1.96	0.82	0,9	0.86	0.77	1.96	1
10	0.4	0.6	1.96	0.82	1	0.82	0.82	1.97	1.01

each of the shapes, the recovery ratio would be solved by comparing to rectangular blocks having the same volume as the ones. The recovery ratio of each stone block was calculated by comparing rectangular areas having the same volume as the stone block with a total of the surrounding area of the block, and the ratio changes from 0 to 1. When the ratio reaches to 1, the shape of block will be the best. However, the paper has not assessed the change in the volume of block due to the intersection of three major joint sets and the recovery ratio has not calculated with the volume and shape the plants need [8].

From the research above, there have not been papers on optimizing dimension stone quarrying through block size and mining direction to increase the recovery ratio and to reduce the cutting rate. Therefore, the study begins with ranging block sizes from joint sets, cutting area, mining equipment and processing machines. After that, the paper establishes an integrated modelling by combining joint set modelling with cutting grid modelling. An optimal block size which has the highest recovery ratio and the lowest cutting rate will be selected. The paper did experiment at Nui Trai dimension stone quarry in Binh Dinh province, contributing to selecting an optimal block size and specific mining direction for the quarry.

2. Method

In dimension-stone extraction, determining recovered block sizes and mining directions is significantly important to suit to the joint network so that the recovery ratio of intact blocks could get the highest as well as the cutting cost reduces to the lowest level. Therefore, it is necessary to consider block-size optimization so that the lateral cutting area will be the smallest and the size will be suitable for cutting machines, processing machines and market-required products. For this reason, the optimization will need to be implemented with the following requirements.

2.1. Block size optimization

The purpose of dimension-stone extractions is to produce high-quality blocks at an optimizing cost with the highest recovery. To get the purpose achievement above, importance is choosing a suitable cutting technology to bring back a desired result. Cutting direction influences the recovery of market blocks and the direction always parallels to the direction of major joint set.

Thus, the top and bottom planes of blocks do not put into consideration of cutting area, because both planes will not affect to the optimizing production [9]. In this case, the strongest influence is perpendicular to cutting planes. Therefore, an approach is to decrease lateral cutting planes. The desired size of a cutting block should be selected from the base of block modelling. Generally, cube and cuboid cut are the geometric shapes of the minable blocks in quarries. In fact, the height of mining benches is constant in dimensional-stone quarries, and it is determined as the height of minable blocks. On the other hand, the height of minable blocks is prior to determining and during the optimization process of production planning, the other dimensions must be optimized afterwards. The volume of a base block is calculated as Equation (1).

$$V=x \cdot y \cdot h\ ,\ m^3 \qquad (1)$$

In which:
V – volume of a minable base block, m^3
x and y – length and width of a block, m
h – height of a mining bench and blocks, m

It is assumed that the volume of a block is constant, the most suitable dimensions can be formed by Equation (2) with concentration on minimizing the lateral cutting planes.

$$V=x \cdot y \cdot h \Rightarrow y=V/(x.h) \qquad (2)$$

The most important is to decrease production cost to the lowest value by minimizing lateral cutting area of minable block as determined by Equation (3).

$$S=(x+y) \cdot 2h \qquad (3)$$

Combining Equation (2) and Equation (3), we have:

$$S=2h.[(h.x^2+V)/(x.h)] \qquad (4)$$

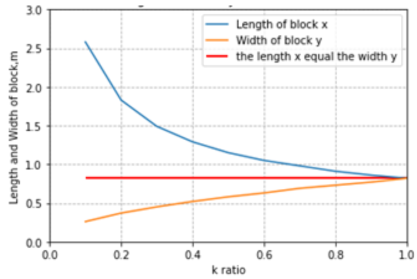

Fig. 2. Change in length and width of a minable block via k ratio.

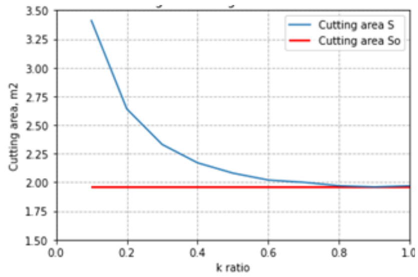

Fig. 3. Change in lateral cutting area via k ratio

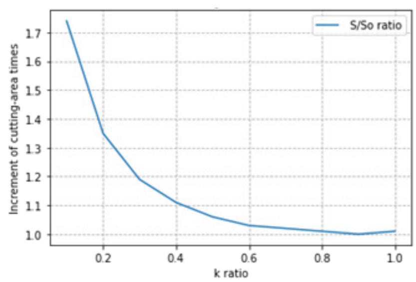

Fig. 4. Increment in cutting area times via k ratio

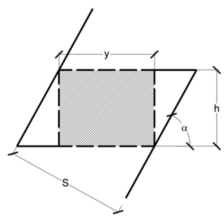

Fig. 5. Calculation on the height of minable block

To minimize lateral cutting area of minable blocks, the derivative of the function S=f(x) must be equal to zero. Dimensions of minable block is calculated with Equation (5) below:

$$\frac{dS}{dx} = 0 => 2h^2 \cdot x^2 - h^2 \cdot x^2 - h \cdot V = 0 => h^2 \cdot x^2 = h \cdot V => x = \pm\sqrt{\frac{V}{h}} \quad (5)$$

From the value x in equation (5), replacing $x=\sqrt{(V/h)}$ into equation (2), the width y is defined in equation (6):

$$y=V/(x\cdot h)=V/\sqrt{(V/h)}\cdot 1/h=\sqrt{(V/h)} \quad (6)$$

Therefore, to collect the blocks with the minimum cutting cost, cutting area is square, where the width is equal to the length *($x=y=\sqrt{(V/h)}$, m)*.

To calculate lateral cutting planes, the value $x=y=\sqrt{(V/h)}$ is replaced in Equation (3):

$$S_o=4\sqrt{(V\cdot h)} \quad (7)$$

A relationship between the width and the length of a minable block by k ratio is determined with Equation (8):

$$k=y/x,\ m => y=k\cdot x,\ m \quad (8)$$

Replacing the values in Equation (8) into Equation (3), we have an Equation (9) as below:

$$S=4k\cdot x\cdot h,\ m^2 \quad (9)$$

Increment in area will occur when the two dimensions are not equal, defined by equation (10):

$$S/So=(4k\cdot x\cdot h)/(4\sqrt{(V\cdot h)})=k\cdot x\cdot \sqrt{h},\ m \quad (10)$$

In which:

k – ratio between the width and length of minable block, m;

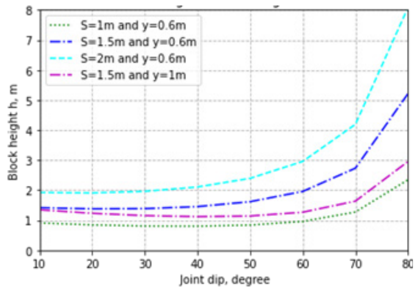

Fig. 6. Change in height of minable block via change in the dip angle in the same joint set

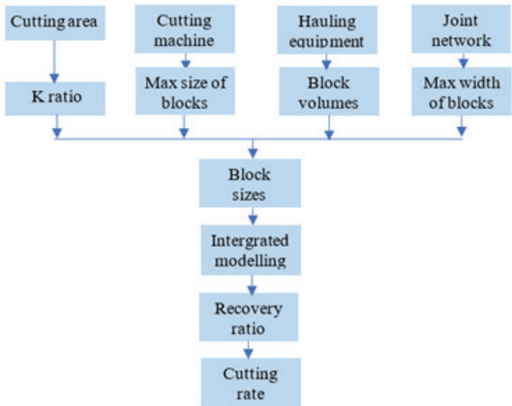

Fig. 7. Flow chart to calculate suitable size for dimension stone

x – length of minable block, m;
h – width of minable block, m;

It is assumed that a minable block has a volume of 0.4 m^3, its height of 0.6 m and k value changes from 0.1 to 1, leading to the outputs represented in Tab.1 and a relationship between the width and the length shown in Fig. 2, Fig. 3 and Fig. 4.

In addition, if cutting area of minable blocks gets the lowest value, the optimization shape of the blocks will be a cuboid with square planes and the height h. It is proven that when h has a trend in reaching each dimension of minable block, the whole cutting area will reduce. Therefore, a cube with its edges of h and a cuboid with its cutting area of b^2, its height of d has the same volume. This could be proven under a condition $h^3 = b^2 \cdot d$ và $d<h<b$, as in Equation (11).

$$h^2<b^2 => 2h^2<2b^2 => 6h^2<2h^2+4b \cdot d \quad (11)$$

From the interpolation in Equation (11), the whole areas of a cube are smaller than that of a cuboid with square sections in the same volume. Moreover, Equation (7) is also demonstrated with the acceptance $b<h<d$. As a result, a cube and a cuboid having square planes is the most suitable for the shape of minable blocks.

Optimal shape of minable blocks is assessed through an index called cutting rate. The rate is defined as a cutting area per an unit volume of recovered blocks. The rate is shown as in Equation (12).

$$t=(\Sigma S_i)/V \quad (12)$$

In which:
t – cutting rate;
Si –i^{th} cutting area in minable block, m^2;
V – minable-block volume, m^3;

Consideration about a minable block with squared area and height h could be written in Equation (13).

$$t=(2h.(x+y))/V=4\sqrt{(h/V)} \quad (13)$$

As mentioned above, a minable block will reach the most suitable volume when the cutting rate is the smallest. As Equation (14), the volume of a minable block has a trend in reaching infinite when the rate reaches to zero.

$$\lim_{V\to\infty} t = \lim_{V\to\infty} 4\sqrt{\frac{h}{V}} = 0 \quad (14)$$

From Equation (14), if block volume increases, the cutting rate will reach zero. This could be explained that when the volume increases, mining effectiveness will increase. In the fact of dimension-stone quarrying, the volume of block only reaches a specific limit because of depending on hauling and processing equipment.

2.2. Height of minable block

According to section 2.1, when height of minable blocks reaches the other dimensions, the cutting area will decrease. In addition, cutting blocks needs to be interested in major joint set to decrease the influence of joints on block fragmentation. This could be done by cutting blocks along to the strike of the major joint set. In the other hand, the length of minable blocks parallels to the strike of the major joint set, the width is perpendicular to the major joint set. Therefore, to ensure the width of minable block, the height of minable block needs to be calculated following spacing of joint set and joint set dip angle. This calculation is represented in Fig. 5 and Equation (15).

$$h=((S-y \cdot sin\alpha) \cdot tg\alpha)/sin\alpha \quad (15)$$

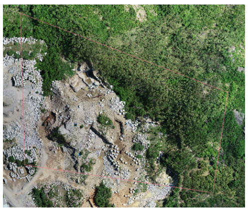

Fig. 8. Location of Nui Trai quarry in Binh Dinh Province (Mapped byUAV)

Tab. 2. Parameters of joint sets at Nui Trai quarry, Binh Dinh Province

No	Joint set 1			Joint set 2			Joint set 3		
	Dip, degree	**Dip direction, degree**	**Spacing, m**	**Dip, degree**	**Dip direction, degree**	**Spacing, m**	**Dip, degree**	**Dip direction, degree**	**Spacing, m**
1	80	70	3.5	80	190	2	80	35	5
2	80	70	2	80	190	3	80	35	2
3	80	70	3.5	80	190	2	80	35	2
4	80	70	2.5	80	190	2	80	35	2
5	80	70	4	80	190	1	80	35	2
6	80	70	2.5	80	190	2	80	35	5
7	80	70	2	80	190	3	80	35	4
8	80	70	1.5	80	190	2	80	35	2
9	80	70	3	80	190	1	80	35	2
10	80	70	2	80	190	4	80	35	5
11	80	70	5	80	190	1	80	35	2
12	80	70	3	80	190	4	80	35	5
13	80	70	3	80	190	3	80	35	1
14	80	70	2	80	190	1	80	35	1.5
15	80	70	3	80	190	2	80	35	5
16	80	70	2	80	190	1	80	35	5
17	80	70	2	80	190	1	80	35	2
18	80	70	2	80	190	2	80	35	3
19	80	70	4	80	190	2	80	35	5
20	80	70	4	80	190	1	80	35	2
21	80	70	2	80	190	2	80	35	6
22	80	70	3	80	190	1	80	35	3
23	80	70	5	80	190	5	80	35	2
24	80	70	3	80	190	2	80	35	2
25	80	70	3	80	190	4	80	35	3
26	80	70	3	80	190	5	80	35	3
27	80	70	1	80	190	2	80	35	2
28	80	70	3	80	190	2	80	35	4
29	80	70	2	80	190	2	80	35	3
30	80	70	3	80	190	1	80	35	3
31	80	70	2	80	190	2	80	35	1
32	80	70	2.5	80	190	4	80	35	6.5
33	80	70	3	80	190	2	80	35	3
34	80	70	5	80	190	1	80	35	6
35	80	70	4	80	190	3	80	35	6
36	80	70	1	80	190	2	80	35	2
37	80	70	3	80	190	3	80	35	5
38	80	70	2	80	190	1	80	35	2
39	80	70	2	80	190	5	80	35	2
40	80	70	1	80	190	1	80	35	5
41	Average Spacing		2.75	Average Spacing		2.25	Average Spacing		3.3

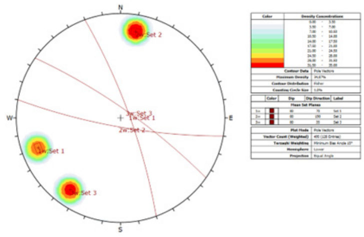

Fig. 9. Analyzing and representing joint sets for Nui Trai dimension stone quarry in Binh Dinh Province

Tab. 3. Working parameters of selected disc sawing, CXVQ-3300-2

No	Parameters	Unit	Value
1	Machine size	m	3.45*1.35*2.6
2	Number of discs	disc	2
3	Disc diameters	m	2.2; 3.5
4	Cutting depth	m	0.85-1.5
5	Cutting width	m	1.3-1.35
6	Machine weight	ton	9.5
7	Power capacity	kW	2*45kW

Fig. 10. Disc sawing machine at the quarry.

Tab. 4. Parameters of disc sawing machine, QSQ2200B, at processing plant

No	Parameters	Unit	Value
1	Maximum cutting depth	m	0.95
2	Cutting length (axis X)	m	3,8
3	Cutting length (axis Y)	m	2
4	Power motors	Kw	45/55
5	Disc diameters	m	2.2;2;1.8;1,6 1.2;1;0.8;0.6
6	Block width	m	2.1
7	Block height	m	1.35
8	Block length	m	3.6
9	Cutting velocity (axis X)	m/s	Modify
10	Beam velocity	m/mi	Modify
11	Vertical displacement velocity	m/s	Modify
12	Beam-moving power	Kw	3
13	Vertical displacement motor	Kw	1.5
14	Installed power	Kw	45
15	Cooling water (1,5 bar)	l/m	30
16	Machine length	m	7.5
17	Machine width	m	4.35
18	Machine height	m	6
19	Machine weight	tone	12

Tab. 5. Summary of necessary parameters for limiting sizes of minable blocks

No	Parameters	Block length, m	Block width, m	Block height, m	Block volume, m^3
1	Disc sawing machine for blocks	-	1.4	1.35	-
2	Disc sawing machine for slabs	3,6	2,1	1.35	-
3	Cutting paralleling to joint set 1	-	2,94	-	-
4	Cutting paralleling to joint set 2	-	1.92	-	-
5	Cutting paralleling to joint set 3	-	2.94	-	-
6	Hauling and transporting machines	-	-	-	7

Tab. 6. Minable-block sizes

No	Block name	Block length, m	Block width, m	Block height, m	Block volume, m^3
I	Cutting paralleling to joint set 1				
1	Size 1_1	1.9	1.3	0.6	1.5
2	Size 1_2	1.6	1.1	0.6	1.1
3	Size 1_3	1.3	0.9	0.6	0.7
4	Size 1_4	2	1.4	1.35	3.8
5	Size 1_5	1.7	1.2	1.35	2.8
6	Size 1_6	1.4	1	1.35	1.9
7	Size 1_7	1.1	0.8	1.35	1.2
8	Size 1_8	0.9	0.6	1.35	0.7
II	Cutting paralleling to joint set 2				
1	Size 2_1	1.9	1.3	0.6	1.5
2	Size 2_2	1.6	1.1	0.6	1.1
3	Size 2_3	1.3	0.9	0.6	0.7
4	Size 2_4	1.7	1.2	1.35	2.8
5	Size 2_5	1.4	1	1.35	1.9
6	Size 2_6	1.1	0.8	1.35	1.2
7	Size 2_7	0.9	0.6	1.35	0.7
III	Cutting paralleling to joint set 3				
1	Size 3_1	1.9	1.3	0.6	1.5
2	Size 3_2	1.6	1.1	0.6	1.1
3	Size 3_3	1.3	0.9	0.6	0.7
4	Size 3_4	1.7	1.2	1.35	2.8
5	Size 3_5	1.4	1	1.35	1.9
6	Size 3_6	1.1	0.8	1.35	1.2
7	Size 3_7	0.9	0.6	1.35	0.7

Tab. 7. Summary of recovery ratio and cutting rate for different block sizes in three cutting directions

No	Block name	Total number of blocks	Total number of intact blocks	Recovery ratio, %	Cutting rate, m^2/m^3
1	Size 1_1	12480	451	3.61	81.97
2	Size 1_2	17856	932	5.22	61.32
3	Size 1_3	27360	2375	8.68	40.86
4	Size 1_4	4032	86	2.13	91.66
5	Size 1_5	5742	191	3.33	65.01
6	Size 1_6	8307	490	5.90	41.62
7	Size 1_7	12960	1220	9.41	30.80
8	Size 1_8	21780	3021	13.87	25.37
9	Size 2_1	12480	276	2.21	133.94
10	Size 2_2	17856	739	4.14	77.34
11	Size 2_3	26752	2049	7.66	46.31
12	Size 2_4	5742	149	2.59	83.33
13	Size 2_5	8520	397	4.66	52.69
14	Size 2_6	13500	1140	8.44	34.34
15	Size 2_7	21978	2691	12.24	28.74
16	Size 3_1	12480	263	2.11	140.56
17	Size 3_2	17856	681	3.81	83.92
18	Size 3_3	26752	1862	6.96	50.96
19	Size 3_4	5742	139	2.42	89.32
20	Size 3_5	8520	344	4.04	60.80
21	Size 3_6	13500	1033	7.65	37.90
22	Size 3_7	21978	2592	11.79	29.83

In which:
h – height of minable block, m;
α – dip angle of joint in a joint set, degree;
y – width of minable block, m;
S – Spacing of joint in the same joint set, m.

Through analysis on heights of block with dip angle of joint in a joint set changing from 0^0 to 80^0 and spacing S changing from 1m to 2m, the width of minable block changing from 0.6m to 1m, the heights were changed and shown in Fig. 6.

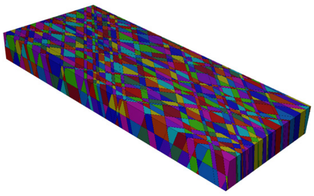

Fig. 11. Three-dimensional modelling for Nui Trai dimension stone quarry, Binh Dinh Province

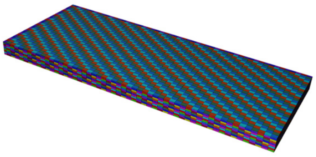

Fig. 12. Three-dimensional cutting-grid modelling

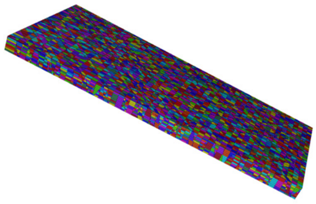

Fig. 13. Three-dimensional integrated modelling

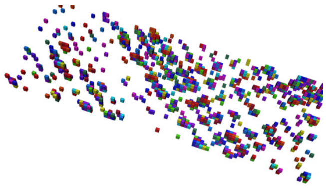

Fig. 14. Three-dimensional modelling after applying filter algorithm for intact blocks

Through Fig. 6, it is claimed that when dip angle of joint in the same joint set becomes steeper, the height will be raised and inversely.

2.3. Flow chart to determine the most suitable block size

1. Cutting area: Based on optimal block size, the length and width of minable block are equal, bringing back the highest effectiveness, but consideration on ratio relationship, the width being 80 percent as much as the length still ensures cutting area which is little larger than the optimal cutting area.

2. Mining and processing equipment: When implementing mining and process operation for dimension stone, working parameters of the equipment are interested in the dimensions of block, including length, width, and height the equipment could operate properly. This is a foundation to select block size, which is not larger than the chosen equipment.

3. Hauling equipment: Hauling equipment is interested in the volume of minable block. Therefore, the volume could not exceed the one the equipment delivers.

4. Joint Network: Joint network mentions to the maximum width of a block, which is calculated via average spacing of joints in the same set. The maximum width satisfies conditions in equation (16).

$$y_{max}=(S_{tb}\cdot tg\alpha-h\cdot sin\alpha)/cos\alpha \quad (16)$$

in which:

y_{max} – maximum width of minable block, m
S_{tb} – average spacing of joints in the same set, m
α – dip angle of joints in the same set, degree

5. The length of minable block is firstly selected from the dimensions satisfying the width of slabs cut following the standard of dimension stone and the height of cutting blocks being smaller than the maximum height mining and processing equipment could operate. The maximum width, ymax, is defined in step 4, checking the width according to the equipment from mining and processing operation and giving a range of wide value decreased gradually to zero. After that the length of a cutting block is defined following the ratio have been defined in step 1. Checking dimensions of cutting blocks is according to the width and length of working operation from the equipment and the working volume of hauling equipment, more than 0.4 m^3. As a result, lists of the satisfied sizes are given with the strike of joint sets.

6. Integrated Modelling: Modelling is formed with a base on joint sets, mining direction, block sizes of minable block, leading to forming an integrated modelling being a result of intersection between joint sets and cutting grid.

7. Recovery ratio is a result after modelling, where the ratio is calculated by the number of intact minable blocks divided by the total blocks in the modelling.

8. Cutting rate, t, is defined a ratio between total cutting area and recovered block volume, shown in equation (17).

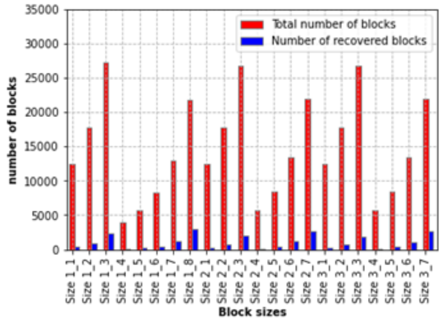

Fig. 15. Total number of blocks and recovered blocks for each block size

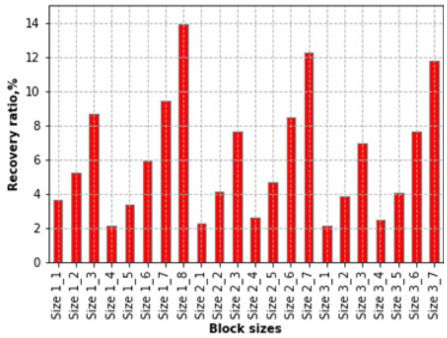

Fig. 16. Recovery ratio for each block size

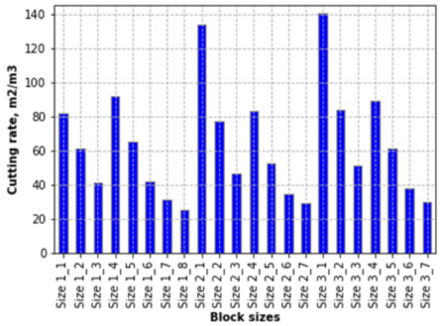

Fig. 17. Cutting rate for each block size

$$t=(\Sigma S_{ij})/(\Sigma V_i) \quad (17)$$

In which:

t – cutting rate.

S_{ij} – j^{th} cutting area in i^{th} minable block, m².

V – i^{th} recovered block volume, m³.

i, j – index for blocks, index for the number of cutting areas in a specified block.

In cutting operation in dimension stone quarry, due to adjacent blocks, the number of cutting planes is three, including bottom, side, and back planes. The flow chart to determine the most suitable block size is represented in Fig. 7.

3. Case study at Tan Long dimension stone quarry in South-central coastal province of Binh Dinh

3.1. Joint data collection

Nui Trai dimension stone quarry extracts granite to produce dimension stone in Phu Cat district, far from 35km Northern Quy Nhon city. The quarry speads about 4.9 ha at side hill with an elevation from +30m to 70m (Fig .8). Joints selected in Tab. 2 was carried out with scan line on the surface. After that these joints was classified into joint sets with classified algorithms via software Dips [10],[11] (Fig .9). The group include three major joint sets with the dip direction and the dip of 70º<80º, 190º<80º và 35º<80º, respectively.

3.2. Mining fleet information

Dimension stone quarries in Binh Dinh Province mostly used modern sawing methods, such as disc sawing, diamond wire sawing. In which, quarries popularly applied main sawing method of being disc sawing at large-output quarries because smooth planes were created to form block sizes satisfying size standard for the processing plant.

In dimension stone quarries estimated to use disc sawing machines but this research only carried out with the same disc sawing machine on supplying firms. For example, disc diameters and working parameters were shown in Table 3 (Fig. 10).

The quarry estimated to use disc sawing machine to slice blocks into slabs with blaze diameters from 0.6 to 3m on the same rotary axis, unchanged spacing of the blazes installed equal to slab thickness. In processing operation, blaze system was moved in three-dimension cutting. Basic parameters of disc cutting at processing plant were shown in Table 4. The quarry used front-wheel excavators to transport blocks from the quarry to stockpiles, the excavators could evaluate up to 7 m³ (about 20 tonnes).

Through joint-set analysis, mining fleet and necessary sizes to determine the sizes and volume of minable blocks were shown in Tab. 5.

The inforamtion summarized in Table 5 combined with the flow chart in Fig .7 to design the sizes of minable blocks given Tab. 6.

3.4. Establishment of an integrated modelling between joint sets and cutting grid

From the joint data measured in Tab. 2, a three-dimensional modelling was built with joint sets. The size of the modelling of being 100 m x 40m 5m was generated through software 3DEC of atasca brand [12], given in Fig .11.

Cutting grid modelling formed by the sizes of minable blocks with cutting operation paralleling to each joint set in Table 6 was represented in Fig. 12.

4. Results and discussions

By intersection between joint set modelling in Fig. 11 and cutting-grid modelling in Fig. 12, an integrated modelling was generated and shown in Fig. 13.

By a filter algorithm in 3DEC software for filtering intact blocks in the modelling, the number of intact blocks were derived from the integrated modelling and shown in Fig. 14.

Particularly, establishing three-dimensional integrated modelling between joint sets and cutting grid generated with one of the three cutting directions (paralleling to joint set 1, joint set 2 and joint set 3) and block sizes in Tab. 6. The total number of blocks and intact blocks, recovery ratio and cutting rate were obtained in Tab. 7. The result showing the total number of blocks and intact blocks was represented in Fig. 15. Similarly, the figures for the recovery ratio and the cutting rate were represented in Fig. 16 and Fig. 17, respectively.

In Tab. 7, Fig. 15, Fig. 16 and Fig. 17, block sizes of size 1_8, size 2_7 and size 3_7 have the same size of 0.9m x 0.6m x 1.35m. Recovery ratios relating to these sizes are 13.87 %, 12,24% and 11,79%, respectively. Meanwhile, respective cutting rates for these sizes are 25.37%, 28.74%, 29.83%. As a result, the size of size 1_8 with its value of 0,9 x 0,6 x 1,35m cut in the direction paralleling to joint set 1 has the highest recovered ratio of 13.87% and the lowest cutting rate of 25.37%.

4. Conclusions

Dimension stone has been more and more popular extraction to bring back higher effective economic compared with the extraction for common construction materials. Effectiveness of quarrying dimension stone depends on less joint sets existed in quarries and selecting suitable cutting and processing methods. This is shown via improving the recovery ratio and the low cost of dimension stone. The paper showed clearly that mining direction and block size play an important role in selecting cutting machine from joint network at quarries. There are some conclusions below:

- Integrated modellings selected play an important role in calculating the volume and the size of minable blocks because the modelling is interested in dips, dip directions, spacings of joints and cutting grids.
- Optimizing block size plays an important role in decreasing block-cutting area. Optimization size is square, but short edge being more than 80 percent of long edge still ensures and suits with cutting machines. Minable-block size has a significant meaning in calculating recovery ratio, depending on joint-set parameters. The optimizing size in cutting grid must ensure the highest recovery ratio and the lowest cutting rate. For Nui Trai dimension stone quarry, the size of size 1_8 (0.9x0.6x1.35m) is sure that the recovery ratio is the highest while the cutting rate is the smallest from the sizes selected.
- Mining direction for dimension stone is hozirontal length of block size chosen to parallel to one of the strikes of joint sets. The selected direction ensures the recovery ratio is the highest while the cutting rate is the smallest. For Nui Trai dimension stone quarry, mining direction is parallel to joint set 1.

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