

Mining Technology JOURNAL

Volume - Number - Periode January - June 2017

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STUDY OF DIMENSIONAL STONE EXTRACTION WITH DIAMOND-WIRE SAW

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ABSTRACT

In the dimensional stone business, its technical and aesthetic properties are the most important features when choosing a particular type of stone as a building material. So if want to produce dimensional stone must be carefully to extraction it. Marble is one kind of stones that can be made a dimensional stone. Marble according to that genesis consist the discontinuity plane such as cracks. The other condition of marble is metamorphic rock which former from clastic sedimentary rocks, consists of carbonaceous rocks, and soft rocks category. So to make marble in completely cutting condition is very difficulty to be done.

One kind of dimensional stone extraction method is technically process with uses drilling, sawing, and wedging. Producing of marble dimensional stone use technically process of drilling, sawing, and wedging need accurately and effectively working. Drilling activity to make wire track which needed to sawing the marble block must be done accurately to easy in sawing. Demikian juga vertical drilling activity to service hole of wedging must be done accurately too for getting perfectly block. How do it, that is the reason why the research do.

Key word: extraction, dimensional stone, diamond-wire saw

1. BACKGROUND

The process of dimensional stone extraction can be said good result if the stone block are right size, non content the flaw, and sufficient in production target. Marble is one kind of stone that can be make a dimensional stone. Marble according to that genesis consist the discontinuity plane such as cracks. The other condition of marble is metamorphic rock which former from clastic sedimentary rocks, consists of carbonaceous rocks, and soft rocks category. So to make marble in completely cutting condition is very difficulty to be done. Base on that conditions, to make marble became dimension stone with perfect condition, the extraction of marble needs technically effort, and effective working to completely production target.

2. OBJECTIVE

The research objective is to study the dimensional stone extraction with diamond-wire saw which the result of dimensional stone is perfect enough and sufficient production target in efficient working.

3. METHODS

Research methodology is began with field data collecting (primary data) which consists of large block size and small block size, and technically cutting. Furthermore, the next step is literature study (secondary data) which consists of cutting plan data and rock characteristic data. The last steps are data calculation, analysis, and conclusion.

4. RESULTS

The research try to study of dimensional stone extraction process with uses drilling, sawing, and wedging. Kind of rock that study do it is marble stone. Extraction process is start doing with intersect vertical and horizontal drilling at the corner to leafing the wire of the diamond wire saw. After that, sawing with diamond-wire saw is doing to cutting marble stone for getting large blocks size of marble. And then the large blocks size are made small size block using vertical drilling and wedging. Small size blocks is delivery to stone dressing for making slabbing the block uses blade sawing.

4.1 Extraction Condition

The mining system to marble stone extraction is surface mining system with quarry method. Results of the extraction is block stone in (15m x 8m x 1.5m) size, and then its size to be reduction became (2.5m x 1m x 1.5m) size. Extraction methods are combination of drilling, sawing with diamond-wire saw, and wedging.



Figure 1. Extraction Condition

4.2 Production Target

Marble stone production target is 400 m³ per month in block form with (2.5m x 1m x 1.5m) size. But, the result of marble stone production is not enough to completely production target. About the result are affected by :

- 1). working efficiency
- 2). weather
- 3). result of wire thread hole drilling
- 4). equipment.

4.3 Working Day and Working Hour

Working day these are six days from Monday until Saturday, one shift for drilling and three shifts for sawing with diamond-wire sawing (see Table 1 and 2).

Table 1 Working Hour for drilling

| Days | Shift | Hour | Rest | Total Working Hour |
|-----------------------------|-------|-------------|-------------|--------------------|
| Monday-Thursday | I | 08.00-16.00 | 12.00-13.00 | 7.0 hours |
| Friday | I | 08.00-16.00 | 11.30-13.00 | 6.5 hours |
| Saturday | I | 08.00-14.00 | 12.00-12.30 | 5.5 hours |
| Total Working Hour per Week | | | | 40.0 hours |

Table 2 Working Hour for Sawing

| Days | Shift | Hour | Rest | Total Working Hour |
|-----------------------------|-------|-------------|-------------|--------------------|
| Monday-Thursday | I | 08.00-16.00 | 12.00-13.00 | 7.0 hours |
| | II | 16.00-24.00 | 20.00-21.00 | 7.0 hours |
| | III | 24.00-08.00 | 04.00-05.00 | 7.0 hours |
| Friday | I | 08.00-16.00 | 11.30-13.00 | 6.5 hours |
| | II | 16.00-24.00 | 19.30-21.00 | 6.5 hours |
| | III | 24.00-08.00 | 03.30-05.00 | 6.5 hours |
| Saturday | I | 08.00-14.00 | 12.00-12.30 | 5.5 hours |
| | II | 16.00-20.00 | 20.00-20.30 | 5.5 hours |
| | III | 24.00-06.00 | 04.00-04.30 | 5.5 hours |
| Total Working Hour per Week | | | | 120.0 hours |

Mean of total working hour per day = 20 hours/day

Total working hour for drilling = 6,67 hours/day

Total working hour for sawing = 20 hours/day

Holiday per year is ±13 days, and that holiday is not in Sunday. So total holiday per year is (52 + 13) = 65 days.

Hence total working day per year is

(365 – 65) days = 300 days.

Hence maximum of total working day per month is

(300 /12) = 25 days.

4.4 Working Efficiency

Result of field observation known that the delays of marble stone extraction is as follow (see Table 3) :

1). Drilling working time = 140 minute

2). Sawing working time = 225 minute.

Working efficiency :

1). Drilling efficiency = 66 %

2). Sawing efficiency = 81%

Table 3 Delays of Extraction Working Hour per Day

| Delay type | Drilling (minute) | Sawing (minute) |
|---------------------------------------|------------------------|----------------------|
| Working start | 25 | 30 |
| Rest in working | 20 | 30 |
| Finish before time is up | 15 | 30 |
| Operator needs | 25 | 50 |
| Working place & equipment clearing | 30 | 45 |
| Moving to new working place | 25 | 40 |
| TOTAL | 140 | 225 |

4.5 Extraction Production

Extraction production is in correlation with individual equipment cycle time. So, to know the produce of extraction, cycle time of each extraction equipment is needed.

4.5.1 Drill holes for diamond-wire track

Beginning the process of dimension stone extraction with diamond-wire sawing on marble stone is making the drill holes for placing the diamond-wire sawing. The drill holes are two horizontal drill holes and one vertical drill hole, and each of them meet at one point (see Figure 2).

For calculating the production of marble stone as a dimension stone, it is essential to know the duration time of the available drill equipment used to do its job. After the calculation is done, the duration time and the production as follow :

Duration time = 8.78 hours

Production = 2.73 cmh

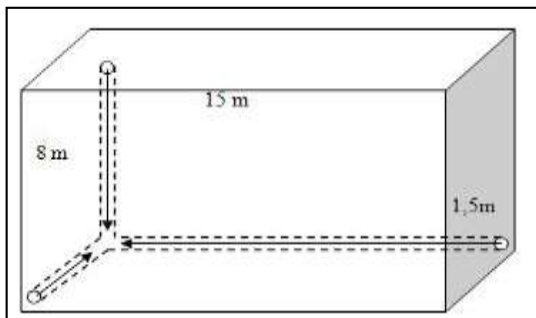


Figure 2. Drill holes for diamond-wire track

4.5.2 Put in the diamond-wire into its track

Diamond-wire's edge is tied tightly onto plastic line. Put in the plastic line's edge into the vertical drill hole of diamond-wire track and push it by compressing air. When the plastic line's edge appears out on horizontal drill hole of diamond-wire track, pull it until the tied of both edges out of the hole. Release the tied, then connect and clam each of the diamond-wire edge into the sawing power motor.

4.5.3 Extraction with diamond-wire saw

Process of sawing with diamond-wire saw, having object to split right size large blocks from in-situ rock. Sawing principal with diamond-wire method is which uses diamond segments mounted around the wire that act as abrasives to rocks will be cutting.

Procedure of sawing is after attaching the wire-ends, the wire is tightened around the support wheel by moving the saw backward along the track. When the wire and rock make contact, water is flushed in (1- 3m³/h) to cool down the wire and to remove the cuttings. The direction of sawing is performed away from the cut. Diamond wire consists of approximately 5 mm diameter wire and diamond coated bits of approximately 10-11 mm in diameter and 30-32 pcs/m. Wire durability depends not only on the rock, but also on the bending of the wire. Therefore at the beginning and end of sawing, the draught must be reduced. To ensure a longer wire lifetime, the pending radius must be big; for example, economical bench height is 8-9 meters.

Base on sawing machine position, so sawing of rock can be done with two action, as follow :

- a) Vertical, on this position, “*fly wheel*” and “*guide wheel*” are vertical too.
- b) Horizontal, on this position, “*fly wheel*” and “*guide wheel*” are horizontal too.

Calculation result of sawing large marble block is as follow :

Total sawing time of large marble block with size (15m x 8m x 1.5m), is 103.60 hours.

Production is 1.41 cmh.

4.5.4 Pushing Block into Horizontal Position

Pushing block into horizontal position is mean that after finishing of sawing the block position is vertical, so to easy cutting become small marble block, the large marble block is pushed by Bulljack to switch it position from vertical to horizontal. Effect of pushing block to horizontal position, the large marble block can break because crashing with floor bench.

Calculation result of pushing the large marble block is as follow :

Duration time : 1.262 hours

Bulljack efficiency : 81.90 %

4.5.5 Vertical Drilling

Vertical drilling is done on large block with standard pattern to cut into smaller pieces. The drill holes formed has function to make the path of crack when wedging is done. Equipment for drilling is Spherical Marini TY 24C 72-2, and there are 4 drills spherical Marini.

Calculation result of vertical drilling is as follow :

Duration time : 38 hours.

4.5.6 Wedging

After vertical drilling is finished, wedging and jacking are to be done. Manually wedging is done with iron bar inside into drill hole by hammer. The purpose of wedging is to split the rock boulder along the surface of the drill holes. The most important fact is to increase pressure smoothly and slowly so that the tension has time to reach the drill line.

Production of marble dimension stone base on calculation is as follow :

Production large marble block per month : 324 m³

Production small marble block per month : 319 m³

5. DISCUSSIONS

5.1 Increasing of Marble Dimension Stone Extraction Production

Based on field research, extraction production of marble dimension stone is 319 m³ per month, but extraction production target is 400 m³ per month. So the actual extraction production is not enough to complete the extraction production target. That problem can be arisen because working time is not efficient.

The increasing of marble dimension stone extraction production can be done by improving the working efficiency. Sometimes the working time efficiency decreases and delay time is happening, that is, as follow :

- a) Working start
- b) Rest in working
- c) Finish before time is up
- d) Operator needs
- e) Working place and equipment clearing
- f) Moving to new working place

Result of field research about delay time has been written on Table 3.

To increase the extraction production of marble dimension stone, the extraction activity is needed to be improved. This can be done by decreasing delay time (see Table 4) so working efficiency can be raised and marble block break is strained to decrease on extraction activity.

Decreasing delay time makes working efficiency arise and can be saw in Table 5.

Table 4 Suggested of decreasing delay time

| Delay type | Drilling (minute) | Sawing (minute) |
|--------------------------------------|---------------------|-------------------|
| Working start | 15 | 10 |
| Rest in working | 10 | 15 |
| Finish before time is up | 10 | 10 |
| Operator needs | 15 | 20 |
| Working place and equipment clearing | 15 | 20 |
| Moving to new working place | 15 | 20 |
| TOTAL | 80 | 95 |

Table 5 Working efficiency and production before and after decrease delay time

| Working efficiency | Decrease delay time | | | |
|--------------------|---------------------|--------------------------|------------|--------------------------|
| | before | | after | |
| | Efficiency | Production | Efficiency | Production |
| Drilling | 66% | 319 m ³ /week | 81 % | 431 m ³ /week |
| Sawing | 81 % | | 92 % | |

5.2 Improving of Marble Stone Extraction

5.2.1 Activity of diamond-wire track drilling

Difficulty to drilling of diamond-wire track are :

- Sometimes the bore hole is not precision, so one and each other of bore hole can not meet at a point.
- Drill rod break in drilling process of diamond-wire track.
- Soil layer or discontinuity in marble stone can make inefficiency drilling process.

To improving of drilling process can be done by :

- Increasing the working efficiency during drilling process.
- Measuring precision in bore hole determine, so three bore holes can meet at a point.
- Maintenance of drilling tools and changing of broken drilling tools.
- Operator's skill is needed in drilling process specially on discontinuity marble stone

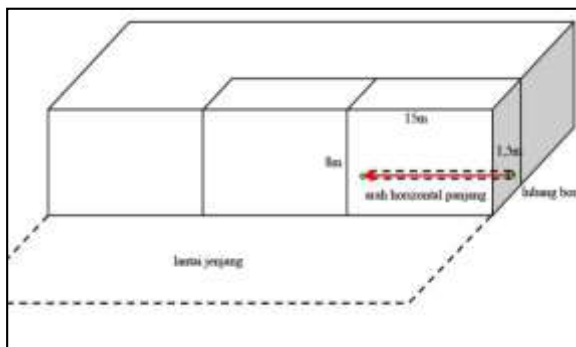


Figure 3. Drilling of 15 m horizontal hole of diamond-wire track

Diamond-wire track drilling activity is a first step to marble stone extraction. The first activity of diamond-wire track drilling makes a horizontal hole with 15 m length equal to length of block dimension will be extracted. Drilling 15 m length of horizontal hole is worked step by step because length of drill rod is 1 m and 15 m drill hole length so that need 15 drill rod to finish it (see figure 3).

When drilling is done, lot of cutting lost, and volume lost of marble stone caused of drilling can be counted as the following:

$$\begin{aligned} \text{Volume lost} &= \text{drill rod volume} \times \text{total drill rod} \\ &= \frac{1}{3} \pi r^2 h \times 15 \\ &= \frac{1}{3} (3.14 \times 0.045 \times 1) \times 15 \\ &= 0.7065 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \% \text{ lost} &= (\text{volume lost} / \text{block volume}) \times 100 \% \\ &= (0.7065 / 180) \times 100 \% \\ &= 0.3925 \% \end{aligned}$$

Total cycle time = 4.204 hours

Horizontal hole drilling velocity = 3.568 m/hour

So lot of lost during 15 m horizontal hole drilling is 0.3925 % and drilling velocity is 3.568 m/hour.

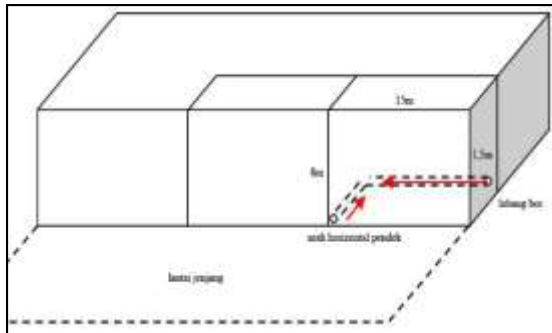


Figure 4. Drilling of 1.5 m horizontal hole of diamond-wire track

The second activity of diamond-wire track drilling makes a horizontal hole with 1.5 m length because block dimension of marble stone will be extracted, i.e 15 m x 8 m x 1.5 m. Precision measuring of direction hole must be done before beginning of second drilling (see figure 4).

Production volume lost in second drilling can be calculated as the following:

$$\begin{aligned} \text{Volume lost} &= \text{drill rod volume} \times \text{total drill rod} \\ &= \frac{1}{3} \pi r^2 h \times 2 \\ &= \frac{1}{3} (3.14 \times 0.045 \times 1) \times 2 \\ &= 0.0942 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \% \text{ lost} &= (\text{volume lost} / \text{block volume}) \times 100 \% \\ &= (0.0942 / 180) \times 100 \% \\ &= 0.052 \% \end{aligned}$$

Total cycle time = 1.6654 hours

Horizontal hole drilling velocity = 0.90 m/hour

So lot of lost during 1.5 m horizontal hole drilling is 0.052 % and drilling velocity is 0.90 m/hour.

The last hole drilling of diamond-wire track is vertical hole drilling with 8 m depth (see Figure 5).

Production volume lost in last drilling can be calculated as the following:

$$\begin{aligned}
\text{Volume lost} &= \text{drill rod volume} \times \text{total drill rod} \\
&= \frac{1}{3} \pi r^2 h \times 8 \\
&= \frac{1}{3} (3.14 \times 0.045 \times 1) \times 8 \\
&= 0.3768 \text{ m}^3
\end{aligned}$$

$$\begin{aligned}
\% \text{ lost} &= (\text{volume lost/block volume}) \times 100 \% \\
&= (0.3768/180) \times 100 \% \\
&= 0.3925 \%
\end{aligned}$$

Total cycle time = 2.912 hours
Vertical hole drilling velocity = 2.74 m/hour

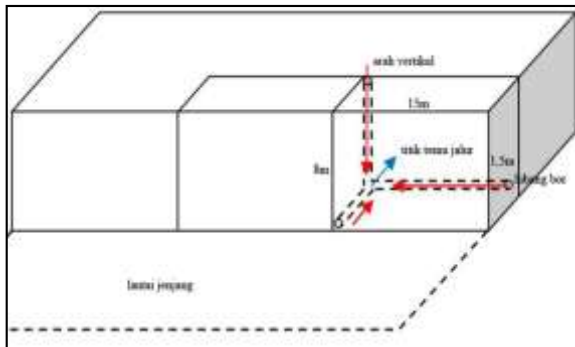


Figure 5. Drilling of 8 m vertical hole of diamond-wire track

So lot of lost during 8 m vertical hole drilling is 0.209 % and drilling velocity is 2.74 m/hour.

$$\begin{aligned}
\text{Total lost of diamond-wire track drilling is :} \\
&= 0.3925 \% + 0.052 \% + 0.209 \% \\
&= 0.6535 \%
\end{aligned}$$

$$\begin{aligned}
\text{Total drilling velocity is:} \\
&= 2,789 \text{ m/hour}
\end{aligned}$$

So total lost of diamond-wire track drilling is 0,6535 % and total drilling velocity is 2,789 m/jam.

5.2.2 Sawing with diamond-wire saw

Extraction marble stone with diamond-wire saw is began vertically of 8m x 15m, horizontally of 15m x 1.5m, and vertically 15m x 8m. Extraction process is done step by step because sawing method is matched with rail length which as saw machine tract. Cutting and joining of diamond-wire must be done to match it with rail of saw machine tract (see Figure 6).

Few of difficulty to sawing with diamond-wire saw as the following :

- Diamond-wire sling is broken.
- Water supply to diamond-wire sling can not be available.
- Sawing Block remain is broken.
- Diamond-wire condition is not good in maintenance.
- Bad weather can affect working efficiency and break sawing machine.

Procedure to eliminate delay of sawing activity with diamond-wire saw:

- Maintenance diamond-wire saw.
- Water supply to diamond-wire sling is attempted to be available.
- Sawing is began vertically of 8m x 1.5m, horizontally of 15m x 1.5m, and vertically 15m x 8m.
- Marble block which has physically good condition will be extracted.
- Increasing the working efficiency during sawing activity with omit delay time and improving effective working time.
- Sawing machine completed with canopy to protect it from breaking which is caused by rain drop.

Wire length is used to sawing for marble block of 8m x 1.5m is

$$\begin{aligned}
&= (2 \times (p+l) + 5) \text{ m} \\
&= (2 \times (8+1.5) + 5) \text{ m} \\
&= 24 \text{ m}
\end{aligned}$$

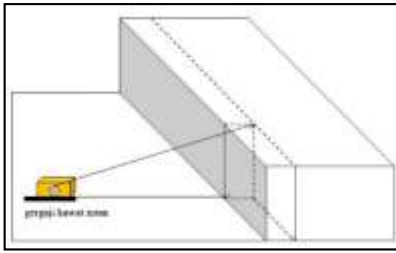


Figure 6. Sawing vertical plane of 8 m x 1.5 m

Sum of diamond ring

$$\begin{aligned}
&= ((24/\text{m}^3)/((0.04\text{m}^3)) \\
&= 600 \text{ diamond ring}
\end{aligned}$$

Production volume lost during sawing with diamond-wire saw is

$$\begin{aligned}
\text{Volume lost} &= V \text{ of diamond ring} \times \text{total of diamond ring} \\
&= (1/3) \pi r h \times 600 \text{ ring} \\
&= (1/3) \times (3.14 \times 0.0025 \times 0.007) \times 600 \\
&= 0.01099 \text{ m}^3
\end{aligned}$$

$$\begin{aligned}
\% \text{ lost} &= ((\text{volume lost})/(\text{block volume})) \times 100\% \\
&= ((0.01099)/(180)) \times 100 \% \\
&= 0.0061 \%
\end{aligned}$$

So lot of lost during sawing of vertical plane of 8m x 1.5m or 12 m² area is 0.0061 %.

Second step is sawing marble stone block horizontally of 15m x 1.5m (see Figure 7).

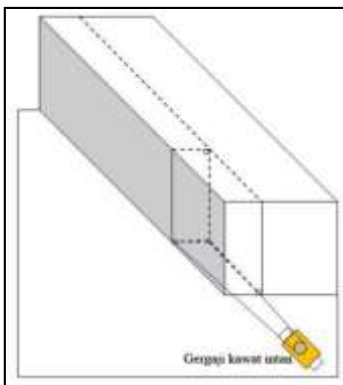


Figure 7. Sawing horizontal plane of 15 m x 1.5 m

Wire length is used to sawing for marble block of 15m x 1.5m is

$$\begin{aligned}
&= 2 \times (p+l) + 5 \\
&= 2 \times (15+1.5) + 5 \\
&= 38 \text{ m}
\end{aligned}$$

Sum of diamond ring

$$= ((38/m^3)/(0.04m^3))$$

$$= 950 \text{ diamond ring}$$

Production volume lost during sawing with diamond-wire saw is

$$\begin{aligned} \text{Volume lost} &= V \text{ of diamond ring} \times \text{total of diamond ring} \\ &= (1/3) \pi r h \times 950 \text{ ring} \\ &= (1/3) \times (3.14 \times 0.0025 \times 0.007) \times 950 \\ &= 0.0172 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \% \text{ lost} &= ((\text{volume lost})/(\text{block volume})) \times 100\% \\ &= ((0.0172)/(180)) \times 100 \% \\ &= 0.0095 \% \end{aligned}$$

So lot of lost during sawing of horizontal plane of 15m x 1.5m or 22.5 m² area is 0.0095 %.

Last step is sawing marble stone block vertically of 15m x 8m (see Figure 8).

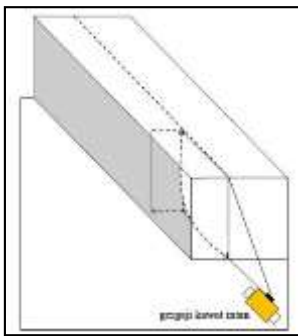


Figure 8. Sawing vertical plane of 15 m x 8 m

Wire length is used to sawing for marble block of 15m x 8m is

$$\begin{aligned} &= 2 \times (p+l) + 5 \\ &= 2 \times (15+8) + 5 \\ &= 245 \text{ m} \end{aligned}$$

Sum of diamond ring

$$\begin{aligned} &= ((245/m^3)/(0.04m^3)) \\ &= 6,125 \text{ diamond ring} \end{aligned}$$

Production volume lost during sawing with diamond-wire saw as the following:

$$\begin{aligned} \text{Volume lost} &= \text{Volume of diamond ring} \times \text{total of diamond ring} \\ &= (1/3) \pi r h \times 6,125 \text{ ring} \\ &= (1/3) \times (3.14 \times 0.0025 \times 0.007) \times 6,125 \\ &= 0.1110 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \% \text{ lost} &= ((\text{volume lost})/(\text{block volume})) \times 100\% \\ &= ((0.1110)/(180)) \times 100 \% \\ &= 0.0617 \% \end{aligned}$$

So lot of lost during sawing of horizontal plane of 15m x 8m or 120 m² area is 0.0617 %.

Total lost during sawing with diamond-wire saw is

$$\begin{aligned} &= 0.0061 \% + 0.0095 \% + 0.0617 \% \\ &= 0.0773 \% \end{aligned}$$

Total sawing velocity of 15m x 8m x 1,5m area is

$$= 1.61 \text{ m}^2/\text{hour}$$

So total lost sawing marble block is 0.0773 % and total sawing velocity is 1.61 m²/hour.

5.2.3 Pushing Block into Horizontal Position

Pushing block to horizontal position is mean that after finishing of sawing the block position is vertical, so to easy cutting become small marble block, the large marble block is pushed by Bulljack to switch it position from vertical to horizontal. Effect of pushing block to horizontal position, the large marble block become breaking, cracking, or fracturing. These can be occurred because of the following :

- Operating of Bulljack machine is not equilibrium when pushing on large marble block.
- Large marble block crashing with floor bench when it is pushed into horizontal position by Bulljack.
- Size of marble block is not accurate, for example, vertical dimension is too long.

The effort to solve that problem can be done as the following:

- Marble block volume must be suitable with Bulljack machine power.
- Make mattress from soft material, for example soil material, to support marble block when it is pushed into horizontal position by Bulljack.
- Clearing the bench floor to provide of comfortable place when marble block fall in down.

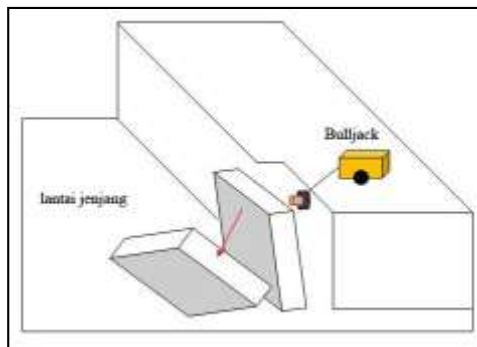


Figure 9. Pushing block into horizontal position

Pushing block into horizontal position can be done if the mattress has been ready. This is to prevent marble block breaking, cracking, or fracturing when it fallen down and crash with bench floor. Mattress is made from soft material and it is be ready by excavator. Mattress thickness is about 1 m to 1.5 m.

Pushing block into horizontal position is performed by Bulljack. Vertical drilling about 40 cm depth is used to place the jack as length as 25 cm. The jack is needed to support the marble block will be fallen down (see Figure 9). Working mechanism of Bulljack is moved by compress air from compressor. Compress air push out the jack until 10 cm to fallen down the block.

5.2.4 Vertical Drilling

Vertical drilling is done for dividing the marble block with size (15m x 8m x 1.5m) to marble block with size (2.5m x 1m x 1.5m). Drilling pattern is carefully make by manually measurement base on production size standard e.i (2.5m x 1m x 1.5m) (see Figure 10). Drilling equipment is used to make the hole is *pherical* Marini 24C 72-2. Drilling geometry are 3.6 cm hole diameter, 10 cm hole spacing, and vertical hole inclination (see Figure 11).

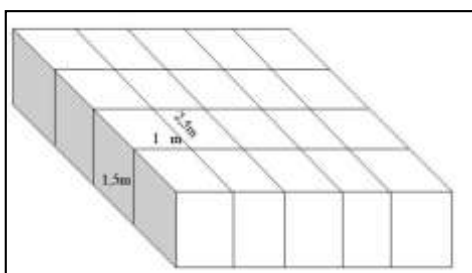


Figure 10. Drilling pattern

Drilling process is done according to the pattern which it beginning from first step direction and than second step direction (see Figure 11).

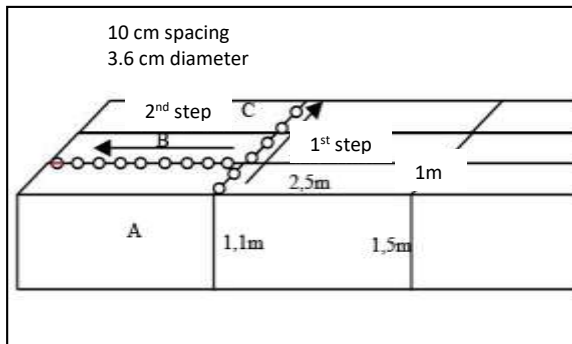


Figure 11. Drilling Geometry

Drill holes which is formed has function as crack track when wedging is done. Drilling and wedging have objective to simplify in choosing block either produced or reduced. Drilling and wedging more easy to be done than sawing with diamond-wire saw.

The problems in vertical drilling activity are as the following :

- a) Inaccuracy spacing and inclination.
- b) Broken drill rod in drill hole when vertical drilling process.
- c) Discontinuity is found in marble stone block.

The effort to solve that problem can be done as the following:

- a) Accurately measuring for determine spacing, inclination, and position of drill hole.
- b) Maintenance drilling equipment and replace broken equipment.
- c) Operator skill can be raised in drilling operational.

Production volume lost in vertical drilling can be calculated as the following:

$$\begin{aligned}
 \text{Volume lost} &= \text{Volume of drill rod} \times \text{total of drill hole} \\
 &= (1/3) \pi r^2 h \times 1,219 \text{ drill hole} \\
 &= (1/3) \times (3.14 \times 0.017 \times 1.5) \times 1,219 \\
 &= 32.20 \text{ m}^3
 \end{aligned}$$

$$\begin{aligned}
 \% \text{ lost} &= ((\text{volume lost})/(\text{block volume})) \times 100\% \\
 &= ((32.20)/(180)) \times 100 \% \\
 &= 18 \%
 \end{aligned}$$

Total vertical drilling velocity in 1.5 m depth is:

$$= 0.19 \text{ m/minute}$$

So total lost of vertical drilling is 18 % and total drilling velocity is 0.19 m/minute.

5.2.5 Wedging

Marble block has been drilled vertically in all side therefor wedging is manually done to marble block use hammer and wedge to make crack (see Figure 12). Wedging is vertically block size reduction system. After wedging has been finished and than jacking the block by excavator to easily separate it.

Difficulty on wedging process is resulting of roughness marble block wall. To eliminate this, needed training drilling and wedging operator. Beside that, matching between wedging tool and vertical drill hole is needed too.

Marble block production can be calculated as the following :

$$\begin{aligned}
 \text{Assumption imperfect marble block production is } 25 \% , \text{ so good condition of marble block production is:} \\
 &= 709.5 \text{ m}^3/\text{month} - (709.5 \text{ m}^3/\text{month} \times 25 \%) \\
 &= 709.5 \text{ m}^3/\text{month} - (177.37 \text{ m}^3/\text{month})
 \end{aligned}$$

$$= 532 \text{ m}^3/\text{month} = 129 \text{ block}/\text{month}$$

Total of % lost of marble stone production is:

$$= 0.6535 \% + 0.0773 \% + 18 \% = 19 \%$$

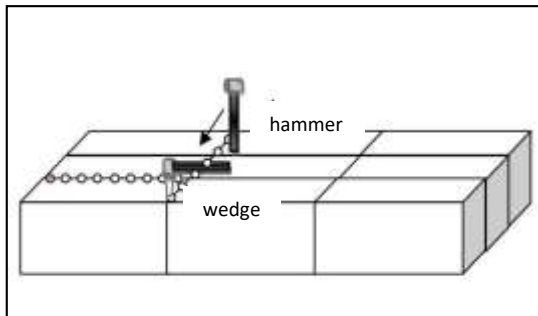


Figure 12. Wedging process

Total of final production :

$$= 532 \text{ m}^3/\text{month} - (532 \text{ m}^3/\text{month} \times 19 \%)$$

$$= 532 \text{ m}^3/\text{month} - (101 \text{ m}^3/\text{month})$$

$$= 431 \text{ m}^3/\text{month} = 104 \text{ block}/\text{month}$$

So total production of marble block with 19% lost is 431 m³/month or 104 block/week.

6. CONCLUSION

1. Extraction method is combination between drilling method, and sawing method.
2. Working efficiency of drilling method is raising from 66 % to 81 %.
3. Working efficiency of sawing method is raising from 81 % to 92 %.
4. Total percentage lost during extraction process is 19 %.
5. Total marble block production is raising from 319 m³/month to 431 m³/month.

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