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Comparative analysis of different techniques used for dimension stone mining

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Abstract

Pakistan is blessed with large reserves of different types of dimension stones in all provinces. Dimension stone industry has great potential to become one of the leading industries in Pakistan economy. This potential is being held back by inefficient mining practices that affect the quality and economy of the dimension stone. This paper focused on the selection of the best feasible mining technique to get high recovery, minimum losses, and ultimately the generation of higher revenues. In this study conventional (pre-splitting), modern mechanized mining (diamond wire saw) and expansive powder techniques were used for extraction of black granite blocks in district Mansehra Khyber Pakhtunkhwa. The analyses and comparison of these mining techniques were carried out based on extraction costs, quality, revenue and recovery. The diamond wire saw technique was noted much effective than expansion powder and pre-splitting techniques because it gives maximum recovery, revenue and minimum waste material.

Keywords: Dimension stone; Mining techniques; Recovery; Revenue.

1. Introduction

Generally the natural stones that are used in construction and decoration purposes are called dimension stone (Ashmole, 2008; Merke, 2000). In other words all naturally occurring rock materials that can be cut and shaped or selected for use in the form of blocks, slabs, sheets or in other construction units that requires specialized shapes and sizes are called dimension stone (Hrush, 1968). The prime most uses of dimension stone for different purposes in construction is shown in figure 1.

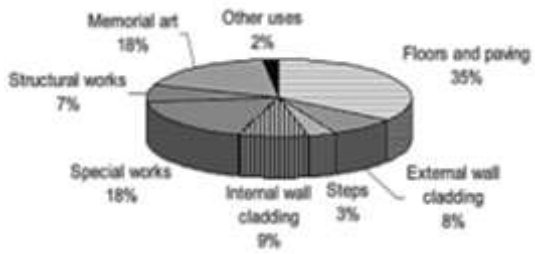

Fig. 1. Dimension stone uses.

Pakistan is blessed with different rich natural resources and is a growing country showing great potentials especially in dimension stone sector. Pakistan has major deposits of high quality marble and granite in a wide range of colours, shades and patterns. Pakistan has approximately 290 billion tonnes indicated marble reserves. About 90 % of different types and color of dimension deposits exist in Khyber Pakhtunkhwa. Khyber Pakhtunkhwa produces about 87% Marble, 1% Granite and 12% slate. (Khan, 2017). The black granite of Mansehra district is famous worldwide because of its beauty and elegance and total reserves are estimated to be 169 million tons. Other varieties are Chitral white marble, Nowshera pink marble, Dir green granite, Shangla serpentinite, while lime stone reserves are in Peshawar, Buner, Chitral, Haripur and D.I.Khan (DGMM, 2006). Demand for uses of dimension stones according to statistical survey is increasing @

7% annually and international trade of around 50 billion dollars per year. The main exporter is china, Italy and India. Pakistan number is on 20th position in top twenty countries, although Pakistan has rich resources of dimension stone. Dimension stone is an emerging and promising sector of Pakistan which has huge potential of investment, export and providing livelihood to the local at door step (Group, 2013; Khan, 2017).

The province is producing marble and granite using different mining techniques for dimension stone extraction. These include modern mechanized mining (wire saw and chain saw), presplitting control blasting, conventional mining, and expansion powder techniques. The conventional method involving un-controlled blasting is causing severe damage to dimension stone reserves in terms of high losses, production of micro cracks, macro cracks and substandard blocks due to which It is estimated that there is more than 85 percent of waste produced in extraction phase of marble and granite which is more than 45 percent as per international standard (Muhammad Omair, 2014; Shaker Mahmood, 2011). Due to lack of technology and mechanism in extraction phase, the industry is unable to produce marble and granite according to national and international market standards (Muhammad Omair, 2014; Shaker Mahmood, 2011).

In present research work three different mining techniques i.e modern mechanized mining, pre-splitting and expansion powder techniques were applied at Indus Mining Pvt limited, district Mansehra Khyber Pakhtunkhwa for extraction of granite blocks. These methods were evaluated based on extraction costs, quality, quantity, revenue and recovery. The results obtained were analyzed and compared for selection of best and economical mining technique among these three mining techniques.

2. Mining techniques for extraction of dimension stone

The following mining techniques are used for extraction of dimension stone

2.1. Conventional mining techniques

Conventional techniques involve the use of explosives for splitting of blocks. In case of improper blasts and drilling pattern, the potato shaped blocks are obtained which not only wastes the valuable blocks but also reduce the economy of the operation. Conventional techniques of dimension stone extraction consist of drilling and blasting**.** In first step vertical, inclined and horizontal holes are drilled at suitable locations by using hydraulic drill machine or compressed air drill machine with keeping in view the geology of the rock as shown in figure. 2a. In second step the drilled holes are charged with suitable explosives following a proper charging and blasting pattern. The dimension stone deposits through conventional mining techniques result in huge wastage up to 85 % as shown in figure 2b. The conventional method used indiscriminate blasting resulting in potato shapes blocks which further increase the transportation and processing cost and have no value in international market (Rehman, 2010).

2.2.Modern mechanized mining

This technique is also called non-blasting technique in which the dimension stone is extracted in block shape according to the market demand through Diamond Wire Saw and Chain Saw Technique. In diamond wire saw technique diamond wire is used as cutting source for dimension stone. Its best feature is that it can be used for any cut size and gives fine faces. It gives high quality and reliable cutting according to the standard size of dimension stone required as by national and international market. A range of diamond

wire saw machines of different horse power is used for cutting in quarry operations (Rehman, 2010). The diamond wire saw machine is shown in figure 3.

2.2.1. Cutting of dimension stone using wire saw

In this technique three free faces are favorable for cutting of primary block by diamond wire saw machine. If there are two faces then a V shape cut is made to open a third face. The block of dimension stone extracted through drilling and cutting. In drilling three holes are drilled at suitable location in parent rock. During drilling one hole is made vertical while other two holes are made horizontal. All the three holes should intersect each other at a single point. The scheme for making three holes to meet at a point is shown in the figure 4. Normally down the hole (DTH) drill machine is used for the drilling purpose. Diameter of drill is kept such that if there is variation in the drilling alignment even then they meet at a single point (Rehman, 2010).

The next step after drilling is cutting of primary block. Cutting sequence is very important in order to smoothly carry out the process. First of all horizontal cut is made. It is done so because if vertical cut is made first then the load of the block will choke the diamond wire in horizontal cut and diamond wire can be damaged. The horizontal cut in the block is shown in figure 5a. After making horizontal cut, two vertical cuts are made step by step as shown in the figure 5b and figure 5c.

Fig. 2. Drilling, Blasting and Wastage in Conventional mining of Dimension stone (Rehman, 2010).

Fig. 3. Diamond wire saw machine (Rehman,

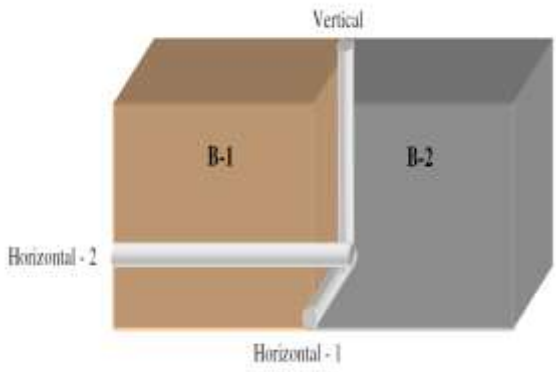

Fig. 4. Drilling pattern for extraction of

2010). dimension stone from parent rock (Rehman, 2010).

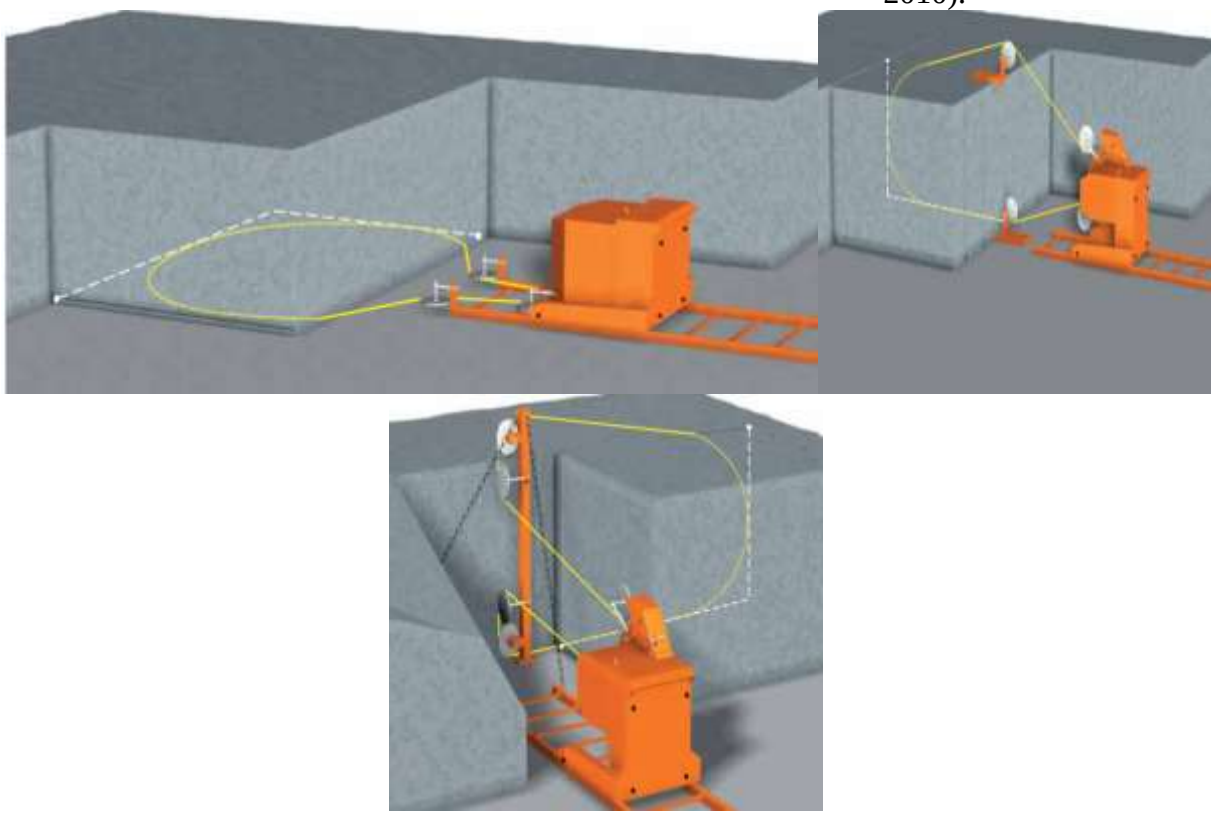

Fig. 5. Horizontal and vertical cuts pattern (Rehman, 2010).

After freeing the block from parental rock the block is further cut into different size or according to standard size.

2.2.2. Chain saw

In this method the cutting machine used contains an arm, which can cut in horizontal as well as in vertical direction. The length of the arm is normally 3.5 meter longer. Cutting tool is an endless chain that runs along the frame and contains Tungsten Carbide at some angle for cutting purposes. Great care must be taken in ensuring regular supply of water to machine and maintaining appropriate velocity of the chain. When the block is separated from the bottom, wedges are inserted in order to reduce load on the cutting arm. This method can be applied to almost all types of quarries. It is preferred for soft stone quarrying. Its production is about 8 to 10 m^2 per hour in carbonated marbles. Analysis shows that around 60% of power is consumed in friction losses. Therefore, extensive lubrication is required for the machinery that again increases the cost of operation. Chain cutting method is more productive. There is no need of horizontal and vertical holes drilling. It is more time saving method. When this machine is combined with diamonds wire cutting machine and drilling rigs, then its productivity and economy increases. This method requires high skill and therefore, is not widely used (Onagran, 2004; Rehman, 2010).

2.3.Cracking/expansion powder

Expansion powder known as SPLIT.AG, Expansive mortar, Non-Explosive demolition agent, is a non-toxic and cementation powder, which consisting of calcined oxides of

calcium, silicon and aluminum, SPLIT.AG produces a highly powered amazing expansive pressure of 18000 psi when mixed with water. Marble, granite, limestone, boulders, and ledge are fractured overnight without noise, vibration, or fly rock. Especially, used as environment constraints or when explosive is not permitted for use. In mining and quarrying industry, Split-AG helps to achieve perfect slabs and blocks from limestone, onyx, marble, granite or any other type of stone you are working with. Compares to blasting, Split-AG avoids wastage of valuable stone, high insurance, costly storage and labor (Aamir, 2012).

2.3.1. Extraction of dimension stone using cracking powder

First the cracking powder is prepared by mixing 1.5liters (0.4us gallon) clean water with one bag (5kgs) of Split AG powder in container. All the material mixed is stirred gradually until it got good fluidity. The cracking powder is now prepared to use for extraction of dimension stone block. The dimension stone block is extracted through drilling of holes using stich drill machine as shown in figure 7, filling of drilled holes from cracking powder, curing (Cover the filled holes with a plastic cover etc to avoid any accident caused by blow out shots. The time required for crack formation in material at 20 to 68^{o}C is approximately 10-20 hours the lower the temperature is, the longer the time for crack formation. Spraying the surface with water after cracks initiate tend to expand the width of cracks and speed up the cracking process) and finally the required size block is extract from parental/extracted rock portion (Aamir, 2012).

Fig. 6. Chain saw cutting (horizontal and vertical) (Rehman, 2010)

Fig. 7. Line drilling for filling of cracking powder (Rehman, 2010)

2.4. Pre-splitting

Presplitting, sometimes called pre-shearing. This is the most successful and widely adopted controlled blasting method and creates a plane of shear on the desired line of break, exposing the half-barrel of the blast hole after excavation**.** In this method drilled holes are fired before any of the adjacent main blast holes. The light explosive charges propagate a crack between the holes. The light powder load may be obtained by using specially designed slender cartridges, partial or whole cartridges taped to a detonating cord down line, an explosive cut from a continuous reel, or heavy grain detonating cord. A heavier charge of tamped cartridges is used in the bottom few feet of hole. The maximum depth for a single Presplit is limited by the accuracy of the Drill holes and is usually about 50 feet (15 m). Depths between 20 and 40 feet (6 and 12 m) are recommended. A deviation of greater than 6 inches (152 mm) from the desired plane or shear will give inferior results (Olofsson, 2000).

3. Results and discussion

Case study 1:

102.30 m^3 block of black granite were extracted using diamond wire saw technique from parental rock as primary cut. The drilling and cutting cost of primary cut is given in table 1. In secondary cutting six numbers of blocks of each size 17.02 m^3 (3.66*1.55*3) were further extracted from primary block using same method. The drilling and cutting cost of secondary cutting is given in table 1.

The percentage of drilling versus cost and distribution of various operations (drilling, primary cut & secondary cut) in the total cost of extraction for diamond wire saw technique is presented in table 2 and figure 8 respectively.

Table 1. Drilling and cutting cost

Primary cutting		**Secondary cutting**	
Drilling cost in Rs.	Cutting cost in Rs.	Drilling cost in Rs.	Cutting cost in Rs.
10,130	61,585	0.00	23,770
Total Primary cutting cost = 71,715		Total secondary cutting cost = 23770	
Total cost on extraction of granite blocks = Rs. 95485 The yield cost is Rs. 933/m^3 or Rs. 343.01/ton			

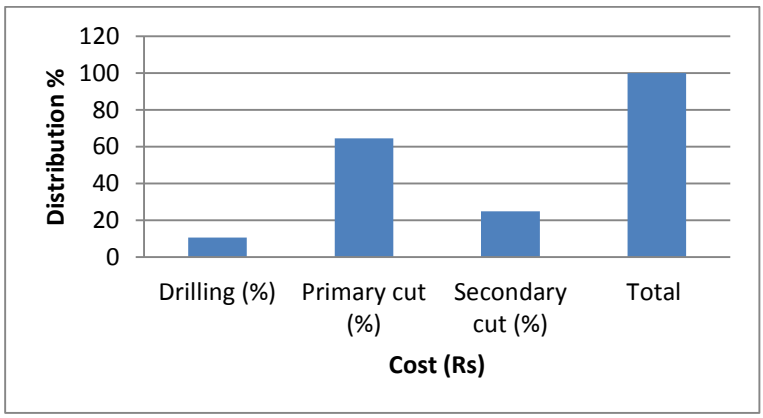

Fig. 8. Cost versus distribution for extraction of block.

Table 2. Primary and secondary cutting cost

Drilling (%)	Primary cut (%)	Secondary cut (%)	Total
10.61	64.5	24.89	100

Diamond wire saw technique cut the block with smooth faces and accurate dimensions. The dimension stone blocks were divided into four different categories according to the quality of block (i.e A, B, C and D). **"A"** quality blocks are of export quality that is free from any defect and the maximum revenue is generated from such blocks. Other degraded qualities are due to the presence of cracks, white lines, green lines, irregular shapes, cutting faces or poor sizes. In six extracted block through diamond wire saw cutting techniques 2 blocks were **"A"** quality block because it was according to international standard, one was **"B"** quality, two blocks were **"C"** quality and one block was **"D"** quality. The recovery and revenue generated of these six blocks is given in to table 3.

Table 3. Recovery and revenue

Quality	Weight (ton)	Recovery (%)	Price in Rs./ton	Revenue (Rs.)
A	92.59	33	24115	2,232,807
B	46.29	17	9000	416,610
C	92.59	33	7000	648,130
D	46.29	17	3000	138,870
Total amount Rs.				**3,436,417**

Case study 2:

102.30 m^3 block of black granite were extracted using diamond wire saw technique from parental rock as primary cut. Six numbers of blocks each size of 17.02 m^3 (3.66*1.55*3) were extracted from primary cut block through expansion powder as secondary cut. In secondary cutting the drilling and splitting cost for expansion powder is given in table 4.

Table 4. Drilling and splitting cost

Primary cutting		Secondary cutting	
Drilling cost in Rs.	Cutting cost in Rs.	Drilling cost in Rs.	Splitting cost in Rs.
10,130	61,585	7,552	9,926
Total Primary cutting cost = 71,715		Total secondary cutting cost = 17,478	
Total cost on extraction of granite blocks = Rs. 89,193 The yield cost is Rs. 871/m^3 or Rs. 320.22/ton			

The percentage of primary cut cost, splitting cost and cost versus distribution in the total cost of extraction for diamond wire and expansion powder technique is presented in table 5 and figure 9 respectively.

Table 5. Primary and Secondary cutting cost

Primary cut (%)	Secondary cut (splitting) (%)	Total
80.40	19.60	100

In secondary cutting expansion powder was used for extraction of blocks from primary block. It was observed that due to splitting action of expansion powder the micro cracks were produced at the surface of block which affects not only the quality of rock but also decrease the worth of blocks. Due to use of expansion powder as secondary cutting agent only B, C, and D quality of blocks were extracted and about 33% the wastage were produced. The recovery and revenue generated from this technique is presented in table 6.

Case study 3:

102.30 m^3 block of black granite were extracted using diamond wire saw technique from parental rock as primary cut. Six numbers of blocks each size of 17.02 m^3 (3.66*1.55*3) were extracted from primary cut block through pre-splitting technique as secondary cut. In secondary cutting the drilling and pre-splitting cost including explosives and its accessories cost is given in table 7.

The Percentage of primary cut cost, splitting cost and cost versus distribution in the total cost of extraction for diamond wire and pre-splitting technique is presented in table 8 and figure 10 respectively.

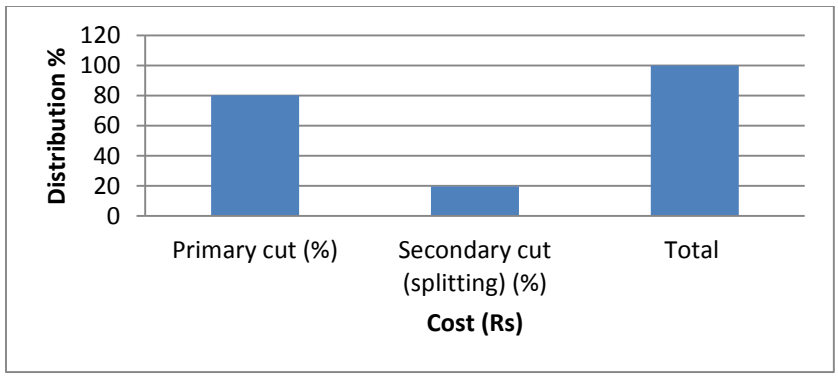

Fig. 9. Cost versus distribution for extraction of block

Table 6. Recovery and Revenue

Quality	Weight (ton)	Recovery (%age)	Price in Rs./ton	Revenue (Rs.)
B	46.29	17	8000	370,320
C	92.59	33	6000	555,540
D	46.29	17	2500	115,725
Total amount Rs.				1,041,585

Table 7. Drilling and Splitting cost

Primary cutting		**Secondary cutting**	
Drilling cost in Rs.	Cutting cost in Rs.	Drilling cost in Rs.	Splitting cost in Rs.
10,130	61,585	5,407	11,272
Total Primary cutting cost = 71,715		Total secondary cutting cost = 16,679	
Total cost on extraction of granite blocks = Rs. 88,394 The yield cost is Rs. 864.06/m^3 or Rs. 317.70/ton			

Table 8. Primary and secondary cutting cost

Primary cut (%)	Secondary cut (splitting) (%)	Total
81.13	18.87	100

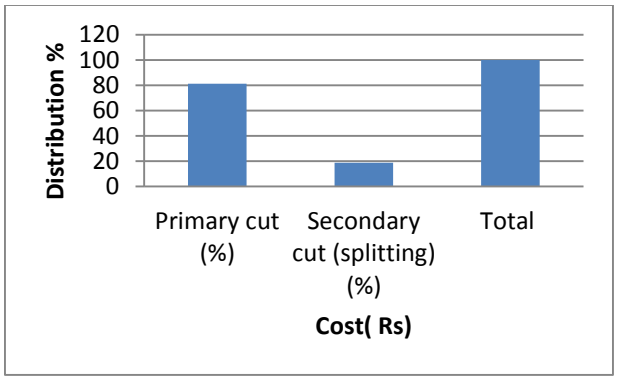

Fig. 10. Cost versus distribution for extraction of block

Pre-splitting technique was used as secondary cutting for extraction of blocks from primary block. It was observed that due to splitting action the micro cracks, macro cracks and some major cracks were produced at the surface of block due to intense velocity of shock waves after initiation of explosives through safety fuse and explosion, which affects not only the quality of rock but also decrease the worth of blocks as compared to diamond wire saw and expansion powder technique. Due to use of explosives as secondary cutting agent only B, C, and D quality of blocks were extracted and about 49% of the total volume of primary cut block was loss as waste material. The recovery and revenue generated from this technique is presented in table 9.

3.1. Comparative analysis of diamond wire saw, expansion powder and pre-splitting techniques

The cost of diamond wire saw techniques for extraction of block was noted high as compared to expansion powder and pre-splitting techniques as shown in figure 11.

The revenue and recovery from blocks extracted by diamond wire saw technique was noted much high then expansion powder and pre-splitting mining techniques as shown in figure 12 and figure 13 respectively. In expansion powder and pre-splitting about 33% and 49% of granite rock was lost as waste material during extraction process respectively due to micro, macro and some major crack produced through blasting.

Table 9. Recovery and revenue

Quality	Weight (ton)	Recovery (%age)	Price in Rs./ton	Revenue (Rs.)
B	46.29	17	6000	277,740
C	46.29	17	5000	231,450
D	46.29	17	2500	115,725
Total amount Rs.				**624,915**

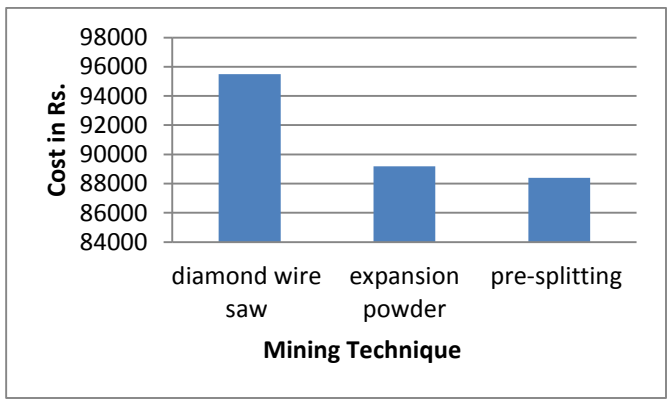

Fig. 11. Cost of different mining techniques for block extraction

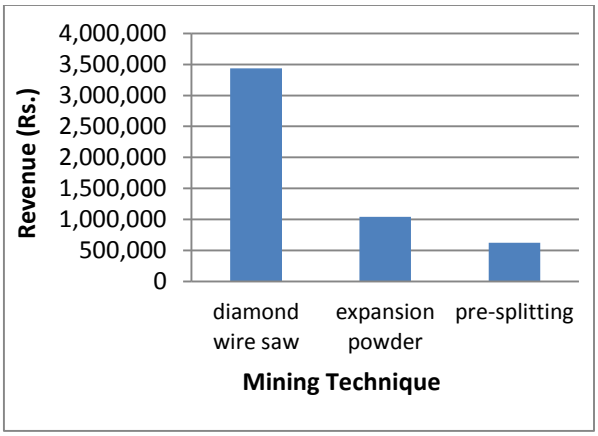

Fig. 12. Revenue generated from different mining techniques

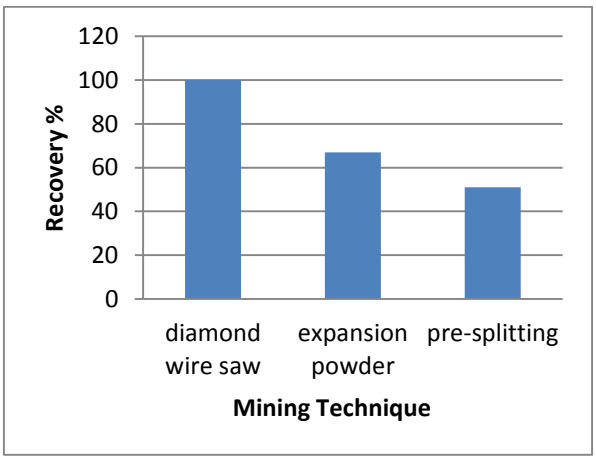

Fig. 13. Recovery for different mining techniques

4. Conclusions and recommendation

Diamond wire saw technique gives higher revenue and recovery as compared to other two techniques. The total yield cost for this technique was more than expansion powder and pre-splitting. i.e Rs. 933/m3. The minimum waste was produced in extraction of blocks through diamond wire techniques, thus reducing waste handling problems and consequently saving natural resources and increase the worth of blocks. It ensures accurate sized blocks for export and local demand. Its drawback is high capital and maintenance cost. In expansion powder and pre-splitting technique the production of micro, macro and major cracks were noted, due to which the quality, recovery and revenue were much decreased as compared to diamond wire saw technique. The revenue of the diamond wire saw is Rs 3,436,417, while the other techniques revenue is Rs. 1,041,585 and Rs 624,915 respectively. The production of waste was noted more at the quarry and at processing plant in pre-splitting and expansion powder techniques. Keeping in view the benefits, safety of diamond wire saw technique it is recommended for extraction of granite blocks through primary and secondary cutting.

Authors' Contribution

Zahid Ur Rehman, did actual work at site, main idea, literature review, paper writing and interpretation of results from case study. Sajjad Hussain, contributed in literature review, performing of actual work at site and analysis and interpretation of results. Noor Mohammad, contributed in literature review and paper writing and technical evaluation of paper. Salim Raza, contributed in literature review and paper writing. Saira sherin, contributed in literature review and paper writing. Mujahid khan, contributed in tests work and evaluate paper. Muhammad tahir, contributed in tests work and evaluated paper. Murtaza khan, contributed in tests work and evaluate paper.

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