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# Determination of the Optimum Size of Building Stone Blocks: Case Study of Delichai Travertine Mine

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***Abstract*****—**Determination of the optimum block size with high profitability is one of the significant parameters in designation of the building stone mines. The aim of this study was to determine the optimum dimensions of building stone blocks in Delichai travertine mine of Damavand in Tehran province through combining the effective parameters proven in determination of the optimum dimensions in building stones such as the spacing of joints and gaps, extraction tools constraints with the help of modeling by Gemcom software. To this end, following simulation of the topography of the mine, the block model was prepared and then in order to use spacing joints and discontinuities as a limiting factor, the existing joints set was added to the model. Since only one almost horizontal joint set with a slope of 5 degrees was available, this factor was effective only in determining the optimum height of the block, and thus to determine the longitudinal and transverse optimum dimensions of the extracted block, the power of available loader in the mine was considered as the secondary limiting factor. According to the aforementioned factors, the optimal block size in this mine was measured as 3.4×4×7 meter.

***Keywords*****—**Building stone, optimum block size, Delichai Travertine Mine, loader power.

## I. Introduction

TRAVERTINE has been widely used as flooring and wall cladding on buildings since ancient Greece up to now. The appropriate physical properties of travertine including large holes and stone durability in constructing facades and buildings result in that this stone still be widely used [1]. Examples of travertine can be found in Heritage Building in Magna Graecia [2], in ancient Greece and in ancient Rome in particular. The Romans have used travertine in a great many well-known buildings throughout the Roman Empire [3]-[8].

It is considered as a crucial matter for an investor to be able to estimate the average block size that can be produced of ore body before any mining operations. If a mining investment is made without knowing its block size, then this fact can play as a contributing factor in not being cost-effective and this leads to mine closure in a short time. Considering this fact, the principal step in mining designation is determining the appropriate as well as optimum dimensions of stone block that has three dimensions of length, width and height. Such dimensions should be determined in a way which provide easy and safe block extraction and impose the least mining cost economically [9].

Among the factors involved in determining the optimum size of stone blocks, we can refer to geostructural parameters including joints, the spacing of the joints and their relative direction, technical parameters such as the mode of excavation, quality and its functionalities, cutting machine power, the mode of block shaping and its dimensions, and economical factors like the cost of repair and maintenance, consumer equipment, personnel and energy. But what is more important in determining the block dimensions comparing to others and what has significant impact on determining the optimum size of blocks are the spacing in the joints and size of required blocks shape which determines the block width. So that block width is better to be fit with the spacing in the joints and an integer multiple of the cut stone dimension and the block width can be increased to the extent that it does not cause any problem in overturning the block after separation to be shaped and creating work space for the extraction of the next block [10]-[13]. Also, block length can be increased to the extent that drilling horizontal holes occur without deviation or with very little deviation, that this fact has significant correlation with type of excavation machine, its capacity, operator skill, and also stone material and its structure. This issue plays an important role in designing decorative stone (building) mines since hole deviation causes drilled hole from different directions do not cut each other at one point. So as far as there is not high deviation of hole, block length increase can be examined.

On one hand, the dimensions of appropriate block shapes that are in demand of stone cutting factories and increases their purchase plays a crucial role in determining the block dimensions, so that we can reach the maximum acceptable dimension range of industries with the least amount of cutting. So most Iranian stone cutting manufacturers believe that their requested size is within the framework of (block stone) with dimensions of 1 and 1.5 to a maximum of 2 meters. Also the levels created on the sides and bottom of the block should be to an extent that the cutting machine can cut those [14]. Due to the importance of this fact, extensive research has been done in this respect that some of them are as follows:

Using the limiting factor of joints system in 2011, S. Mosch et al. studied the optimum block dimensions in several different mines and eventually they provided a model to determine the optimum size with the help of joint system

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through analyzing the data obtained from 3D-block software [2].

In 2014, Hakan and Necdet worked on the quality of block lump ore in mine. Using the lines of Scan line, they managed to remove the joints system within the lump ore and they assessed the quality of lump ore by using core drilling [14]. The proportion of determining the quality of block lump ore to assess the production capacity of lump ore is expressed with $BQD\% = \sum S_{\geq 1m}/L$. The results of studies on selected mines revealed that BQD is more than 50% in working mines and less than 50% in abandoned mines. Then based on the findings of research, they managed to design an excavation model appropriate for building stones.

In general, in line with determining the optimum block size and studying the amount of changes of block size in a mine, the optimum dimensions as well as calculations will be done with engineering viewpoint and appropriate recognition of the special status of the mine. The dimensions that are considered as optimum for the blocks in a mine may change in another mine by changing the spacing in the joints, the dimensions of cut stone and the quality of machinery and its special conditions. The optimum block size for each mine is calculated according to certain conditions and parameters of the mine. But what is certain is that determining the optimum dimensions in building stone mines follows a general process.

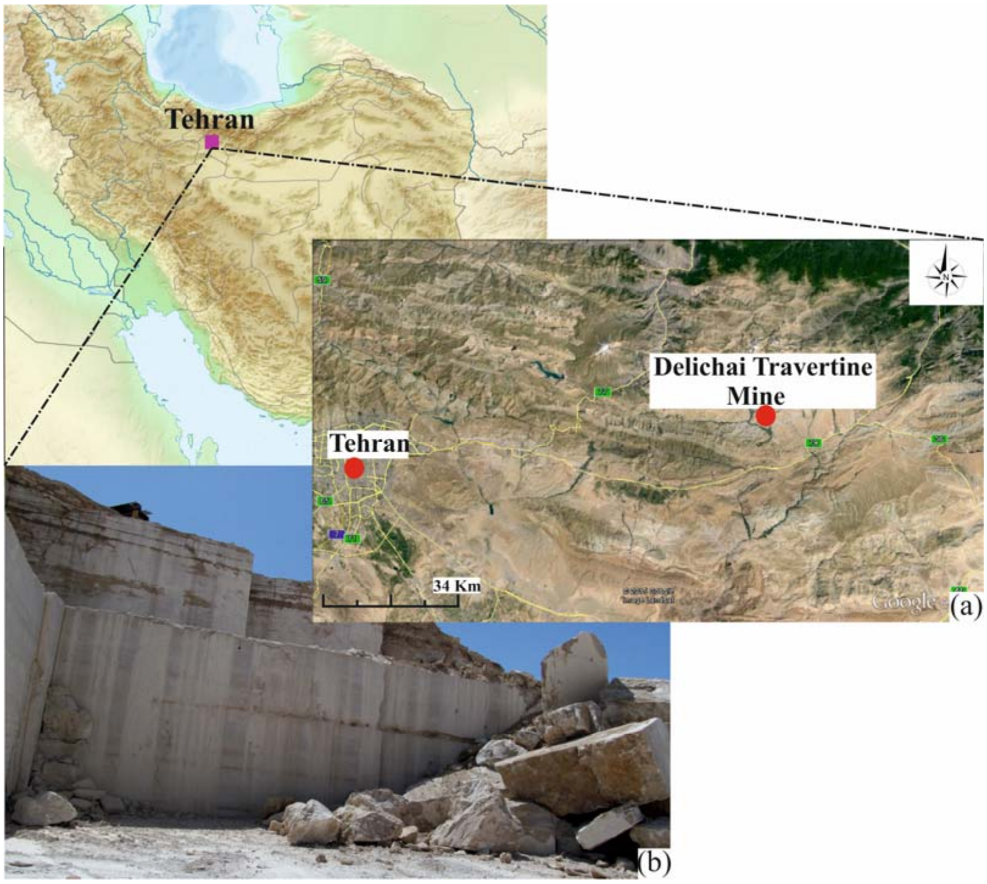


Fig. 1 (a) Access routes to Delichai travertine mine on Google Earth, (b) Delichai travertine mine and the extracted bench face

In this study, the block model in Gemcom gem software has been built by using the effective parameters in determining the optimum block dimensions, and the optimum dimensions of stone block at Delichai travertine mine has been calculated.

## II. Delichai Travertine Mine

Delichai Village is located at a distance of 109 kilometers from Tehran. The height of this place is 2200 meters above sea level. Travertine deposits were explored to provide block stone for stone cutting factories in south Tehran. Due to the proximity of the mine site to Tehran-Firoozkooh road, the costs of building road and transportation has been minimized and it can be exploited with the highest economic efficiency (Fig. 1) [17].

## III. Geological Features

Delichai Travertine mine is located in the South West of Delichai River and limestone springs are considered as the main source of the deposit. Two parts are recognizable in this area in terms of morphology and topography. One part has low slopes and is relatively flat that recent sediments such as alluvium and travertine can be seen in it. This part extends in North and West and a small part of the East of mine area

The other part is steep that conglomerate and sandstone can be seen in it and this area extends in the Southern district of the mine. Mine district is situated in a semi-high area that its height from Firoozkooh road surface is about 120 to 150 meters and its height is about 2,200 meters above sea level. In this district three units of alluvium, travertine and conglomerates are isocline and almost horizontally on each other, in the case that sandstones are located in the form of unconformity under the conglomerate. Angular unconformity is very steep and close to vertical. The reason of this fact is the time difference of sandstone and conglomerate formation. It means that there can be seen sedimentation gap from Jurassic to Neon in the mine area. All lithology units observed in this district from new to old are as follows:

- Recent sediments (QAL) as alluvium with very loose cement related to Quaternary in the north of the mine.
- Recent travertine (QTR) caused by the limestone springs at the time of Quaternary with average slope and extension N305/5NE and thickness between 7 up to 15 meters.
- Neon Conglomerate (NO) which can be seen as a thick layer in the main waterway of the mine and below the travertine with outward color of light gray. These conglomerates are often made of igneous rock and pyroclastic rock connected to each other by relatively loose lime cement.
- Jurassic sandstone (JM) with slope and extension N230 / 75NW related to Shemshak Formation can be seen in the lower level of the central waterway.

In terms of layering, these sandstones are thin layers and they are seen as dark green. In petrography studies it was found that the main mineral of stone is quartz and very small amount of mica mineral is also seen in it. In this group some rocky parts made of andesitic rocks, metamorphic and sedimentary components can also be seen [9].

## IV. Methodology

In this study, in order to achieve a three-dimensional model of the mine district, first a topographic map was drawn through surveying. Then, as shown in Fig. 2, the edge and foot of the stairs, roads and the topographical points are completely differentiated using GEMCOM GEMS software, and finally an appropriate surface has been established on the topographical points obtained from the field operations.

In this study, the optimum block size is determined using block modeling in software, apply the limiting environmental factors, and mathematical calculations of limit equilibrium. One of the most influential factors in the accuracy of estimating the optimum block size is the size of the blocks used in the block model. The reduction in the size of the block to a certain extent causes increase in accuracy and then, the reduction of block dimensions only causes an increase in calculation extent. However, the significant fact to be considered is that the rapid decrease in block dimensions results in the increase in estimation error. To facilitate the work, the block dimensions are considered 1×3×5. These dimensions are obtained by experimental adaptation of various block dimensions with topographical condition of mine stairs through trial and error after implementing several stages of testing and modeling in software that based on the aforementioned dimensions, the most logical mode is between block model and topographical condition of the mine.

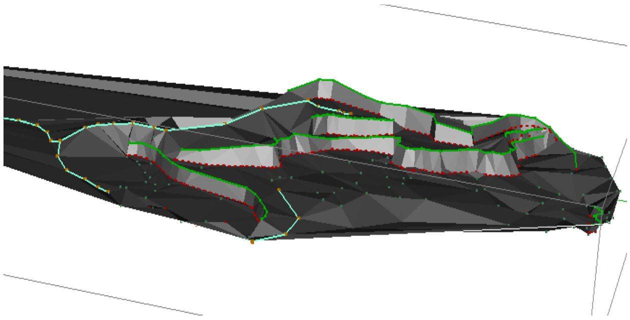

Fig. 2 Three-dimensional model of mine district; as seen in the figure, the mine has three extraction steps. Also, the blue lines represent roads, green lines represent stair edge, red lines represent the foot of the stairs and green points are the topographical points of the region

In Delichai building stone mine, three kind of travertine exist with different densities and colors of dark brown, bright or white and beige. Dark brown color with a density of 2.38 grams per cubic meters depot in the tailings dam due to lack of proper market. Beige and bright colors with densities of 2.45 and 2.66 grams per cubic meters are in the next level of importance in terms of quality and good market sales due to the demand situation in the building stone market recently that accordingly only bright color has proper sale market and so beige color also depot in the mine.

The mine in the created model is divided into three colors: red, blue and green that in Fig. 3 the three-dimensional view and in Fig. 4 its two-dimensional plan is shown. Accordingly, bright or white travertine in height of 1245 to 1257 is in blue, beige kind in height of 1257 to 1270 is in red and brown kind in height of 1270 to about 1286 is in green in the created model (Figs. 3 and 4).

According to geological and geomechanical data, the mine has one original and effective horizontal joint set and an extensive vertical discontinuity along the entire mine. Therefore, the horizontal joint set with a slope of approximately 5° to the horizontal was considered as the block limiting factor in height and vertical discontinuity extended in the total range of deposit was also applied in the model due to the impact on the exceeded stone crushing amount at the intersection points with the horizontal joint set. By applying the horizontal joint set in the block model it is specified that the optimum block size can be increased up to 7 meter in height in the extraction stage and also there is not the extraction possibility of appropriate size block at the intersection points of horizontal discontinuity with vertical joint set due to the excessive rise of crushing amount and therefore these areas should be forbore.

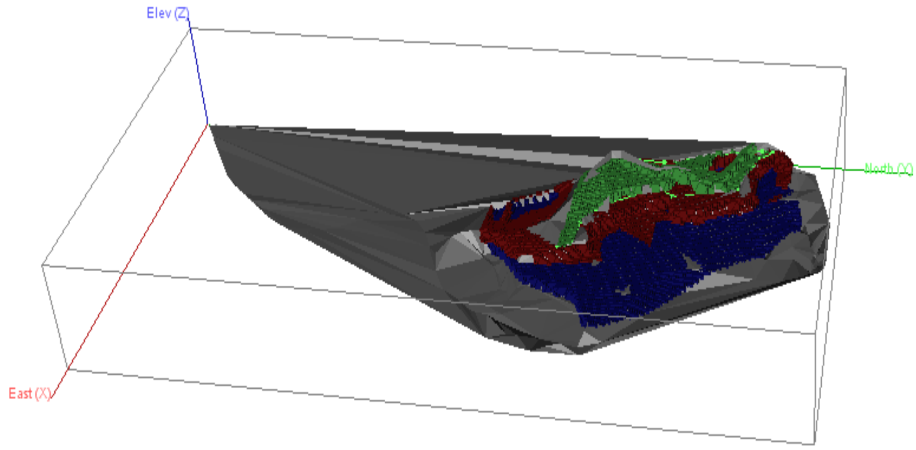


Fig. 3 The created block model of the mine

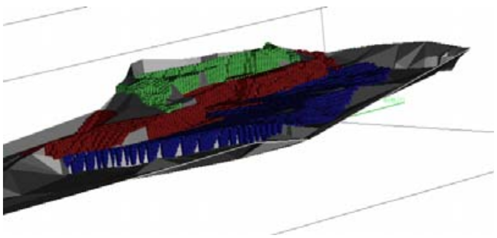

Fig. 4 Mine stairs are shown with color separation by block model

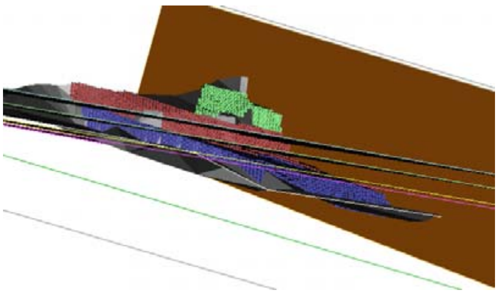

Fig. 5 Far view of the intersection of horizontal joint and vertical joint set with faces along with the block model

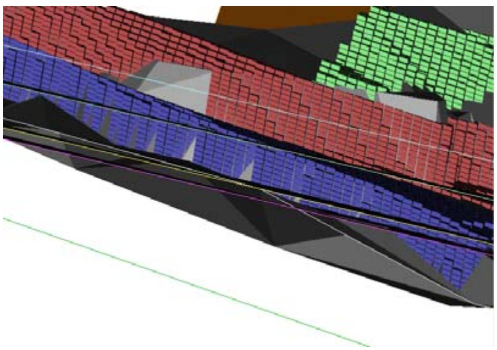

Fig. 6 Near view of the intersection of horizontal joint and vertical joint set with faces along with the block model

In Figs. 5 and 6, two far and near views of extracted bench face after applying the discontinuities are shown.

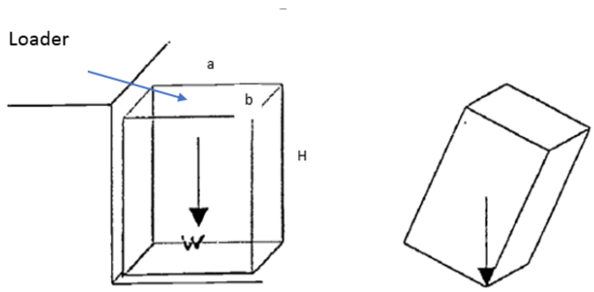


Fig. 7 Block view while being released

In longitudinal and transverse direction due to the lack of vertical joint set openly, there will no possibility of using this factor. Hence, to address this problem another limiting factor should be considered. For this purpose the used loader power in the mine which shoulders the duty of pushing the stone blocks after extraction and the loader administrative constraints in the field of longitudinal and transverse block dimensions that it can afford to do it have been considered.

## V. Loader Power and Its Impact on Block Dimension

After cutting off the block surface, it will be overturned due to its shape and creating the work space for the next block extraction. While overturning the block, as shown in Fig. 7, the resultant vector of the block weight will be out of the block surface in equilibrium and it is much more difficult in very wide blocks. Thus increasing the width of the block is possible to the extent that it does not cause any problem in overturning the block and the power of available loader in the mine should be considered.

As previously mentioned, in order to obtain the longitudinal and transverse optimum block dimensions in Delichai mine, there is no possibility of using discontinuities as limiting factor. Therefore, the limiting factor in this dimension is determined through the following calculations based on the loader driving force and supportive resistant agents during the pushing operation of the extracted blocks. It should be noted that the used loader in the mine is of Komatsu WA800 type with a bucket volume of 10.5 cubic meters and it has the nominal ability to horizontally push the stone block with a weigh of about 61 tons.

Static equilibrium was used in this method. First, according to Newton's first relation, the loader driving force is equal to:

$$\mathrm{F} = \mathrm{ma} \tag{1}$$

To obtain the amount of force that the loader can enter the stone, this formula is used. However, the friction force of the loader wheel with the ground should be considered in the relation as one of the resistance force against movement:

$$\mathrm{F} - \mathrm{F_{kl}} = \mathrm{ma} \tag{2}$$

However, the friction force of the loader wheel with the ground has also a relation:

$$\mathrm{F_{kl}} = \mu\mathrm{N} \tag{3}$$

So, to obtain the resistance force against the movement of the loader friction, the coefficient of the friction force of the loader wheel with the ground is needed. This coefficient will equal to 0.6 regarding the relation proposed by Steffen Müller in 2003 to obtain the coefficient of the friction force of the loader wheel with the ground [18] and the loader weight with regard to the loader type used in the mine is also obtained from the machine catalog [19]:

$$\mathrm{F_{kl}} = 0.6\times 99410\times 10 \tag{4}$$

$$\mathrm{F_{kl}} = 59646\ 0\ \mathrm{KN} \tag{5}$$

Now the loader acceleration should be calculated to help determine the amount of force that the loader enters the stone. According to the device catalog, loader speed using first gear will reach up to 7 kilometers per hour. So, knowing this fact, the time of reaching from complete cessation rate (0 kilometers per hour) up to the final speed in this gear using the timer at the mine site was calculate and accordingly a time about 4 seconds was obtained. So using the following relation we have:

$$\mathrm{a} = \frac{\mathrm{v}}{\mathrm{t}} = \frac{7}{4\times 3.6} = 0.48\ {}^{\mathrm{Km}}/_{\mathrm{h^2}} \tag{6}$$

Thus, the driving force without considering the friction equals to:

$$\mathrm{F} = 99410\times 0.48\times 10 = 477160.8\ \mathrm{KN} \tag{7}$$

And finally, with regard to the calculated items, the loader power is equal to:

$$\mathrm{F} - 596460 = 477160.8 \tag{8}$$

$$\mathrm{F} = 1073620.8\ \ \mathrm{KN} \tag{9}$$

However, due to the friction force between the loader and the stone block, there will be:

$$F = F_{kr} \tag{10}$$

$$F = \rho v \mu_r \tag{11}$$

$$1073620.8 = 2260\times a\times b\times 7\times 0.5\times 10 \tag{12}$$

$$13.57 = a\times b \tag{13}$$

The friction coefficient between travertine stone and the ground was considered 0.5 [20]. However, given that the stone cutting factory does not have the possibility of cutting stone with width and length more than 1.7 and 2 meters, the values of a and b must be a multiple of these numbers. Thus for this purpose and according to equation 11, the amount of a is considered 3.4 meters and the amount of b according to relation 7 is considered 4 meters.

Finally, considering the performed calculations and the height limiting factor, the proposed dimension to optimize the extracted block shape was determined 7×4×3.4m.

## VI. Conclusion

In this study, the optimum dimension of the extracted block was obtained through exploring the joint system and gaps as well as considering the machines power used in the mine. Using Gemcom Gems software, the block model was made considering the existed structural characteristics in the study area including horizontal and vertical joint set and the vertical extended discontinuities and the extracted block dimensions were obtained. But due to the small amount of joints in this mine, only the stair height was gained through this method and then the length and width was determined with the help of loader power. Based on this research, it can be said that determining the optimum block dimensions in the building stone mines is possible through an engineering approach in each mine according to the specific conditions of the mine and also the ability of its machines and it follows a general trend. In other words, it can be used for the stone mines that are extracted by this method. Regarding that the final shape dimensions of the manufacturer required product is considered as the most significant factor in determining the optimum block dimensions, so the extracted block dimension should be considered in such a way that the appropriate block shape required by the stone cutting factory is achieved. In this case, the cutting amount for shaping is minimized and ultimately, the cost of extraction will reach the lowest. Therefore, only the extracted block dimension will not be the cost reduction factor, but the dimension ratio of the extracted block dimension to the shaped block dimension will have the main impact. In this mine due to the loader ability, the optimum dimension of the required shapes and the main block dimensions are considered 3.4 × 4 × 7 meter.

## REFERENCES


[1] M.A. Garcia-del-Cura, M.E. Sanz-Montero, D. Benavente, J. Martinez-Martine, A. Bernabeu, N. Cueto, "Sistemas travertinicos de Alhama de Almeria": caracteristicas petrograficas y petrofisicas. Geo-Temas. 2008, vol. 10, pp. 1555–8 (in Spanish).

[2] S. Mosch, D. Nikolayew, O. Ewiak, "Optimized extraction of dimension stone blocks". Environ Earth Sci, 2011, vol. 63, pp. 1911–1924.

[3] A. Pentecost, 2005. Travertine. Berlin, Springer-Verlag.

[4] B. Soler Huertas, El travertino Rojo de Mula (Murcia), Definición de un mármol local. 2005, Verdolay. 9, pp. 141–164 (in Spanish).

[5] O. Solohen, H. Luodes, C. Ehlers, "Exploration for dimensional stone – implication and examples from the Precembrian of southern Finland". Eng Geol, 1999, vol. 56 (3), pp. 275–291.

[6] K. Goshtasbi, D. Khodadadi, "Determination of Optimum Block Size in the Mining of Ornamental Stones by Diamond Wire". Geoscience, 2005, vol. 57, pp. 120-125.

[7] National brick pavers, committed to quality since, 1989. Available at www.bricksandblocks.com

[8] A. Török, Hungarian travertine: weathering forms and durability. In: Fort, R., Alvarez de Buergo, M., Gómez-Heras, M., Vazquez-Calvo, C. (Eds.), Heritage, weathering and conservation. London, Taylor & Francis Group, 2006, pp. 199–204.

[9] I. Sidraba, K.C. Normandin, G. Cultrone, M.J. Scheffler, Climatological and regional weathering of Roman travertine. In: Prˇikryl, R., Siegl, P. (Eds), 2004. Architectural and sculptural stone in man-cultivated landscape. Prague, The Karolinum Press, pp. 165–181.

[10] H. Sönmez, H.A. Nefeslioglu, C. Gökçeoğlu. "Effects of the number and spacing of discontinuities on weighted joint density (wJd)". Rock Mech Rock Ent, 2004, vol. 37 (5), pp. 403–413.

[11] M. Pedley, "Tufas and travertines of the Mediterranean region: a testing ground for freshwater carbonate concepts and developments. Sedimentology". 2009, vol. 56, pp. 221–246.

[12] A. Török, "Influence of fabric on the physical properties of limestones", In: Kourkoulis, S.K. (editor), Fracture and failure of natural building stones. Dordrecht, Springer, 2006, pp. 487–495.

[13] R.E. Goodman, "Block theory and its application". Geotechnique. 1995, 45 (3), pp. 383–423.

[14] E. Hakan, T. Necdet, "Rock mass block quality designation for marble production". International Journal of Rock Mechanics & Mining Sciences, 2014, vol. 69, pp. 26–30.

[15] K.S. Kalenchuck, M.S. Diederichs, S. McKinnon, "Characterizing block geometry in jointed rock masses". Int J Rock Mech Min Sci, 2006, vol. 43(8), pp. 1212–1225.

[16] Industries and Business Organization, 2013. report of Delichai travertine mine, Tehran, Iran.

[17] S. Muller, "Estimation of the Maximum Tire-Road Friction Coefficient". Journal of Dynamic Systems Measurement and Control, 2003, vol. 125, pp. 607-617.

[18] M. Mutlutürk, "Determining the amount of marketable blocks of dimensional stone before actual extraction". 2007, J Min Sci, vol. 43, pp. 67–72.

[19] Komatsu mining system company, 1998. Komatsu WA 800-2 manual. Available at www.komatsu mining.com

[20] M.D. Jackson, F. Marra, R.L. Hay, C. Cawood, E.M. Winkler, "The judicious selection and preservation of tuff and travertine building stone in ancient Rome". Archaeometry. 2005, vol. 47, pp. 485–510.