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DETERMINING THE AMOUNT OF MARKETABLE BLOCKS OF DIMENSIONAL STONE *BEFORE* ACTUAL EXTRACTION

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The lack of a proper decision variable impedes the planning of dimensional stone quarry operation. So far, "quasi-grade", which may measure the stone quality, developed via multivariate statistical methods is offered as decision variable. However, the marketable blocks of dimensional stones should satisfy not only stone quality requirements, but also conform to certain dimensional standards, and these two are essentially incommensurable. Clearly, for stone with known quality, the amount of marketable dimensional stones (MDS) provides the best decision variable for planning (i.e. sequencing the operation of unit volumes). A method for determining the amount of MDS *before* actual extraction is presented.

Dimensional stone, block size determination, marketable yields, quarry planning

INTRODUCTION

Planning of dimensional stone quarry operation is an important but a neglected task, and the lack of a proper decision variable seems to be the main obstacle. For such planning in metallic and non-metallic industries, usually a single variable such as "mineral grade" is used. However, there is no such single variable to use in dimensional stone quarries [1, 2]. Therefore, similar to the concept of "grade", the existence of a "quasi-grade" for a large number of mining blocks (or a given unit volume of operation) is assumed. In fact, the development of a single composite-index from multivariate measurements via statistical methods as "quasi-grade" is the only approaches so far offered in the literature [2–4].

All these approaches aim to develop a "quasi-grade" of quality for assessing the quarries of the dimension-stone. However, such "quasi-grade" cannot be readily converted to the amount of stone to be extracted from a block with a given unit volume of operation (UVO). Hence, UVO are categorized into recovery classes. For this approach, as expressed in [2], "the identification of a single quality index and the classification of blocks are two major challenges to dimensional stone quarry planning."

Nevertheless, categorizing the blocks according to "quasi-grade" into recovery classes is not satisfactory solution, since it "gives only an arrangement of blocks in an arbitrary quality index values" [5] and it is hard to convert them into commercial values. Even if commercial value classes can be established, they may not be precise enough to make financial calculations for managerial decisions. Moreover, establishing dependable commercial value classes via "quasi-grade" categories that will be applicable to all similar mining areas is not an easy task, if it is not entirely impossible. In short, "quasi-grade" approach provides only a partial solution for the problem of finding a planning variable.

Obviously, the marketable blocks of dimensional stones should satisfy not only stone quality requirements, but also conform to certain dimensional standards. Of course, the rock mass characteristic that affects the block size can be easily integrated into "quasi-grade", but this is not a real solution,

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since stone quality and dimensional standards are essentially incommensurable. Hence, “quasi-grade” should be used only as index of stone quality, and the amount of marketable dimensional stones (MDS) should be determined by some other way. Clearly, the market price of a dimensional stone having a certain block size and a given quality can be easily known. Consequently, for stone with known quality, the amount of MDS provides the best decision variable for planning (i.e. sequencing the operation of unit volumes).

At first, it may seem infeasible to determine the amount of MDS with certain precision *before* actually extracting them. However, such determination is theoretically possible and practically feasible. For this, it is enough to make such determination for a given volume of quarry, namely, for a “unit volume” of operation (UVO) with known dimensions (e.g. 10 m x 20 m x 15 m). After determining the amount of MDS of each UVO, these data can be used for sequencing the extraction operation within the quarry.

CONCEPTUAL FOUNDATION OF THE METHOD

The conceptual foundation of the present method bases upon the principles of solid geometry. Since the discontinuities form the natural boundary surface of each separable stone blocks, hence the size of marketable blocks is constrained by these plane of discontinuities. Therefore, at first, each “rock mass” formed by these discontinuities, namely discrete block (DB), should be determined. This can be done by cutting the unit volume of operations (UVO) with planes of discontinuities. Afterward, by placing marketable blocks with certain shape (e.g. rectangular parallelepiped) and dimension (e.g. $3\times 2\times 1$ or $1.5\times 1\times 1$ m) into these DBs to determine how many marketable blocks of certain dimension can be obtained from each discrete block, and by summation from each UVO. Finally, the total value of marketable blocks, and several other indices can be easily calculated with the data. In practice, some of the plane of discontinuities may not cover the whole unit volume; hence the method gives a conservative result, which reduces the risk of “bad” choice.

STEPS OF GRAPHICAL PROCEDURE

The best way to explain the method is to present the main steps of the graphical determination of the marketable blocks with given shape and dimension in a “unit volume” of operation (e.g. a unit volume of $20\text{ m}\times 20\text{ m}\times 10\text{ m}$). Selection of unit volume can vary depending on the operational conditions.

After collecting the necessary field data about the fractures (i.e. strikes and dips of the discontinuities within UVO), the shape of every “rock mass” formed by these fractures (i.e. DB) can be determined via a graphical procedure (Figs. 1 and 2). The five main steps of this procedure are as follows:

Step 1) In order to delineate the discrete blocks (DBs), placing the plane of discontinuities in unit volume according to their space orientation;

Step 2) Removing the surface waste (i.e. the weathered layer that cannot be used for production) from the faces of unit volume;

Step 3) Selecting the extractable blocks of marketable size within each suitable DB and removing them graphically by considering the feasibility of such removal during actual quarry operation;

Step 4) Sizing the marketable blocks of given shape and dimension into each extractable block that is removed in the previous step;

Step 5) Accounting for the unit volume, by considering the amount of each size of marketable blocks and the quarry waste (i.e. all unsuitable DBs, the leftover of the suitable DBs, and the surface waste), and preparing the final mass balance for each UVO, and the quarry.

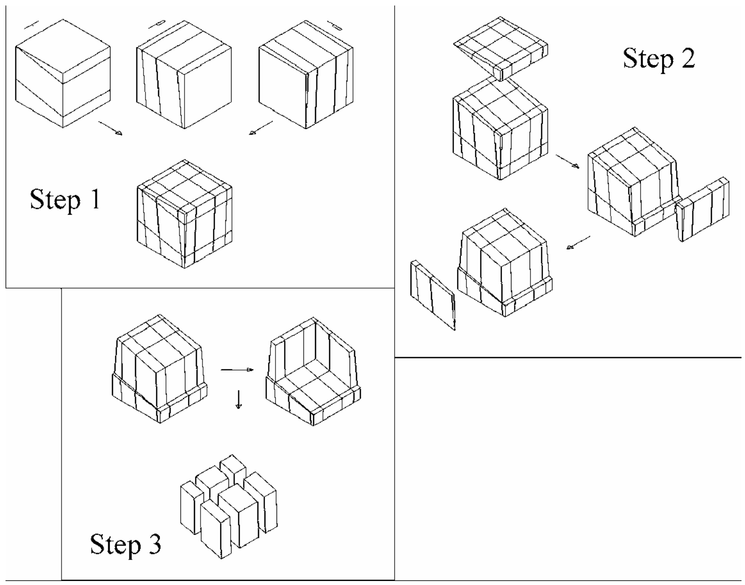

Fig. 1. An example for first three main steps for obtaining extractable blocks graphically [6]

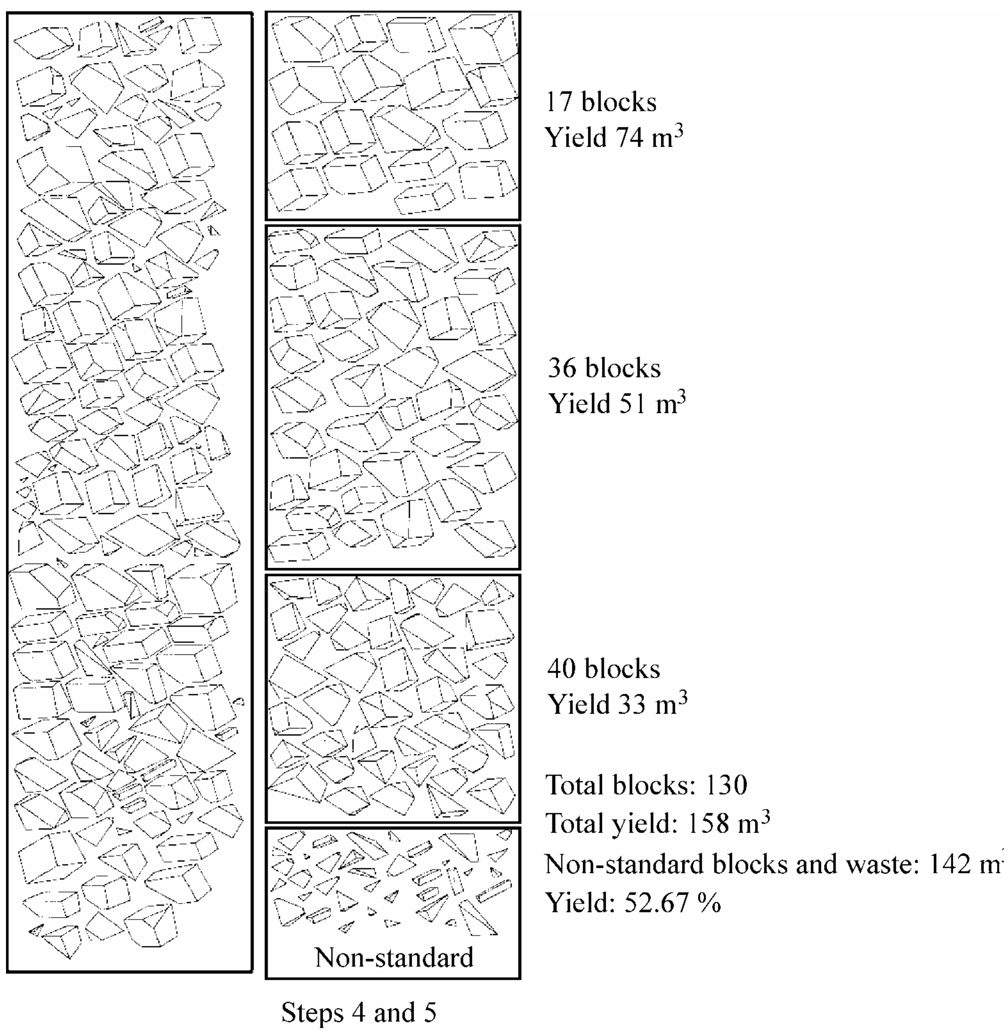

Fig. 2. A real example of sizing the blocks from a total 300 m^3 of projected extraction, according to the marketable blocks of given dimensions and the result of calculation, Bükrüce marble field [7]

This method conceived by the author in 1989 and applied with tedious graphical drafting and calculations carried out with hand calculator. After several of such applications [e.g. 6], a project for developing computer program was started and a proprietary computer software has been developed to aid the consulting work for stone extracting firms. A comprehensive, user-friendly software development is still an ongoing project (information about the software is available from the author).

A REAL-LIFE EXAMPLE

Now, to provide a concrete demonstration of the method, an example of actual marble operation [7] will be presented in brief (Fig. 3). At first stage, the quarry location has been determined: the color map was superimposed upon the multi-category map of the suitable extraction area, and the homogeneous extraction regions called Structural Region (SR) was established within the part covered by green marble, following the mining firm decision. Considering accessibility, ease of operation and potential yield, SR 4 is selected as Operational Target Area (OTA) or quarry locations, and then a more detailed mapping of Sub-SR at 1/100 scale was performed. Finally, UVOs are established upon this map, and within each unit volume of operation (UVO), first each discrete "rock block" (i.e. separable marble mass) were determined by graphical procedure as explained above in steps 1 to 3 (Fig. 1). At last, the number of marketable blocks of each type within DMs (i.e. the separable marble masses of suitable size) were determined and categorized for accounting step. Finally, the yield of each unit volume was calculated (Fig. 2). In practice, the actual result of the quarry operations yielded more blocks than this calculation given in Fig. 2, since the method gives conservative result. The validity and usefulness of the method has been amply demonstrated in practice [6, 7].

When quarries are selected via *ad hoc* procedure, then good sequencing is a matter of luck. The perfect optimization is not possible by the methods using "quasi-grade" for sequencing, either. These methods may reduce the possibility of unpleasant surprises, but do not assure the best solution. Even developing a "yield index" via sophisticated multivariable statistical analysis, which contains stochastic uncertainties, do not provides a good solution. Moreover, combining the stone quality and "rock mass" characteristics as a single index is unwisely and creates possibility of misspecifications. Clearly the stone quality and block size requirements are quite different aspects of the economic outcome of the quarry operation. In fact, the change in the commercial value due to increasing stone quality with decreasing block size (or vice versa), need not be the same as the change in "quasi-grade" calculated by combining variables via statistical techniques. For instance, a very good quality stone with unsuitable block size should not be exploited, but it may have acceptable "quasi-grade" value.

Only the method presented in this paper provides a way free from such uncertainties and makes much better planning a real alternative to current *ad hoc* practice or quasi-index solutions for best sequencing of quarry operation.

The present methodology can be easily applied to any dimension-stone quarry sequencing. Of course, the quarry of different stone may have some peculiarities that should be considered during field data collection. Clearly, error in input data is undesirable (e.g. one less or one extra plane of discontinuities in unit volume might have appreciable consequences), an experience in the field work is needed for obtaining the suitable field data for the application of this method. Of course, improvement in the methods for collection of field data or mapping techniques used in other rock mass studies may be adopted to collect data for quarry sequencing, too.

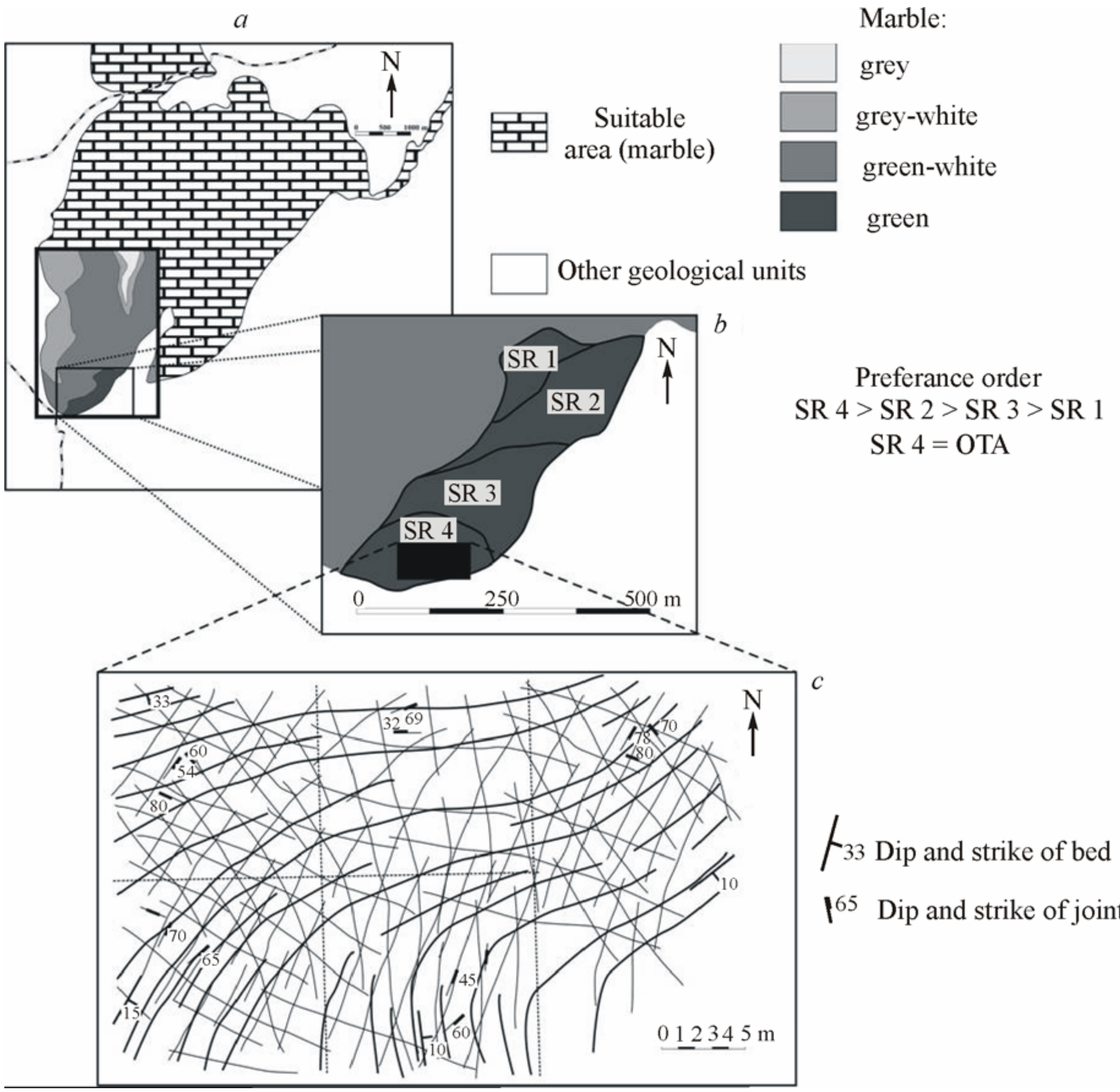

Fig. 3. Main steps for delineating OTA, that will be divided into unit volumes of operation via grid, Bükrüce marble field [7]

CONCLUSIONS

1. The marketable blocks of dimensional stones should satisfy not only stone quality requirements, but also conform to certain dimensional standards.

2. The determination of the actual amount of marketable blocks from each unit volume of operation (UVO) at the dimensional stone quarry can be accomplished by the method presented,

3. The amount of marketable dimensional stones (MDS) provides the best decision variable for planning (i.e. sequencing the operation of unit volumes).

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