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A NEW APPROACH FOR ESTIMATING DISCONTINUITY NETWORK IN ROCK MASS

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Abstract: *It is essential to reveal a rock mass network as realistic as possible for efficient production in natural stone quarries. To create an in-situ rock mass network model, data must first be obtained using one or more robust survey techniques. In addition, it is necessary to use an ideal network model that can reach as many intact blocks as possible that may be encountered in the production sector and even in the next cutting periods with their locations and dimensions. Due to the inhomogeneous and anisotropic structure of the rock mass, numerical and stochastic processes and methods are frequently used to simulate the discontinuity network. These require complex, computationally intensive operations, and the ability to represent the rock mass largely depends on the number and quality of data. In this paper, a practical approach that includes analytical and geometric solution methods for discontinuity network modelling, in which all survey techniques can be used, has been presented. The strategy aims to reflect discontinuities outside the relevant production sector to the rock mass too. Thus, an attempt is made to achieve a realistic rock mass network. The generated model has been tested on samples of highway slope and marble quarry bench, and the results have been presented.*
Keywords: *discontinuity, rock mass, dip/dip direction, field survey, natural stone, deterministic model*

1. Introduction

In natural stone mining, in order to increase economic efficiency, provide a safe working environment and minimize negative environmental effects, detailed on-site analysis of discontinuities before the creation of the rock mass network model is of critical importance. Within rock masses, there are numerous discontinuities of varying sizes characterized by complex and random geometrical features. Discontinuities, a general term for faults, bedding planes, joints, cleavages, foliation, schistosity, etc., are common elements that exist within the rock mass. The presence of these structures has a fundamental role in determining the properties of the rock mass [1, 2, 3]. Discontinuities are the basic elements that affect all the properties of the rock mass classified as geological, physical, mechanical, and hydrogeological. Discontinuity properties are defined according to ISRM [4]. Ten parameters are used for the quantitative characterization of discontinuities in the field. These are orientation, spacing, persistence, roughness, wall strength, aperture, filling, seepage, number of sets, and block size. In practice, orientation is one of the most widely used parameters of rock characterization because it can be directly observed and measured in situ [5].

Revealing the structure of inhomogeneous, anisotropic, and unique rock mass is the most important challenge to be overcome in terms of the safety and success of the next step, the engineering project. The importance of field surveys before the project design to be implemented in the rock mass is also great in termsof the nature of the project. In natural stone quarrying, the collection of data containing location and spatial information of discontinuities is a priority. The cost-effectiveness of extracting commercial blocks from rock reserves depends on several parameters, the most important of which is the network condition of the discontinuities [6-8]. Tercan and Özçelik (2000) [9] emphasised that rock mass with appropriate jointing

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vol. 31, issue 2 / 2025
pp. 38-43

is a mandatory condition for profitable quarrying. This means that extracting the largest intact block from the rock mass is commercially essential.

Unfortunately, insufficient survey methods, mostly based on human foresight cause major resource losses in natural stone quarries. According to Montani (2003) [10], approximately 51% are losses due to properties such as overburden and discontinuity intensity in natural stone deposits. This strikingly demonstrates the importance of field surveys before block production.

Field surveys are indispensable for understanding the nature of the rock mass. However, these studies require a high investment in time and cost and include certain limitations. In addition, measurement of discontinuities, especially on steep slopes, can be both dangerous and time-consuming [11, 12]. Data obtained during field studies cover only the studied areas and may not be representative of the entire rock mass. also stated that results obtained from limited measurement areas may produce incorrect results when generalized to larger areas [13]. The conflicts between discontinuity analysis and their costs often arise from conflicts between short-term budget concerns and long-term safety and quality requirements. Briefly, survey methods are essential for creating a realistic and sufficient network model.

The choice of field study method depends on the project's specific requirements, site conditions, and, of course, the project budget. In general, a model is created using deterministic and stochastic approaches to represent the rock mass. With geometric approaches, discontinuities can be modelled using field observations or measurements as direct data (parameters such as orientations, spacing, and apertures). In addition, the use of technologies such as laser scanning, photogrammetry, and drone-based 3D mapping is also used for direct deterministic processes. With the stochastic approach, the properties of discontinuities are estimated using statistical distributions and probabilities. Generalizations are made about the spatial characteristics of discontinuities by taking samples in the study area. Discrete Fracture Network (DFN) modelling is one example of this method and has recently become widely used in rock engineering applications as a powerful modelling tool. One of the most important reasons for the use of DFN in rock engineering is the unrealistic assumption that discontinuities are present everywhere in the rock mass with infinite length in classical survey methods [14]. Therefore, Salvini et al., (2016) [15] emphasized that stochastic DFN modelling is the best option available. A general comparison of the deterministic and stochastic approaches is presented in Table 1.

Table 1. A general comparison of the deterministic and stochastic approaches

Aplication	Focus	Data Source	Result	Example
Deterministic	Precision and fixed parameters	Field measurements, geological maps	Only single model	Tunnel design, dam foundation, open pit design
Stochastic	Variability and uncertainty	Statistical analysis, discontinuity data	Multi-models and risk analysis	Risk analysis, slope stability, discontinuity network (DFN) modelling

Field surveys used in natural stone production quarries are no different from the methods applied for other rock engineering. When choosing the survey methods, the scope and method of fieldwork should be carefully planned, taking into account the method's advantages and disadvantages and the project's size and requirements. Furthermore, the planning of the economic extraction must be supported by geological studies. A general comparison of this subject is presented in Table 2.

Table 2. Scope-Time-Cost comparison of deterministic and stochastic approaches.

Method	Time	Cost	Scope
Mapping	Medium-High	Low-Medium	Local
Scanline	Medium	Medium	Local
Remote Sensing	Low - Medium	Medium - High	Wide area
Geophysical	Medium- High	High	Deep and wide area
Drilling and Core Logging	High	Very high	Local and deep

One of the main challenges of geomechanically modelling is the gathering and assessment of rock mechanical data. A limited appraisal of a particular site can be made using generic data [16].

In addition, in practical field applications, quantitative descriptions of discontinuity features are mainly obtained by traditional manual measurements. The sample size and accuracy required for the discontinuity parameter study are quite limited, and if subjectivity is included in these studies, biases cannot be avoided, and the reliability of the final model cannot be ensured [17]. From this perspective, the representativeness of the survey methods applied on the rock mass will always be debatable.

vol. 31, issue 2 / 2025
pp. 38-43

In this study, considering the above justifications, a model for generalizing limited field data to a larger scale is proposed and presented in two case studies. The aim is to increase the limited visibility of the rock mass under certain conditions.

2. Methodology

The method includes the geometric orientation of discontinuities and their spatial distribution. In this analysis, the discontinuities have been assumed to be planar and continuous within the rock mass. Detailed information about the methodology of the mentioned model can be found in Turanboy et al., (2019) [18]. In the model, the rock slope or bench to be processed is first defined as representative prisms (RP) (Fig.1).

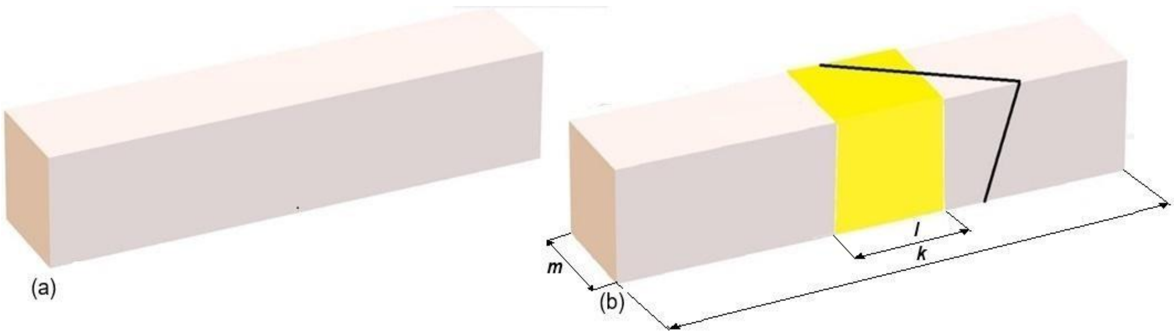

Fig.1. The two RPs used in the model description. a) The RP1 (data is taken throughout the outcrop) b) The RP2 (data is taken throughout the outcrop of yellow mass).

The measured rock mass (RP_1) is represented in Fig. 1a, and the rock mass to be modelled (yellow mass) (RP_2) is represented in Fig. 1b. In Fig. 1b, the trace of a discontinuity (for example, a random discontinuity) that cannot be identified by measurement on the outcrop of RP_2 is also schematized. This discontinuity may be random or may be a member of another set of discontinuities that are not present on the visible surface of the yellow mass and therefore cannot be modelled within the mass by outcrop sampling.

In the study procedure, either the measured area (RP_2) is generalized to a larger (RP_1) scale area or the measurement taken in the RP_1 area is customized to a smaller area and evaluated.

Three basic cases can be explained as follows:

- Case1: Modelling of RP_2 with measurements taken only from the outcrop of RP_2,
- Case2: Measurements made from the entire RP_1 outcrop and displaying the results by customizing them to RP_2,
- Case3: Modelling of RP_2 assuming the measurements taken from RP_2 continue left and right.

Fig. 2 displays the overall plan of the process. Here, examples 1 and 3 are compared using stereo-net and statistical analysis, assuming that the model created using the measurements gathered from the complete outcrop of RP1 is the most realistic.

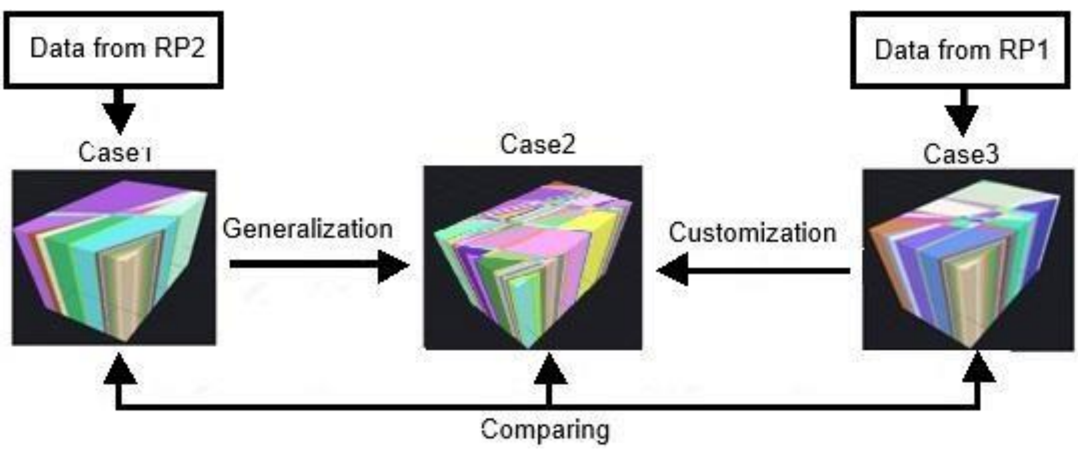

Fig.2. The general scheme of the procedure

Stereonet analysis used in this study is a powerful tool that details the quantitative clustering of discontinuity poles according to the slope and dip direction parameters of the discontinuities in a global projection system. This tool was also used to compare the cases with each other.

 vol. 31, issue 2 / 2025
pp. 38-43

3. Case studies

In this study, a linear line scanline measurement was first applied to a highway slope consisting of bedding limestone formations on the Konya-Antalya highway. The rock slope application aims to obtain higher and more distinct results from the discontinuity density. The results of the stereonet analysis (Fig. 3) obtained from the data and results obtained from cases 1, 2, and 3 are presented. (*k*, *l*, *m*); (12, 40, 10) (m.). *k*, *l*, and *m* dimensions are defined for operations to be performed on RPs.

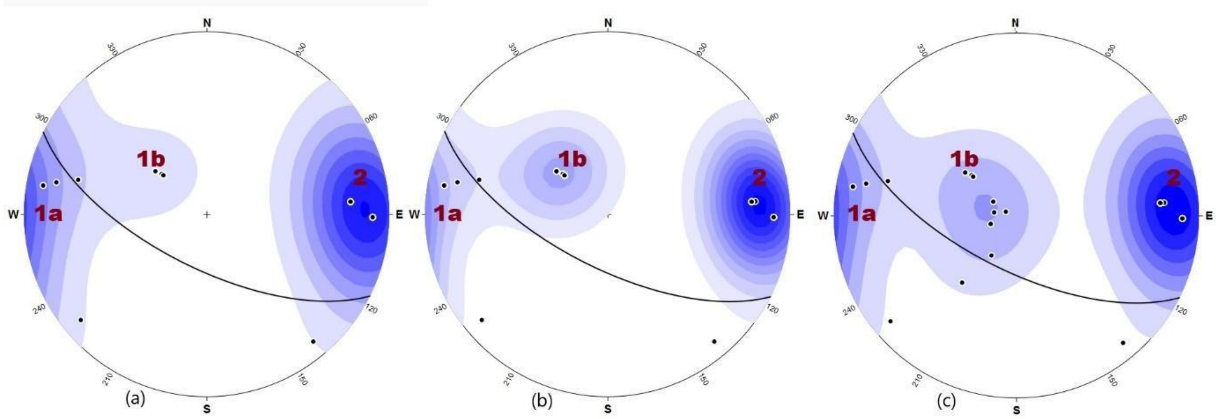

Fig. 3. Stereonet analyses: major sets of discontinuities within the experimental rock slope. Pole plots and their densities: (a) 1st Case; (b) 2nd Case; (c) 3rd Case; counting area: 20,45% of net area, Pole and contour plots were created using the software Stereonet [19]

The second example Stereo diagrams related to discontinuity data obtained from the 2nd. bench of the crystallized limestone production quarry of Ilgın (Konya-Turkey) belonging to Besmar Mining Company. The results of the stereonet analysis (Fig. 4) obtained from the data and results obtained from cases 1, 2, and 3 are presented in the field. (*k*, *l*, *m*) (m.) = (740, 65, 25) each of the crystallized limestone production quarry of Ilgın (Konya-Turkey) belonging to Besmar Mining.

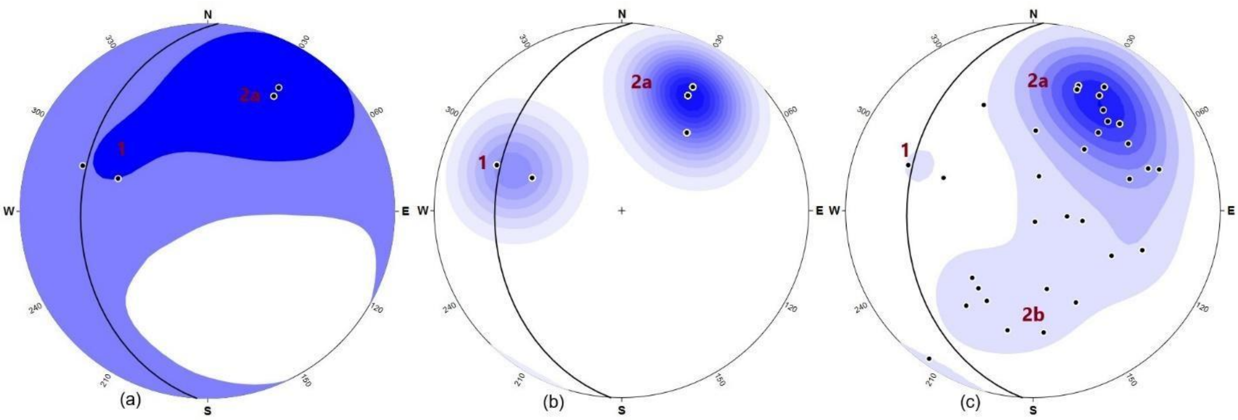

Fig. 4. Stereo-net analyses: major sets of discontinuities within the experimental rock slope. Pole plots and their densities: (a) 1st Case data; (b)2nd Case; (c) 3rd Case; Counting area: 12,16% of net area, Pole and contour plots were created using the software Stereonet [19]

The results prepared according to the data obtained from both fields are presented in Table 3.

Table 3. The results of field data from Seydişehir and Ilgın

Seydişehir RockSlope							**Ilgın Marble 2nd. Bench**						
	Case1		**Case1**		**Case3**			**Case1**		**Case2**		**Case3**	
Sets	**Dip⁰**	**D.dir⁰**	**Dip⁰**	**D.dir⁰**	**Dip⁰**	**D.dir⁰**	**Sets**	**Dip⁰**	**D.dir⁰**	**Dip⁰**	**D.dir⁰**	**Dip⁰**	**D.dir⁰**
1a(Joint)	75	268	76	267	74	268	1a(Joint)	50	111	52	112	56	210
1b(Joint)	29	119	28	130	14	105	1b(Joint)	63	206	62	209	57	212
2(Bedding)	87	98	87	93	89	98	2(Bedding)			45		24	
Number of disc.	29		50		40		Number of disc.	6		67		57	
Slope	66		207				Slope	33		278			

vol. 31, issue 2 / 2025
pp. 38-43

4. Conclusion

Time, cost, environmental sensitivity, work safety, legal sanctions and the desire for high efficiency necessitate optimization in both the production phase and the selection of field research methods. Governments and EU restrictions on environmental problems also necessitate the optimization of technological research methods.

In this study, a geometric approach is presented in terms of generalization and customization of the data obtained from the field with non-destructive survey methods. The new situations have been evaluated by including the discontinuities that are not measured but may be found in the rock mass on which excavation / cutting will be done. In addition, it was investigated whether the field data obtained from a small surface area can be generalized quantitatively to a large-scale rock mass in an optimum way.

The study results can be evaluated as follows,

1. As seen in both examples, modelling a small rock mass (RP2) with samples taken from its surface and generalizing this to a larger-scale rock mass (RP1) can lead to errors.
2. It is seen that missing data will be provided when only the measurement area is taken into account in creating the rock mass network model (Case1).
3. According to the results, more convergence has been achieved in the area reduced to a narrower area with data taken from the entire surface area.
4. Undoubtedly, the generalization application (Case2) will decrease in proportion to the tectonism that the environment has undergone.
5. In addition, customization (Case3) will make it more rational to represent the spatial distribution and density of the rock mass discontinuities.
6. According to the results, more convergence was achieved in the area reduced to a narrower area with data taken from the entire surface area.
7. The dimensions k, l and m define the 3D scale of the RP in the model. Discontinuity density, the presence of random discontinuity(ies) and the number of clusters are related to these dimensions.
8. The approach can be considered a useful tool in applications such as data preparation, evaluation, and the generation of models for rock mass networks. However, the model's use will be limited by the size of the field scale and the tectonism that has already taken place in the field.
9. Moreover, it is also versatile enough to be valid for all survey method(s) applied in the field. Especially in detailed pre-DFN applications, Cases 2 and 3 will contribute to the verification and realism of the final network model.
10. The model can support planning strategies for the rock pits' next hypothetical cutting or excavation sector(s).

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vol. 31, issue 2 / 2025
pp. 38-43

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