Marko Mitrović*, Dragan Ignjatović*, Lidija Ignjatović*, Saša Stepanović*

POSSIBILITY OF APPLICATION THE STATISTICAL METHODS IN DEFINING THE ENGINEERING GEOLOGICAL COMPLEXES**

Abstract

This work presents the procedure of applying the statistical analysis methods for the needs of defining the engineering-geological complexes in the structurally complex geological conditions on the example of working environment of the open pit Gacko – Central Field. The open pits represent the exploitation objects explored over a longer period of time using the different exploration methods, in varying degrees and with different reliability, and the question of selecting the relevant values of investigated parameters is usually a complex task and crucial from the aspect of construction the exploitation objects. For the purposes of forming an open pit and determining its geometric parameters, inclination and height of the final, the system of working and general slopes and slopes of levels; a good knowledge of the basic physical-mechanical parameters of the working environment, and their values for characteristic separated units – the engineering-geological complexes is necessary. In order to present the working environment of the open pit as realistic as possible, and in the process of defining and limiting the engineering-geological complexes within a complex, only those lithological-structural units of similar engineering-geological parameters can be found, it is possible to apply the methods of statistical result analysis of geomechanical data research. The results of this analysis, in addition to the other relevant parameters of the working environment, can facilitate the separation process of characteristic geomechanical units, and enable the formation of a more precise engineering-geological model of the open pit area.

Keywords: open pit exploitation, working environment, geotechnical parameters, slope stability

1 INTRODUCTION

The open pit mining takes place at the open pits representing the objects of exploitation, characterized by their constructive parameters, such as the height and angle of the final, system of working and working slopes of the individual levels and width of horizontal parts between the pit slopes and berms. Slopes of the open pit (working and final) are formed in different materials,

structural - geological environments, collectively referred to the working environment. The basic parameters of the working environment that influence the geometric parameters of the open pit are the volume mass and parameters of material strength (pressure and tensile strength, angle of internal friction, cohesion, modulus of elasticity, etc.).

* Mining and Metallurgy Institute, Zeleni bulevar 35, Bor, e-mail: marko.mitrovic@irmbor.co.rs

** This work is the result from the Science Project TR. 33021 "Investigation and Monitoring the Changes of the Stress Deformation State in the Rock Massif "IN SITU" Around the Underground Rooms with Development a Model with a Special Reference to the Tunnel of the Krivelj River and Underground Mine Jama Bor" and TR33023 "Development of Technologies for Flotation Processing the Copper Ore and Precious Metals to Achieve Better Technological Results ", funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia

The structural parameters of the open pit must be such as to ensure the safe and economic exploitation of mineral resources. Even a slight decrease in the inclination angle of final slopes of the open pit regarding to the depth and size of the area in which the exploitation is carried out, can significantly increase the quantities of excavated waste masses, the order of millions of m³, and significantly affect the economy of exploitation. On the other hand, any increase of the inclination angles of final slopes of the open pit decreases the safety factor of the open pit slope, minimizing the safety of objects, equipment and people at the open pit. Due to these reasons, in adopting the structural parameters of the open pit, the slope stability requirements, in the relevant regulations applicable in the field of open pit exploitation of mineral resources, must be met.

Physical-mechanical characteristics of the working environment, as a rule, are very variable in space, and one of the basic tasks of the experts dealing with this issue (geologists, geotechnicians, construction and mining engineers) is to identify the characteristic units, engineering - geological complexes, which are characterized by similar physical-mechanical parameters, and in that way to perform the required simplification of the problem of determining the stability degree of the open pit slopes [5, 6].

The values of the physical - mechanical parameters of the engineering-geological complexes are adopted with the appropriate reliability, which is also prescribed by the regulations in the field of mining.

In the previous practice, the definition of engineering-geological units within the area of the open pit, or wider area of the mineral resource deposit, has often been reduced to the recognition of the present structural units (for example, clay, sand, silt, loess, marl,

limestone, etc.) and the engineering - geological complexes, as a rule, coincided with the structural complexes. In the real situations, solving this issue is significantly more complex.

For the analyzed example of the working environment at the open pit Gacko, the phenomenon of marls in the overburden of coal seam is characterized by a wide range and great variability of the physical - mechanical parameters. For this reason, application of the method of statistical analysis, using the tests of determined the relevant physical - mechanical parameters, can be very useful in solving the problem of defining the engineering - geological complexes and determining the reliability degree of adopted values.

2 GEOTECHNICAL CHARACTERISTICS OF LITHOLOGICAL UNITS IN THE AREA OF THE FIELD C OF THE COAL BASIN GACKO

During the previous development of coal exploitation in the Gacko basin, the studies of physical and mechanical parameters of sediment overburden, tailings and coal were carried out repeatedly and over a longer period of time. The basic method of research is deep exploration drilling, and from the core of the wells samples for geomechanical laboratory tests were derived. In the course of the research, recognitions of certain structural units (clay, marl, sand, etc.) were carried out, and sampling was attempted to provide the sufficient number of tests from all geological - structural units [1, 4].

Using the laboratory-determined values of physical - mechanical parameters on individual samples, and in accordance with the other characteristics (chemical and mineral composition, color, appearance of fractures,

etc.), the certain engineering - geological complexes have been defined.

Considering the number of geological structures, the scope of tests and extent of their representation, a concrete example of determining the relevant parameters was made for the working environments Ng8 and Ng7, which are mostly represented in the roof of coal seam. The seams marked by Ng8 and Ng7, according to their mineral composition, are marls, and these units are derived from the spatial superposition. Both environments are complex seams in which clayey, sandy, coal and tuffitic marls are separated [2].

For different types of marl, the statistical processing of laboratory-determined values of physical-mechanical parameters was performed in order to define the engineering-geological complexes

Within the geological explorations, carried out in the previous period, from designed drill holes for engineering-geological and geomechanical needs, the physical-mechanical properties of the wall masses of the neogene series as a whole, as well as the seams, were tested on taken samples that are the subject of this paper. The division was according to the parameters of uniaxial pressure strength, bulk density and other characteristic properties. According to Skoković R., the division was made into eight lithological complexes (Table 2) or by Ćimić S., into five categories (Table 1) [2,3].

The latest research of the physical-mechanical properties of the Gacko coal basin sediments dated from 2005 to 2012. By analysis and statistical analysis of the available parameters including the previous tests of physical - mechanical properties and geomechanical tests on samples from exploratory geotechnical drill holes, carried out

in 2005, 2011 and 2012, as well as the results of laboratory geomechanical tests on samples, the review Table 3 was formed. It presents the parameters used to analyze the stability by lithological members within the most common lithogenic units for a part of the Central Field.

By analyzing and insight into the existing geological documentation, it is noticeable that the degree of exploration and geological data interpretation, both from the aspect of the raw material base of coal and its quality, and the aspect of hydrogeological and geotechnical parameters in the rest of the Central, East and South exploitation fields, is only partially sufficient (in the zones where the exploration drill holes are denser) for the needs of design at the level of technical projects.

The values of engineering-geological parameters, used for calculating the stability of the slopes of the open pit and landfills were adopted on the basis on the results of geotechnical explorations, given in:

1. Elaborate on the Research Results of the Southern Rim of OP "Gračanica" Gacko, Geoinženjering, Sarajevo 1986.
2. Elaborate on the Results of Detailed Geological, Hydrogeological and Engineering - Geological Exploration of the Transition Area Between the OP "Gračanica" and Future OP "Gacko", Book IV - Engineering-Geological Part, Republic Institute for Geological Explorations, Zvornik, 2006, and
3. Final Report on Performed Detailed Engineering-Geological and Geomechanical Investigations and Tests of the Central Field at the Open Pit, Geoinj Group, Belgrade, 2012.

Figure 1 Schedule of geomechanical drill holes, developed in 2005 and 2011-12 in the area of Field C

The exploration results, i.e. the values of: bulk density, compressive strength, angle of internal friction and cohesion were statistically processed and analyzed for the needs of classification into the individual complexes and calculation the factor of slope stability. Taking into account the available data, exploration degree of the deposit in terms of knowing the engineering-geological characteristics of the deposit, and reserve categorization of the deposits of the Central Field of the Gacko coal basin, the minimum values of compressive strength, angle of internal friction and cohesion with reliability of 80 % were adopted for calculation the slope stability of the open pit Gacko, while the maximum value with the same reliability was adopted for the value of bulk density [1].

Statistical processing was performed for characteristic examples of structural-geological and, at the same time, engineering-geological complexes of marls, designed

as ^8Ng and ^7Ng in the unique geological nomenclature for this deposit. These two complex engineering-geological units (complexes) are most represented in the geological structure of deposit.

The complex of overlying Neogene sediments is presented by marly limestones, sandy marls, sandy belt marls, marls and clayey marls within the complex ^8Ng , and gray limestone marlsand marl, coal tuffitic marls and belt marls within the complex ^7Ng [2, 3].

2 STATISTICAL PROCESSING OF AVAILABLE DATA FOR THE NEEDS OF IDENTIFICATION THE ENGINEERING-GEOLOGICAL COMPLEXES

Over the set of available values for parameters: the bulk density γ_z (kN/m^3), compressive strength σ_p (MPa), internal friction angle φ ($^\circ$) and cohesion c (MPa) by indi-

vidual lithological units, a statistical analysis was carried out, and the following parameters were determined:

1. Arithmetical mean,
2. Mediana,
3. Standard deviation,
4. No. of samples,

5. Minimum,
6. Maximum,
7. I quartile,
8. III quartile.

The results of statistical processing by individual lithostratigraphic units are given in Table 1.

Table 1 Statistical parameters of the values of the basic physical - mechanical parameters

Layer	Lithological member	Parameter	Arithmetic mean	Mediana	Standard deviation	No. of samples	Min	Max	I quartile	III quartile
N8	Marly limestone	Bulk density γ_z (kN/m ³)	21.74	21.825	0.940	100	19.39	23.53	21.21	22.37
		Pressure strength σ_p (MPa)	6.00	5.8	2.319	98	1.65	11.25	4.28	7.23
		Angle of internal friction ϕ (°)	36.68	38	4.938	100	26	48	32	40
		Cohesion c (MPa)	1.51	1.43	0.579	92	0.41	3.3	1.11	1.85
	Sandy marls	Bulk density γ_z (kN/m ³)	19.88	20.2	1.280	65	16.84	21.77	19.12	20.89
		Pressure strength σ_p (MPa)	2.79	2.7	1.138	67	0.61	5.89	1.92	3.5
		Angle of internal friction ϕ (°)	32.45	33	4.524	67	20	44	30	34
		Cohesion c (MPa)	0.75	0.74	0.288	67	0.2	1.36	0.5	0.95
	Sandy stripped marls	Bulk density γ_z (kN/m ³)	17.28	17.85	2.579	25	12.36	20.89	15.89	19.42
		Pressure strength σ_p (MPa)	3.09	2.8	1.232	23	1.43	5.77	2.14	3.85
		Angle of internal friction ϕ (°)	33.56	34	4.698	25	23	40	30	37
		Cohesion c (MPa)	0.82	0.7	0.326	23	0.42	1.4	0.55	1.15
	Marls	Bulk density γ_z (kN/m ³)	20.15	20.14	1.263	53	17.77	22.26	19.03	21.09
		Pressure strength σ_p (MPa)	3.60	3.5	1.562	52	1.5	8.65	2.69	4.34
		Angle of internal friction ϕ (°)	33.39	32	6.693	53	21	46	28	38
		Cohesion c (MPa)	0.95	0.92	0.369	53	0.42	2.1	0.75	1.1
	Clayey marls	Bulk density γ_z (kN/m ³)	20.94	21.47	1.242	29	18.34	22.63	19.91	21.67
		Pressure strength σ_p (MPa)	2.20	2.08	0.943	29	0.9	4.19	1.55	2.8
		Angle of internal friction ϕ (°)	28.16	25	7.040	25	18	44	23	34
		Cohesion c (MPa)	0.67	0.57	0.248	23	0.38	1.17	0.48	0.92

N7	Grey limestone marls	Bulk density γ_z (kN/m ³)	18.54	18.54	0.711	28	17.36	20.22	18.04	19.03
		Pressure strength σ_p (MPa)	4.80	4.3	1.336	26	3.1	6.8	3.5	6.23
		Angle of internal friction φ (°)	33.69	33.5	5.744	32	19	42	32	37.5
		Cohesion c (MPa)	1.24	1.1	0.360	30	0.72	1.85	0.95	1.5
	Stripped marls	Bulk density γ_z (kN/m ³)	17.37	17.55	0.843	13	16.48	18.73	16.57	17.55
		Pressure strength σ_p (MPa)	3.91	4.4	1.288	11	2.4	5.63	2.51	4.86
		Angle of internal friction φ (°)	32.77	32	5.480	13	26	40	28	38
		Cohesion c (MPa)	0.94	0.71	0.396	7	0.65	1.75	0.69	1.1
	Coal and tuffitic marls	Bulk density γ_z (kN/m ³)	16.90	16.73	0.803	13	15.46	17.85	16.57	17.75
		Pressure strength σ_p (MPa)	2.17	2.14	0.610	11	1.4	3.23	1.8	2.27
		Angle of internal friction φ (°)	33.85	39	7.701	13	22	44	27	40
		Cohesion c (MPa)	0.77	0.75	0.246	13	0.35	1.05	0.74	0.95

Distribution the values of physical-mechanical parameters of the analyzed lithological members is shown in a form of histogram in Figures 2 to 5. In addition to the histogram columns, a normal distribution curve is also given. Although this distribution in principle does not correspond to the distribution of values of the analyzed parameters, it was used to make easier to see the boundaries of the value expansion, and the mean arithmetic value

of the parameters on diagrams. Markings on the diagrams in Figures 2 to 4 are: LK - marly limestone of the complex ⁸Ng, PL - sandy marls of the complex ⁸Ng, PTL- sandy belt marls of the complex ⁸Ng, L- marls of the complex ⁸Ng, GL – clayey marls of the complex ⁸Ng, SKL-N7 - gray limestone marls of the complex ⁷Ng, TL – belt marls of the complex ⁷Ng complex, UTL - coal and tuffitic marl of the complex ⁷Ng.

Figure 2 Distribution the value of bulk density γ_z (kN/m³)

Figure 3 Distribution the value of pressure strength σ_p (MPa)

Figure 4 Distribution the value of internal friction angle φ (°)

Figure 5 Distribution the value of cohesion c (MPa)

Comparing the obtained values of statistical indicators for some lithological members, it is possible to classify them into wider groups, that is the engineering - geological complexes. On the basis of carried out analysis, it can be concluded that the lithological structures of marly limestones and sandy marls, which, besides others, construct a complex of Neogenic sediments, ⁸Ng, are determined according to their strength parameters, and that the separation of these structural units into the separate engineering-geological complexes can be considered. In addition to the above analysis, it is necessary to consider the structural - geological characteristics of the separated lithological units, continuity of expansion, quantity of participation in the total masses and other relevant characteristics in further consideration the physical - mechanical characteristics of the working environment of the open pit Gacko-Central Field.

The importance of proper classification into some complexes is in fact that a characteristic value of the physical – mechanical parameters, such as the angle of internal friction or cohesion is used in forming the geomechanical model of deposit and calculations the safety factor of slopes for the open pit. This simplification is due to a degree of exploration of the working environment and requirements to determine the characteristic quantities of parameters of certain, clearly limited, complexes for the needs of formation an engineering - geological model. This type of analysis allows better understanding o the variability of physical - mechanical parameters and reduces the possibility of finding the geological structures within the same complex with significantly different parameter values.

CONCLUSION

In the phase of exploration and testing of deposit and design of works at the open pit, one of the important issues is to determine the representative parameters of the working environment in which the future exploitation

works will be carried out. The basic requirement is that the designed works can be performed safely and economically. These two requirements are most often opposed to one another. i.e. increasing the security of works as a rule increases the costs of exploitation and vice versa, increasing the economy is ensured by reduction the safety of works.

Defining the geometric parameters of the open pit is carried out using the appropriate geomechanical methods of calculating the stability factor for which the successful application and validity of the obtained results are necessary to dispose of the relevant input data, above all data on the parameters of material strength and bulk density.

In every consideration of the working environment of the open pit, it is necessary to carry out the appropriate separation of characteristic units by their mineralogical, hydrogeological, engineering-geological and other parameters, in order to show the real space of the deposit in which the exploitation object is formed in a manner suitable for formation the appropriate model and design. These units, complexes, are most often represented by the sets of several lithological units that have similar characteristics and behavior, or close values of parameters. In geomechanical term, these complexes, for the purposes of designing the geometric parameters of the open pit, are often the unique values of parameter (for example, compressive strength, cohesion, angle of internal friction, etc.).

The results of statistical analysis of geomechanical parameters, in the case of a satisfactory scope of data, can be a clear indicator for defining which lithological unit can be classified into a common engineering-geological complex. In addition to this analysis, in order to create as realistic as possible the image of the space, it is necessary to examine the other parameters (mineral and chemical composition, hydrogeological characteristics, etc.) that can be of importance for the analysis of engineering-geological processes in the exploitation conditions and in the real space of the open pit.

Correct defining the engineering - geological complexes and selection of representative values the engineering-geological characteristics within them, based on the conducted statistical analysis, must ensure the rational values of parameters and measure of their reliability.

By implementation the shown statistical processing, these two goals are achieved. The results of analysis serve as an evidence of fulfillment the required conditions (the prescribed degree of data reliability), and the adopted values, or their selection from the set by measurement the established parameters are clear for the next processors (geotechnicians, geomechanics, mining engineers, etc.).

REFERENCES

- [1] Strategy of Mining - Technological Opening, Development, Optimization and Maintenance the Continuity of Coal Production With Introduction the Coal Enrichment Process of Dry Separation at the OP - Gacko; MMI Bor, 2015 (in Serbian)
- [2] Elaborate on Coal Reserves in the Deposit Gacko with the State of June 30, 2012; "GEOING GROUP" doo. Belgrade, 2012 (in Serbian)
- [3] Final Report on Performed Detailed Engineering - Geological and Geomechanical Investigations and Tests of the Central Field at the Open Pit Gacko; "GEOING GROUP" doo. Belgrade, 2012 (in Serbian)
- [4] Simplified Mining Design for Exploitation a Part of the Field "C" with the Expansion of the Existing Front of Works in the Southern Part and Part of the Roof Coal ("Elevated Zone") of the Open Pit "Gračanica" - Gacko; MMI Bor, Zvornik; 2015 (in Serbian)
- [5] D. Ignjatovic, L. Dj. Ignjatovic, D. Tasic, M. Ljubojev, Landfill stability analysis at the open pit „Gacko“, Bosnia and Herzegovina – Republic of Srpska, Mining and Metallurgy Engineering Bor, 3-4/2017, pp. 149-154
- [6] D. Ignjatovic, L. Dj. Ignjatovic, M. Ljubojev, D. Zlatanovic, Analysis and relationship of safety coefficient (F_s) and critical factor of influence the stress reduction (SRF) in the case of external waste dump of the east waste dump – profile III-III open pit „Gacko“, Gacko, Mining and Metallurgy Engineering Bor, 1/2015, pp. 17-26