

Review article

UDK 622.274.5:622.33.013(497.11)

DOI: 10.7251/afts.2020.1223.037T

COBISS.RS-ID 129653761

THE PHYSICAL-MECHANICAL CHARACTERISTICS OF COAL SEAMS OF IMMEDIATE FLOOR AND ROOF INFLUENCES ON THE CHOICE OF EXCAVATION SYSTEM IN THE COAL DEPOSITS IN SERBIA

Trivan Jelena¹, Tošić Dražena¹, Todorović Vladimir²

¹University of Banja Luka, Faculty of Mining Prijedor, Bosnia and Herzegovina,
e. mail: jelena.trivan@rf.unibl.org

²JP PEU Resavica, Serbia

ABSTRACT

The physical and mechanical characteristics of coal seams, immediate floor and roof significantly influence to the choice of systems (the methods and technologies) of coal underground exploitation, and in this paper, their grouping and sorting by importance for the conditions of active underground mines in Serbia was carried out. The research is based on the results of laboratory tests performed in all mines, on the basis of which individual parameters were evaluated. The results of the research proved the complexity of the choice of excavation system in the specific conditions and individual limitations.

Keywords: *coal, excavation method, excavation technology, physical and mechanical properties, coal seam.*

INTRODUCTION

When choosing a rational system of underground excavation of coal seams, the physical-mechanical characteristics of the immediate floor, coal seams and the immediate roof play a significant role. Physical-mechanical characteristics represent a segment of the natural-geological conditions, which also includes basic geological conditions, natural and structural conditions. The subject of research within this paper are coal mines with underground exploitation in Serbia, which operate within the JP PEU Resavica, in order to more explain the impact of natural and geological conditions on the choice of coal mining system.

The question of the rank of the influence of natural-geological conditions comprehensively and especially of physical-mechanical characteristics is a complex question in the field of underground coal exploitation and in this paper a review of this question is given. Numerous project and technical documentation was used for a more complete understanding of the topic that is being processed, and especially the studies and elaborations in the field of geology, geomechanics and coal reserves in the deposits of the JP PEU-Resavica mine.

An unavoidable factor in the success of the topic processing is the long-term work experience in the operational work of technical management of the mine.

ANALYSIS OF EXPLOITATION CONDITIONS IN THE MINES OF JP PEU RESAVICA

All active underground coal mines in Serbia operate within the unique economic system of JP PEU Resavica, and now there are 8 active mines in exploitation, in which bituminous and brown coal and lignite are exploited. Within the conducted research, data on natural-geological conditions in coal deposits were collected and processed on the basis of which conclusions were formed on this paper:

- coal seams are mostly complex structures, most often of variable thickness varying from 1m to 40m
- in almost all deposits there is a pronounced micro and macro tectonics which formed the fields of excavation and excavation blocks of irregular shape and relatively small dimensions,
- coal deposits are mostly moderately and in some mines steeply inclined (Soko, Ibarski rudnici, Vrška Čuka)
- most of the mines belong to the group of mines with an average depth of exploitation of about 350 m, except for the mines Soko, Strmosten and Jarando
- pronounced tendency of coal to self-ignite in frequent pit endogenous fires,
- explosive and flammable characteristics of coal dust
- in the deposits of the mines Vrška Čuka, Ibarski rudnici, Rembas (pit Jelovac) and Soko there are methane phenomena and in the Soko mine there are also expansions of gas and materials
- the stability of mining rooms is within wide limits, depending on the working environment, which requires appropriate security and support systems, and the general characteristic is the high ratio of reconstruction works in the rooms
- explosive and flammable characteristics of coal dust
- in terms of water bearing all deposits, except for the deposits of the Štavalj mine, belong to the group of mines with a water inflow of less than 1 m³/min, i.e. to the group of poorly hydrated mines

According to the research, the natural-geological conditions are classified into:

- the basic geological conditions of the deposit
- the natural geological conditions in the deposit
- physical and mechanical characteristics of coal and surrounding rocks
- the structure of coal seams

Table 1 shows the categorization (rank) of the influence of certain natural-geological conditions on the choice of the excavation system [1].

According to their influence, the conditions are grouped into the following:

Group I-determining conditions are those that represent the basic condition for the application of the appropriate principle of concentration, method and technology of excavation.

Group II-additional conditions are natural-geological conditions that require periodically technical measures to eliminate their negative manifestation in the applied excavation system.

Group III-restrictive conditions are those conditions that limit the application of technological solutions of excavation systems and affect the technical and economic effects and are characterized by the need to take the systematic technical measures to reduce or eliminate their negative manifestations.

Group IV-exclusive conditions, represent a group of conditions that exclude the application of certain technological solutions of the excavation system.

Table 1. Categorization (rank) of the influence of the natural-geological conditions on the choice of the excavation system

Excavation system		CATEGORY-RANK OF INFLUENCE OF NATURAL-GEOLOGICAL CONDITIONS			
		I Determining	II Additional	III Limiting	IV Exclusive
Principle of excavation concentration	HK	1. Layer thickness up to 5	1. Dip angle	1. Rock burst 2. Gas and material expansion	1. Layer thickness less than 5m
	VK	2. Layer thickness over 5 m	1. Dip angle	2. Tendency to coal self- ignition	1. Irrational length of the excavation field to strike and dip
METHOD OF EXCAVATION	Longwall Mining (HK)	1. Layer thickness up to 5m 2. Rational length of the excavation field to strike and dip	1. Dip angle 2. Physical and mechanical characteristics of the coal seam and surrounding rocks	1. High methane content 2. The size of coal reserves 3. Physical and mechanical characteristics of the floor	1. Irrational length of the excavation field to strike and dip
	Longwall Mining (VK)	1. Layer thickness over 5 m 2. Rational length of the excavation field to strike and dip	1. Dip angle 2. Physical and mechanical characteristics of the coal seam and surrounding rocks	1. Abundant in water 2. Tendency to coal self- ignition 3. High methane content 4. Size of coal reserves	1. Irrational length of the excavation field to strike and dip
	Room method	1. Layer thickness over 5 m 2. Strength and compactness of immediate roof	1. Changes in layer thickness and slope	1. Dip angle 2. High methane content 3. Tendency to coal self- ignition	1. Unfavorable size of strength and roof compactness
	Pillar method	1. Layer thickness over 5 m 2. Rational length of the excavation field to strike and dip	1. Dip angle 2. Physical and mechanical characteristics of the coal seam and surrounding rocks	1. Dip angle 2. High methane content 3. Tendency to coal self- ignition 4. Rock burst	
TECHNOLOGY OF EXCAVATION	Blasting	1. Physical and mechanical characteristics of the coal seam	1. Coal seam thickness	1. Dip angle 2. High methane content 3. Coal seam structure	According to the chosen principle and method of excavation and determining factors, the appropriate excavation technology is selected (alternative combination of two or more technologies)
	Under-cutting	1. Physical and mechanical characteristics of the coal seam	1. Coal seam thickness	1. Coal seam structure	
	Ploughing	1. Physical and mechanical characteristics of the coal seam 2. Layer thickness	1. Physical and mechanical characteristics of floor	1. Coal seam structure	
	Cutting	1. Physical and mechanical characteristics of the coal seam	1. Dip angle 2. Physical and mechanical characteristics of floor	1. Dip angle over 25 2. Coal seam structure	
	Hydro cutting	1. Physical and mechanical characteristics of the coal seam		1. Expresses tendency to coal self- ignition	

APPLIED EXCAVATION SYSTEMS IN JP PEU MINES

The technological process of excavation, i.e. the excavation system, is the basic phase of the exploitation process and affects the other phases that are adapted to it.

Practically, the system of excavation of a mining facility and the model of development and preparation depends on the method of excavation, which is also the main influencing factor on the safety, technical and economic efficiency of the exploitation process [2].

In different natural-geological conditions of coal deposits of mines with underground exploitation in Serbia, numerous technical-technological solutions were applied, depending on the conditions and degree of industrial development [3]. The complex natural-geological conditions have influenced the choice of technological solutions for the system of excavation of coal seams, so that today in all underground mines, only pillar and room excavation methods are applied in different variants.

The method of longwall mechanized excavation was used for a shorter time in the Rembas mines (Jelovac, Strmosten, Senjski rudnik) and Bogovina mine (Istočno polje), with different success, but it is evident that the production results exceeded those achieved by using pillar and room excavation units [4]. Pillar and room excavation methods in the mines of JP PEU are characterized by the following:

- wide application due to the great possibility of adapting the excavation geometry and excavation tactics in complex excavation conditions,
- low degree of mechanization,
- high ratio of mining preparatory works,
- low production capacity and low productivity, and
- relatively low coefficient of coal reserves recovery.

An overview of the applied excavation methods in the mines of JP PEU in the last 30 years is given in Table 2.

Table 2. Method of excavation in the mines of JP PEU (in the last 30 years)

METHOD AND TECHNOLOGY OF EXCAVATION	MINE
Pillar methods with inclined and lateral excavation, in variants V and G with the application of the technology by blasting the undermining and overburden part	Vrška Čuka, Ibarski rudnici, Rembas, Soko Bogovina, Štavalj, Jasenovac
T method of excavating pillars with blasting technology	Lubnica
Room excavation method with coal roof collapse and roof caving	Štavalj, Soko
Longwall method of excavation with complex mechanization	Rembas, Bogovina

INFLUENCE OF PHYSICAL-MECHANICAL CHARACTERISTICS OF THE WORKING ENVIRONMENT ON THE CHOICE OF EXCAVATION SYSTEM

Only on the basis of research and testing the conditions of excavation can be defined and the manner of manifestation of the selected technological process on the working environment determined.

The characteristics and composition of the immediate floor and roof and the coal seam are important for the modeling and calculation of the caving mechanism during the excavation process [5].

The composition of the basic and immediate roof, compactness, consistency, humidity and strength are the influential conditions for the choice of the method of supporting both the excavation and the mining rooms.

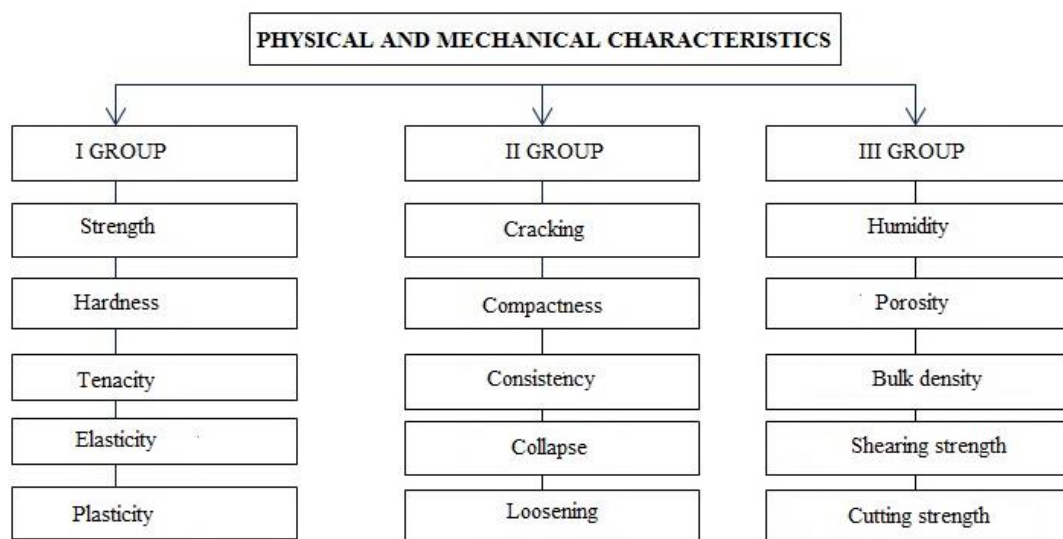
The process of the immediate roof caving depends on the petrographic composition, interlayers and poorly bonded materials, network and crack density, compactness, humidity and applied technical-technological solutions for excavation and roof control [2,6].

The immediate floor, with its physical and mechanical characteristics conditions the technical solutions of the excavation.

The non-compact, clayed, sandy and clayed-marly immediate floor causes intensive floor pressures, volume increase, slipping and sinking of the excavation support [1]. For the choice of the support type in the methods of longwall mining, and applied mechanization in pillar and room excavations, the parameters of the floor rocks are important: compactness, consistency, influence of moisture and bearing capacity [7].

Table 3. presents the physical and mechanical characteristics of the floor, layer and roof, systematized by importance for the selection of the excavation system, based on the research conducted during the processing of this paper.

Table 3. Physical and mechanical characteristics of the working environment systematized by importance for the selection of the excavation system [3]



The first group of characteristics includes the following: strength, hardness, toughness, elasticity and plasticity with the following effects:

- Strength represents the ability of coal and rocks to resist the action of external forces, and there is a difference between compressive strength and tensile strength. It is determined by laboratory testing of samples, and on the basis of strength, the angle of internal friction and cohesion is determined, and the analysis of stress and deformation characteristics is performed with these parameters.
- Hardness is a characteristic of the working environment to resist penetration, and during excavation it affects the drilling and blasting operations and the choice of equipment for cutting, scraping, loading and transport.
- Toughness is the ability of the working environment to provide resistance when cutting pieces in the massif and influences the choice of technological schemes of blasting and the choice of mechanization technology.
- Elasticity is determined in the laboratory, as the modulus of elasticity (tangential and secant) which defines the deformability of rocks. The modulus of elasticity is an important parameter in the calculations of blasting, stability and deformability.
- Plasticity is a characteristic of the working environment to change the shape under the external forces and it is used when considering the technological procedures for excavation and in choosing the support.

The second group of characteristics includes: cracking, consistency, caving and looseness.

- Cracking is a characteristic of the working environment to create systems of cracks and fissures, and the stability of the working environment depends on this characteristic.
- Consistency is determined by basic characteristics and by this the rocks are classified into hard, plastic, loose and liquid.
- Caving is the characteristic of the working environment to collapse under the influence of various loads, and depends on cracking, hardness, cohesive connections of the contact surfaces and dimensions of open surfaces, and affects the process of roof controlling and support of excavation.
- Looseness is determined by the looseness coefficient and it is a characteristic of the working environment to increase the volume when caving from the massif, and is important for the roof management process, especially in methods with roof caving.
- Compactness means the characteristics of the working environment to maintain the condition in different conditions of action on it, and depends on the strength, cracking, size of the open surface and holding time without support. This characteristic influences the choice of the type and construction of the excavation support and the manner of roof controlling.

The third group of characteristics includes: moisture, porosity, bulk density, shear resistance and cutting resistance.

- Humidity is the filling of the gaps in the working environment with water and it is determined by the humidity coefficient. The characteristics such as compactness, caving and hardness also depend on the amount of humidity.
- Porosity is expressed by voids in the massif-working environment and it is defined by the porosity coefficient which represents the ratio of the volume of voids to the volume of solid mass.
- Bulk density is a characteristic of the working environment required for the calculation of stable rooms and excavation parameters of blasting and excavation and transport equipment.
- Shear resistance consists of cohesion parameters and internal friction angle, which are the basic mechanical parameters that serve in determining stable mining rooms and excavations.
- Resistance to cutting is an important characteristic when choosing the technology of obtaining coal by cutting and scraping.

Within this research, data on some physical and mechanical characteristics of the floor, coal seams and roof in the mines of JP PEU were processed and shown in Table 4.

Table 4. Data of some physical and mechanical characteristics (floor, coal seams and roof) in the mines of JP PEU Resavica [8]

MINE	ROCK	1	2	3	4	5
Vrška Čuka	P- argillite	2,24	418	40	120	55
	S- coal	1,52	170	20	-	53
	k - sandstone	2,65	852	81	146	53
Ibarski rudnici	P- clay	1,50	120	18	19	
	S- coal	1,28	130	28	26	39
	k- marl		55	39	58	
Rembas	P- floor sandstone	2,31	134	19	29	50
	S- coal	1,33	246	31	112	38
	k- red sandstone	2,57		51	123	57
Bogovina	P- coal-clay	1,56	75	14	71	36
	S- coal	1,30	115	28	95	35
	k- marl	2,06	106	14	79	36
Soko	P- clay	1,75	83	94	17	32
	S- coal	1,35	290	58	36	38

	k- sandstone	2,51	124	42	35	33
Jasenovac	P- coal, clay	1,70	6,8	12	15	24
	S- coal	1,30	138	30	19,5	37
	k - sandstone	2,2	78	8,2	33	40
Lubnica	P- sandstone	2,63	93		16	55
	S- coal	1,33	143	16,8	15	52
	k- marl	265	81	9,2	16	52
Štavalj	P- coal, clay	1,52	214	12	31	59
	S- coal	1,28	250	23	38	54
	k- marl	1,93	193	17	32	55

Legend:

P-floor

S-coal seam

k-roof

Data source - Study of the geomechanical tests for certain excavation fields and types of rocks that are often interchangeable

1. Volume mass (t/m^3)
2. Compressive strength (daN/cm^2)
3. Tensile strength (daN/cm^2)
4. Cohesion (daN/cm^2)
5. Angle of internal friction ($^\circ$)

CONCLUSION

The natural-geological conditions present in the coal deposits have a decisive influence on the choice of the excavation system and its technical-technological, economic and safety parameters. Within the natural-geological conditions, there is a segment of physical-mechanical characteristics of the working environment, especially the influence on: the construction of the underground system, the manner of repairing the excavation space, the choice of parameters of the excavation method and technology and the choice of support and loading and transport equipment. In the conditions of active coal deposits, the dominant geological features are layered inclined structures, with micro and macro tectonics that formed exploitation areas, the excavation fields and blocks of relatively short lengths with frequent changes of direction, extension and dip angles. The thicknesses of the coal seams are variable and range from 1m to 40m, with frequent changes in the thickness of the pure coal in the seam.

The analysis of exploitation conditions suggests that the use of mechanized longwall excavations (with shorter lengths of the excavation front) can be rationally applied only in some area of the Soko and Stavalj coal deposits, and research should focus on the use of mechanized equipment on pillar excavations. The application of mechanization in pillar excavations will increase production capacity, higher performance, improve safety and overall more favorable economic parameters. The choice of a modern variant of pillar excavation directly depends on the physical and mechanical characteristics of the working environment (immediate floor, coal seams and immediate roof) and for the successful choice of the method and technology of pillar excavation it is necessary to know more about specific conditions [9].

The conducted research is systematized and grouped the physical and mechanical characteristics of the working environment and determined their individual influence in terms of importance in the selection of the excavation system, which was the purpose and aim of the research. The paper systematizes the data on the application of excavation systems in active mines and presents the required values of some physical and mechanical characteristics in the deposits, obtained by the laboratory tests.

(Received August 2020, accepted September 2020)

REFERENCES

- [1] Ivković, M., (1997): Rational systems of underground excavation of large brown coal layers in complex exploitation conditions. Doctoral dissertation, RGF Belgrade, Serbia. *[Serbian language]*
- [2] Ivković, M., Figun, Lj., Živojinović, I., (2011): Optimization of production and technical parameters of the pillar method of excavation of coal seams, Journal of Mining Works, No. 4/2011. Committee for underground exploitation of mineral resources – Resavica, Serbia. *[Serbian language]*
- [3] Miljanović, M., Ivković, M., (2014): Systematization of technical-technological solutions of exploitation of underground coal mines in Serbia, Monograph, Committee for underground exploitation of mineral resources – Resavica, Serbia. *[Serbian language]*
- [4] Todorović, V., (2019): Optimization of parameters of the pillar system of excavation of coal seams in complex conditions of exploitation on the example of the "Strmosten" RMU Rembas-Resavica, Master thesis, Faculty of Mining Prijedor (Republic of Srpska, Bosnia & Herzegovina). *[Serbian language]*
- [5] Stević, M., (1991): Soil and rock mechanics, Textbook, Faculty of Mining-Tuzla, Yugoslavia. *[Serbian language]*
- [6] Bednarek, L., Majcherczyk, T., (2020): An analysis of rock mass characteristics which influence the choice of support, Geomechanics and Engineering, Vol. 21, No.4. pp 371-377.
- [7] Jeremic, M.L., (1985): Strata Mechanics in Coal Mining, Laurentian University, Sudbury, Ontario.
- [8] Todorović, V., Đukanović, D., Dramlić, D., (2017): Possibility of applying a new excavation method in the RMU "Rembas" - Resavica, with a review of the "Strmosten", 2nd International Symposium "Investments and New Technologies in mining", Lake Bor, Serbia. *[Serbian language]*
- [9] Kokerić, S., Janošević, P., Todorović, V., (2017): Mutual dependence of factors of adaptation of local mining conditions in Serbian coal mining to a new manner of coal mining, Proceedings of the conference "Mining 2016", Sremski Karlovci, Serbia.