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MECHANISED COAL EXPLOITATION IN THE "BREZJE" PIT OF THE "DJURDJEVIK" BROWN COAL MINE

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ABSTRACT

In addition to the coal and electricity market and changing geopolitical circumstances, there are other sufficiently rational reasons for opening new underground mining facilities and modernizing existing mining methods.Significant limiting factors and influences, in complex mining-geological conditions, most significantly affect the possibilities of the mechanized way of mining brown coal. The "Brezje" pit is a part of the deposit where the mining-geological factors are complex and determined by the natural conditions of the deposit's genesis. Excavation methods and technologies in complex deposit conditions must be based on great flexibility and adaptability.The complexity of the tectonic structure in the "Đurđevik" pit justified the application of chamber excavation methods with borehole blasting, in various technical modifications and solutions. In all previous solutions, the degree of mechanization of the method was not significantly improved and all modifications of the chamber method were non-mechanized or semi-mechanized with a large participation of manual work, technology based on drilling and blasting, high risk of injuries, low utilization of deposits, unjustified economic effects of work.

The aim of this paper is to give an adequate answer to the hypothesis "in the block structure of the deposit with pronounced tectonics, it is possible to reduce the unfavorable influence of the complex mining-geological factors of the deposit on the excavation method by choosing modern mechanization for underground exploitation". The mechanized chamber method of excavation is a conceptual solution for the possible application in complex conditions of the proposed flexible mechanization for work in the "Brezje" pit. The advantage of modern multifunctional mining machines is a high degree of adaptability to the elements of the coal layer with the use of different working mechanisms (tools) that can be changed in a very short time depending on the working phase of the process.

Key words: Pit, complexity, factors, chamber method, flexible, multifunctional machine

1. THE COMPLEXITY OF THE MINING-GEOLOGICAL CONDITIONS OF THE ,,BREZJE” AREA

The area of the pit ,,Đurđevik“ is a smaller part of the general tectonic complex of the Đurđevik basin, where tectonics was intensively reflected. The disturbance of the layer is different in certain parts of the deposit, so the continuity of the coal layer is interrupted and the passage from one block to another is possible only through barren fault zones. The faults are of variable intensity, they break the coal seam, closing one coal block with amounts from 100.000 to 2.5 million tons. In the area of the ,,Brezje“ district, a large number of faults were found that break the continuity of the coal seam, and the general complexity is difficult to follow. The complexity is reflected especially in the small dimensions of the mining blocks of the possible mining fields and excavations, pronounced tectonics and variable elements of the coal seam. The distribution of faults can be seen on the structural map of the ,,Đurđevik“ basin and the ,,Brezje“ region (figure 1), as well as on the characteristic geological profile (figure 2).

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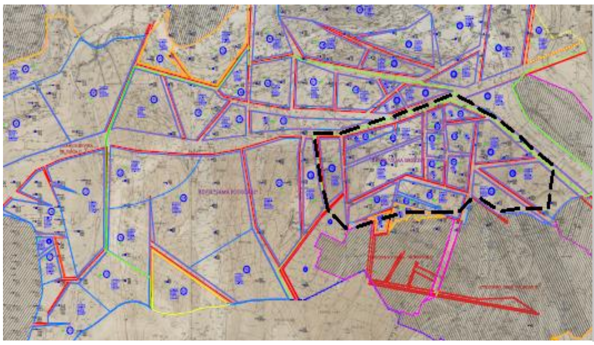


Figure 1. Structural map of the „Đurđevik“ basin and the „Brezje“ region

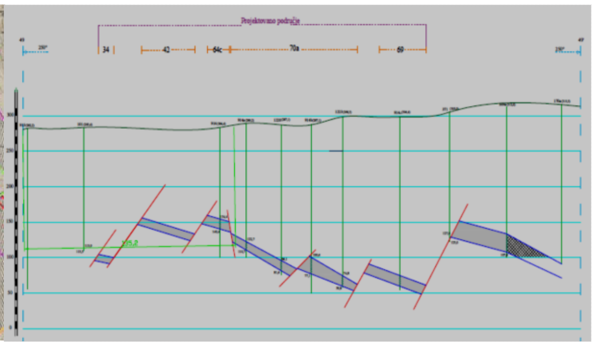


Figure 2. Characteristic geological profile (49-49')

From a tectonic point of view, the „Đurđevik“ coal basin area has been strongly tectonically shaped on several occasions. Strong tectonic activity was carried out in several phases over a long geological time in an area where there are masses of rock with different physical and mechanical properties in a relatively small area, which caused the formation of specific deformations with considerable movement of rock masses.

1. INFLUENTIAL FACTORS ON COAL MINING IN COMPLEX MINING-GEOLOGICAL CONDITIONS

In researching the possibility of a mechanized way of preparing and digging brown coal in the complex mining-geological conditions of the „Brezje“ pit there are significant limiting factors and influences that need to be adequately addressed. The mining-geological factors of the deposit (picture 3) are prerequisite for all research into possible methods and technologies of excavation in the pit in order to plan and design new capacities for the exploitation of deep reserves that will not be mined by surface exploitation. All future excavation methods and technologies must be based on great flexibility so they can adapt to deposit conditions, a significant degree of process dynamism and equipment manipulability, in order to achieve the necessary justification of exploitation within the framework of small capacities (coal blocks of variable thickness and layer inclination), satisfying the economic indicator while improving the degree of utilization of deposit and ensuring a high degree of safety at work. Mining-geological factors are determined by the natural conditions of the deposit's genesis, but with the correct choice of technical-technological factors, it is necessary to minimize or exclude negative influences on the possibility of applying the method or reduce it to a rational measure. Therefore, it is immediately necessary to define the most significant influencing factors and boundary conditions on the possibility of applying the mechanized excavation method in the "Brezje" pit.

2.1. Selection of mining-geological and technical-technological influencing factors

Geological reserves of coal in the tectonic blocks of the "Brezje" pit amount to 6.4 million. tons. The exploitation field of the pit has approximate dimensions of 1,000 x 400 m or a total area of approx. 400,000 m² of the productive part of the deposit. Total exploitation reserves in the "Brezje" area amount to 4.5 million tons. The thickness of the layer has a multiple influence on the choice of the excavation method and is reflected in the adjustment of the basic dimensions of the excavation, the method of rehabilitation of the excavation space in the process of roof management and the direction of excavation. The thickness of the coal layer in the "Brezje" pit is very variable and ranges from 4.05 m (block 66 b) to 22.25 m (block 62 b), as determined by investigative work. In the "Brezje" area/pit, there are blocks of great thickness and a variable angle of bedding, so their dimensions and the slope of the layer's extension and fall require modern flexible equipment and mechanization. The natural conditions of exploitation in the "Brezje" pit are characterized by the natural tendency of coal to self-ignite, very rare occurrences of methane, and due to high humidity, the slight presence of dangerous coal dust. The coal belongs to hard brown coal whose individual components correspond to the components of hard coal. The complexity of mining-geological factors causes an appropriate choice of technical-technological ones that influence the application of mechanization in the designed method in the "Brezje" pit (figure 3.)

The hydrogeological characteristics of the deposits show, based on the characteristics of the roof deposits and the results of exploratory drilling, that in an undisturbed state the roof deposits are weak collectors of groundwater. However, surface water reaches the mining works through the system of cracks, caverns and faults and infiltrates the pit rooms as underground water, and when the underground works reach the fault zones, they enter the mining works.

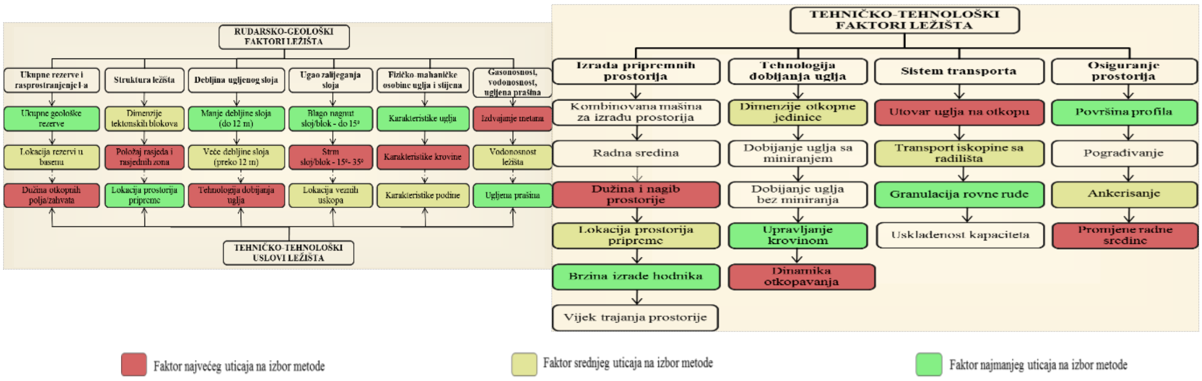


Figure 3. Selection of mining-geological and technical-technological factors by degree of influence on the choice of method

2.2 Selection of organizational, security and economic influencing factors

Organizational factors are very closely related to technique, technology and work efficiency and include the organization of work on preparation and excavation, transport and ventilation systems, crews on multifunctional machines, conformity of capacities and conformity of technological phases. Safety factors correspond to the mining-geological conditions of the deposit with adequate measures to ensure safety and protection at work. They define measures in the area of providing measures to control the gas condition, drainage, dangerous coal dust, securing premises and working comfort, measures related to the geomechanical characteristics of the working environment. The economic factors of opening the „Brezje" pit are mostly geopolitical, they determine the limits of realistic possibilities for opening and exploitation and exclude a technical, technological and economic approach to considering and defining the decision on justification. However, there are other, relatively more numerous factors, which support the justification of opening a new pit, and the economic evaluation shows the justification of opening the „Brezje" pit with significant positive effects.

3. CHAMBER METHOD OF EXCAVATION WITH DEEP WELLS

In the „Đurđevik" pit, there were changes in excavation methods throughout the periods of work and development. In the period when the pit was shallow and the deposit conditions were more favorable (with a minor influence of tectonics), variants of Š.Č method were used (until 1990). The specificity of the mining-geological factors, and especially the tectonics of the deposit, has conditioned the application of the chamber method of excavation with a variety of deep mine wells (from 1991 to the present), as a method that is adaptable to the natural conditions in the deposit. The goal has always been how to choose a rational system of excavation and to achieve better work results through the improvement and modernization of the process, in order to economically justify the existence of pit exploitation. The technical solution of the new excavation method is based on a certain practical experience and positive legacy of coal exploitation in complex mining-geological conditions in the „Đurđevik" pit in the mentioned period of development, which is characterized by the application of several variants of the chamber method with a variety of deep mine boreholes. The chamber method underwent developmental modifications and was limited to the excavation of a coal layer with a thickness of 10 to 13 m, until 2020, when the mine innovated the chamber excavation method in the tectonic blocks of the „Živčići" area, which defines the method of chamber excavation in conditions of increased layer thickness (from 13m to 25m) by deep borehole blasting.

3.1 Basic parameters of the chamber method of excavation by deep-well blasting

Due to the large thickness of the coal seam, in addition to DOH-1 and GOH-1, it is necessary to construct auxiliary pits POU-1 and POH-1. POU-1 is made from GOH-1, and the purpose of the room is to achieve a sufficient height difference compared to GOH-1 and DOH-1. POH-1 is made 8 to 10 m from the roof of the coal seam and 6 to 10 m from the elevation of GOH-1 in the middle, between DOH-1 and GOH-1. The opening of the trench is made from the prepared average DOH, GOH and POH length of 4 to 5 meters, from which mine holes are drilled for the opening of the trench by parallel blasting of the fan at the opening of each OH. After the excavation is opened, coal is obtained by blasting a fan of mine wells with 2, 3 or 4 partial fillings. After the blasting of each fan, separate ventilation of the work site is carried out, and coal is transported from the mining unit. OJ should be led so that the corridors end at the same distance from SU, without the collapse of one OH taking precedence over the other two OHs.

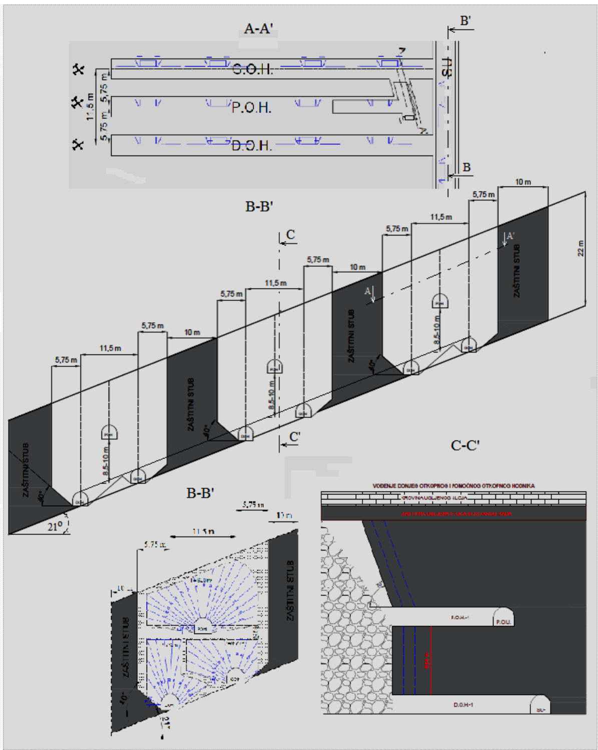


Table 1. Parameters of the chamber method

Excavation Unit (OJ) DOH-1 (lower excavation corridor) GOH-1 (upper excavation corridor) POU-1 (auxiliary excavation corridor) POH-1 (auxiliary excavation corridor)		
The thickness of the coal seam	m	15-30
The length of excavation	m	50
Excavation width	m	25
Excavation unit width (OJ) - max	m	17
Height of excavat. unit (OJ) - max	m	23
Width protect. interventricular column	m	28
Choir. distan. between DOH and GOH	m	7-10
Parameters of drilling blasting- fans	m	11,5
Area - Σ(DOH, GOH, POH)	I+II+III	
Number and length of wells (Nw/Lw)	m^2	591,6
Amount of explosives	/m	110/288
Number of lighters	kg	256,6
Amount of air at OH	kom	329
Number of employ. on site- 3 sit.x4 sit.	m^3/s	2,37
Number of cycles per day on excavation	empl.	12
Utilization. of coal in OJ	cyc/day	0,66
Utilization. of coal in the mining field	%	86
Productivity (t.r.u./working/month)	%	55,53
The thickness of the coal seam	t/empl	335

Figure 4. Chamber method with deep-well blasting

Coal will be transported from the mining unit with double-chain rake conveyors type DGT-440. Loading of demined material is done by self-loading, gravity rolling and sliding of demined coal from the chamber onto the rake conveyor, and by raking on the sides. The ventilation of the work site is carried out from the flow system of ventilation of the pit, with separate fans. For the organization of the phase of excavation using the chamber method with deep-hole blasting, three working groups at OJ per shift are needed.

4. NEW EXCAVATION TECHNOLOGIES APPLICABLE IN THE CONDITIONS OF THE „BREZJE“ PIT

No matter how advanced mining science, technique and technologies are, sometimes it is difficult to find technical solutions that will meet all the conditions and requirements of rational (safe and techno-economically justified) exploitation of coal in the pit. Modernization and mechanization of the technological process in the phase of excavation in the pit always brings improvement through a higher level of mechanization, humanization of work, increased dynamics of excavation, higher degree of utilization of coal reserves, improvement of safety while reducing the risk of injuries at work, as well as significant improvement of the economic effects of work.

4.1. Key parameters of the existing and proposed solution of the chamber excavation method

Table 2. Comparative conceptual parameters of the existing and proposed solution of the excavation method

Parameter – Indicator	Modified chamber excavation method with deep borehole blasting	Mechanized chamber method of excavation with multifunctional machines
Method of making preparatory rooms	The method of production is not set as a condition - at the level of non-mechanized classical production	Mechanized method of production
Adaptation to complex mining and geological conditions	High degree of customization	High degree of customization
Achieving the maximum possible degree of utilization of the coal seam	A significant improvement in the degree of utilization compared to earlier variants of chamber methods	A significant improvement in the degree of utilization compared to earlier variants of chamber methods
Reduction of the cost of manual labor in the phase of obtaining coal and increase of the mechanization of work	Manual work has not decreased, especially the volume of drilling and blasting work has increased	Manual work significantly reduced, all phases of work are carried out mechanized by the use of connecting mechanisms on the machine
Increase of working effects on OJ (chambers) - productivity of the unit and work productivity,	Work efficiency increased due to the productivity of OJ, but the number of workers is higher due to the management of three excavation corridors (chambers).	Work efficiency increased due to the geometry of the excavation unit, the number of workers significantly reduced (the crew on the machine does everything)
Improvement of safety working conditions at the mining unit	Due to the significant participation of manual labor and the large number of workers in the operation, the risk of injury has not been reduced	Due to the reduced participation of manual labor and the smaller number of workers in the operation, the risk of injury is significantly reduced
Improving the economic effects of work	Improved economic effects of work	Significantly improved economic effects of work

1.2. Conceptual solution of the mechanized chamber excavation method in the “Brezje” pit

The mechanized chamber mining method using multifunctional mining machines is a universal mining method regardless of the thickness of the coal block/layer. Given that in the „Brezje“ district, a large number of coal blocks have a thickness of less than 13 m, the aspiration is to define a method for the entire district, where the mechanized method has significant advantages. Comparative conceptual parameters of the existing and proposed solution of the excavation method are given in Table 2. Due to the complexity of the mining-geological conditions, the size of deposits and coal blocks, the thickness and slope of the coal seam, it is not possible to rationally apply the broad-front mechanized method. By introducing a mechanized method of excavation, the key requirements of a rational system will be met, and the equipment that will be used will be in accordance with the influencing factors on the choice of method.

1.3. Basic parameters of the mechanized chamber excavation method

Based on previous research and analysis, it is possible to give a rational proposal for equipment and mechanization for the mechanized chamber method of excavation, and the conceptual solution of the method, and based on clear criteria for the specific dimensions of the excavation unit and the safety pillar, the technology of work at the excavation site, the organization of work and some production – economic parameters.

4.3.1. Multifunctional mining machine – features and capabilities

The machine is designed on tracks for rehabilitation and reconstruction of pit rooms and leveling of swollen floors of rooms in the pit, in the version with a loading bucket and an active bucket it is used for loading the excavation. In the version with a hydraulic hammer, it is used for the destruction of the working environment (destruction of coal and accompanying rocks), and in the version with a hydraulic drill for drilling holes for explosives and anchor bolts, as well as with a cutting head for shaping and bringing it into the designed profile of the room. The machine can be supplied for different voltages according to the customer's wishes. Equipped with an LCD screen to view operating conditions and error warning messages. All data is stored on the SD card.

As a mining machine to be used for mechanized chamber mining of coal:
- the machine will also be used for the creation of pit rooms (OH), the surface of the light profile of the corridor (F_s=10.5 m²)
- the excavation machine will excavate excavation blocks with a maximum reach of (8,634 x 8,065) m,
- obtaining coal will be done by cutting in the phase of opening the pit (with a cutting head as the working mechanism) and processing the pit with a hydraulic impact hammer and drilling (the working organ is a hydraulic drilling tool)
- the mining machine has a device for knocking down coal dust, which is created during the mechanical destruction of coal; - the engine and all electrical devices of the digging machine are in safety design (Ex);
- the characteristics of the excavation machine (load on the floor, cutting force, angle at which the machine can work, etc.) correspond to the characteristics of the working environment of the „Brezje“ pit;
- the excavation conveyor that will be used on the mechanized chamber method corresponds to the capacity of the excavation machine, it is easy to mount, extend, shorten, occupy little space under the machine, and its length must correspond to the length of the excavation block, i.e. to the maximum length of OH.
- by its design, the machine meets the requirements of group I category M2 (EU Directive 2014/34/EU) and can be used in mines with hazardous atmospheric conditions 2 according to ČSN EN 1127-2 (EN 1127-2) and in areas with a risk of methane explosions and coal dust.

Figure 5 shows the combined machine multipurpose dinting loader type KL-PSU9000-II-EN

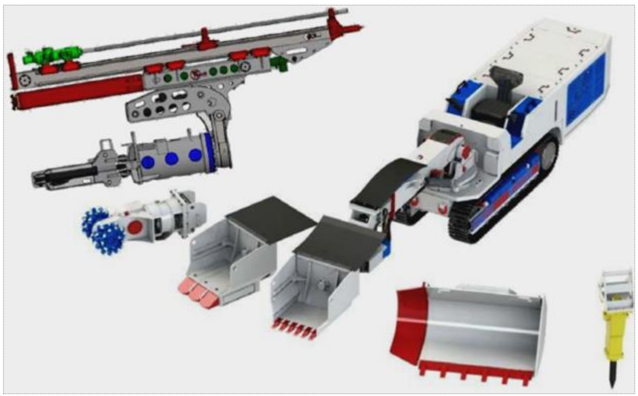


Figure 5. Machine with connected working mechanisms

Table 3. Basic machine parameters

Parameter/Characteristic	Size
Mass with a spoon	9.680- 9.870 kg
Table with a hammer	9.230 kg
Table with cutting head	9.650 kg
Table with drilling accessories	11.450 kg
The length of the machine with mechanism. (min-max)	6.287- 9.572 mm
Machine width	1.216 mm
Machine height	1.358 mm
Chassis ground clearance	300 mm
Electric motor power	55 kW
Specific floor pressure	8,7 N/cm^2
Driving speed	0,7 m/s
Transverse force	70 kN
Along. floor slope during operation	-20°/+20°
Max. trans. floor slope	-10°/+10°
Cooling	ulje/zrak
Nominal working pressure	19 MPa

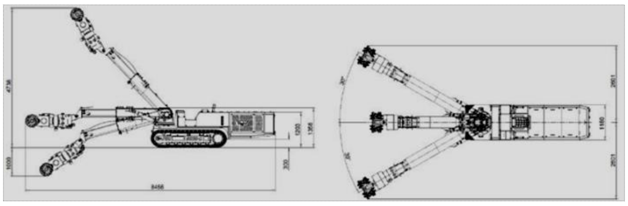


Figure 6. Machine with connection mechanism - cutting head

Table 4. Basic parameters of the machine with a cutting head

Parameter/Characteristic	Size
Mass	9.650 kg
Main dimensions (hxwxl)	1358x1180 x7706 (8.456)
Horizontal. angle of rotation	±30°
Rotation of the cutting head	2x180°
Max. reach height above the floor	4.738 mm
Max. reach depth below the floor	1.000 mm

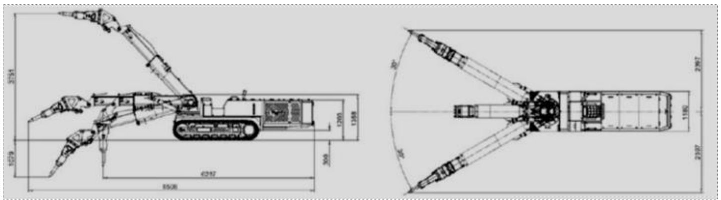


Figure 7. Machine with connecting mechanism - impact hammer

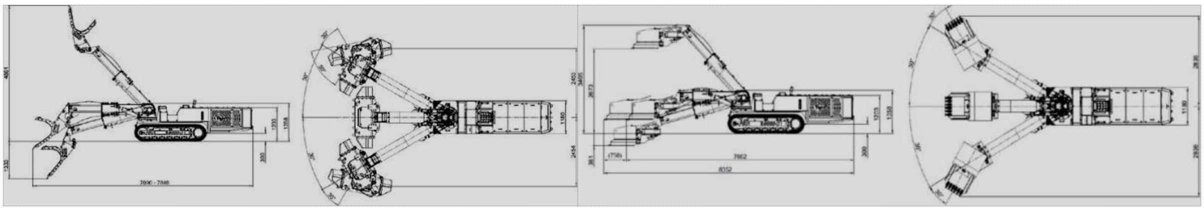


Figure 8. Machine with attachment mechanism - side and front loading bucket

Table 5. Basic parameters of the machine with connected active mechanisms - hammer and loading bucket

Parameter/ Characteristic	Hammer mechanism	Mechanism with loading bucket	Mechanism with active bucket
The lower edge of the stroke at the maximum lifting of the arm	3.235 mm	3.235 mm	2.673 mm
The lower edge of the stroke at the maximum lifting of the arm	3.751 mm	3.613 mm	3.405 mm
Maximum walking reach height	-	4.861 mm	4.005 mm
Lateral reach of bucket/hammer	2x2.397 mm	2x2.453 mm	2x2.836 mm
Maximum reach below floor level	1.079 mm	1.333 mm	600 mm
Maximum arm rotation angle	30°	30°	30°
Maximum bucket rotation angle	-	-	30°
Arm extension	750 mm	750 mm	750 mm
Volume of the spoon	-	850 l	300 (350) l
Bucket height	-	1.430 (2.170) mm	830 mm
Max. height of the upper edge of the tipping bucket	-	3.600 mm Max.	-
Maximum tipping angle of the bucket		50º	
The maximum angle of inclination of the bucket		65º	
Penetration force on the bucket tooth			150 kN
The length of the machine - the tip of the hammer in the horizon. hand position	7.758-8.508		

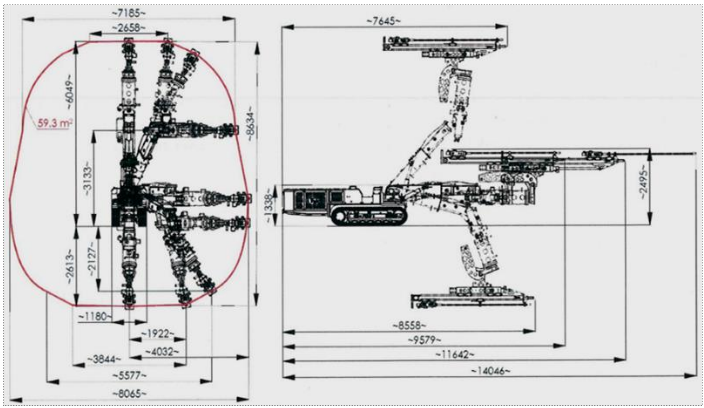


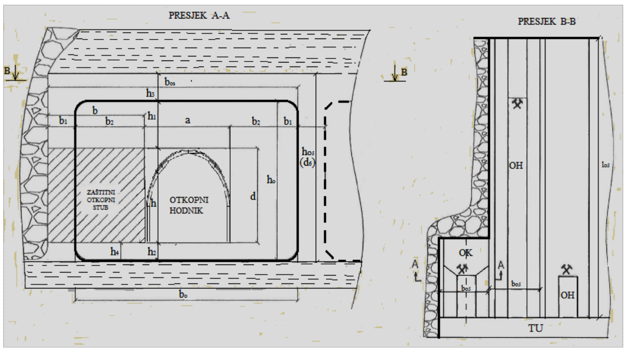
Figure 9. Machine with connecting mechanism – hydraulic arm for drilling

Table 6. Characteristics of a machine with a hydraulic arm for drilling

Parameter/ Characteristic	Size
Mass	11.450 kg
Main dimensions (hxwxl) 1,216 x 1,180 x 9,579	11.642/14.046
Horizontal angle of rotation	±30º
Horizon. impact hammer rotation	0°+90º
Vertical rotation of the impact hammer	±180º
Max. field of coverage/ profile	59,32 m^2
Drilling length	2.400 mm
Max. height reach (horizontal)	6.049 mm
Max. height reach (vertical)	4.032 mm
Extending the telescope	750 mm

4.4. Geometrical parameters of the mechanized chamber excavation method

Based on the research of the conditions and technical capabilities of the machines, the constructive parameters of the excavation method were determined. Modern equipment and machinery available on the market for underground coal mining will reduce the impact of natural unfavorable deposit conditions on the application of efficient mining methods and technology.



l_o ; b_o; h_o - length, width and height of the excavation chamber
b;h – width and height of the protective pillar;
a- width of excavation column;
d- layer thickness;
h_3 - height of the ceiling;
h_2- the depth of the subfloor;
h_3- thickness of the ceiling protective plate;
b1- thickness of protective barrier;
b2- depth of lateral engagement

Figure 10. Geometry of the excavation chamber

With the excavation chamber, it is necessary, for the defined depth at which the excavation is carried out and the height of the OK, to determine the other two dimensions, the length "l" and the width "b" of the excavation chamber, by mathematical and analytical means.

Optimization of the excavation chamber height

The height of the excavation-chamber is not determined by calculation and is adopted. The height of the excavation chamber is affected by the thickness of the coal layer, the levels in thick and steep layers and the size of the vertical reach of the mining machine, so that in thick layers.

$$h_s = \sum_{i=n}^{i=n} h_i + h_i^{'} + h_i^{''}$$

h' - thickness of the protective plate in the ceiling (m)
h" - thickness of the protective plate in the floor (m)
The height of the excavation chamber is determined at the beginning of the research and represents one of the main limiting parameters in the selection of the excavation machine.

Optimization of the width of the excavation chamber

In the case of inclined layers and variable terrain configuration, as in the example of the "Brezje" pit, the depth of the deposit changes as the layer falls. The depth limit for the adopted width of the excavation chamber is determined mathematically

$$H = \frac{\sigma_o}{K_p \cdot K_s \cdot \gamma_k} \sqrt{\frac{b}{h}} \qquad H = \frac{233,2}{2,25 \cdot 1,35 \cdot 1,38} \sqrt{\frac{16,2}{18,2}}$$

H (m) - excavation depth, H=220-320 (m); corresponding limit depth H=250 m

Determining the length of the excavation corridor from the conditions of the coefficient of machine working time

To determine the length of the excavation corridor for excavation - using the machine, we will use the form from the conditions of daily production from the excavation according to the coefficient of the machine's working time.

General expression for the length of excavation: $l = \frac{q_p \cdot n_{sm} \cdot T_{sm} \cdot 60 \cdot k_m}{n_c \cdot r \cdot m \cdot \gamma} + l_n$ (m) (k_m=0,49-0,67)

Mining front productivity

The productivity of the excavation front is expressed in tons per meter of the excavation front of the pit, the horizon of the excavation field or excavation, and is determined by a mathematical expression: $q_p=P_o/Nn \rightarrow max$;

Technical and technological parameters of excavation

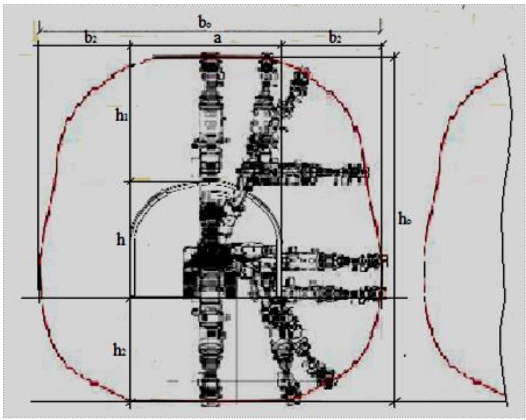


Figure 11. Geometry of the excavation chamber

Table 7. Parameters of the mechanized method

Parameter/ Characteristic	Unit	Size
Maximum digging cross-section	m	8,6 x 8,1
Cross-sectional area of the excavation-chamber	m^2	cca 70
Width of excavation corridor (a)	m	4,0
Height of excavation corridor (h)	m	3,1
Height of machine reach above OH (h1)	m	3,0
Reach height of the machine below OH (h2)	m	2,1
Lateral width of engagement - right and left of OH (b2)	m	2,0
The total width of the machine is bo=a+2b2	m	8,1
Max. along. the slope of the room during machine operation	o	-20°/+20°
Max. across. the slope of the room during machine operation	o	-10°/+10°

Optimal length of the mechanized chamber

The length of the excavation chamber-corridor corresponds to the conditions of continuous removal of coal with the DGT-440 (120 t/h) and is determined based on the criteria for the capacities of transport means-equipment

The width of the excavation chamber

The calculation of the minimum width of the excavation unit was made according to the Slesareva pattern:

$$l = k \cdot \sqrt{\frac{R_z \cdot h}{n \cdot \gamma}} \;(m) \qquad l = 1{,}41 \cdot \sqrt{\frac{22{,}7 \cdot 34{,}4}{0{,}8 \cdot 24{,}8}} \qquad l = 1{,}41 \cdot \sqrt{\frac{780{,}88}{19{,}84}} \;(m) \quad l = 8{,}84 \;(m)$$

According to the geomechanical characteristics of the working environment and the capabilities of the machine (KL-PSU9000-II-EN), a double maximum profile width that can be processed by two machines in parallel operation (2x8.1) m=16.2 m is adopted, which is approx. 75% of the calculated width during chamber excavation (by drilling and blasting technology) - 23 m.

The width of the interchamber protective column

The following formula was used for this calculation:

The calculation is done for the depth value H= 250 m

$$\sigma_p \geq 0{,}1 \cdot \gamma \cdot H \cdot \left(\frac{a+b}{a}\right)$$

calculated $a \geq 5{,}99$ m ; adopted a=6,4 m

In the case of mechanized excavation with a multi-functional combined machine (type KL-PSU9000-II-EN), the width of the inter-chamber protection pillar is adopted of 6.4 m, which is approx. 75% of the possible calculated width of the inter-chamber pillar during chamber excavation with deep-hole blasting (8,5 m).

The demolition step in the chamber excavation

We will obtain the step of crushing chamber excavation according to the pattern:

$$l_š = h_n \sqrt{\frac{R_s}{3 \cdot \gamma_s \cdot h_v}}$$

gdje je: h_n = 2 (m) - the thickness of the protective carbon plate according to the roof,

h_v - height of roof collapse (m) ; m=17,2 (m) - excavation thickness

$$h_v = \frac{m}{k_r - 1} \;(m) \qquad h_v = \frac{17{,}2}{1{,}5 - 1} = 34{,}4 \;(m)$$

k_r - looseness coefficient of the immediate roof of the coal seam (k=1,5)

$$l_š = 2{,}0 \sqrt{\frac{7090}{3 \cdot 1{,}38 \cdot 34{,}4}} = \sqrt{\frac{7090}{142{,}42}} = \sqrt{49{,}789} = 7{,}06 \;(m)$$

When the thickness of the protective coal plate towards the roof is 2.0 m, the step of submergence in the chamber excavation is 7,06 m.

Work system on the mining unit

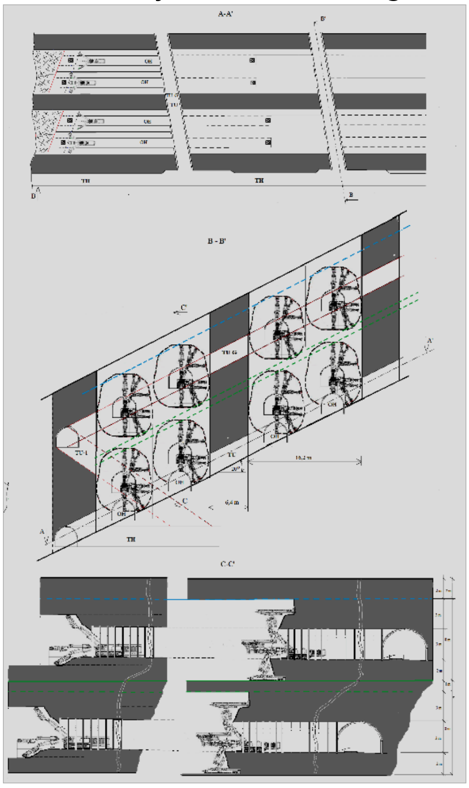


Figure 12. Mechanized chamber method

The geometry of the excavation chamber (8.1 x 8.6) m, shows that the multifunctional machine is applicable in blocks (8-12) m, when applied in one operation, and it is possible to apply two machines in parallel operation. Excavation of the excavation chamber is carried out by a combination of connecting mechanisms (tools) by destroying the rock without blasting. For tectonic blocks of greater thickness (block 62a and 62b), the application of these machines is possible in two zones (lower and upper), where there must be a great coordination of the working operations of the machines in simultaneous operation in both zones, i.e. the progress of the mining work front in the excavation unit. Excavation processing consists in the formation of chambers by expanding the OH, destroying coal in the ceiling, sides and floor and it expands symmetrically from the axis to the sides by 4.05 m, to a total width of the excavation chamber of 8.2 m. The maximum height of coal destruction is 6.05 m and the depth of the floor of the excavation corridor is 2.61 m. By processing the excavation according to the height of the excavation, a protective plate is left for the roof of 2 m. The protective plate against the roof of the layer, the space in the pit where the coal is destroyed in the sides, ceiling and floor, and that after the destruction in the pit moves to a certain distance, it breaks and successive collapse of the roof occurs..

Coal production from mining

Coal production per meter of mining chamber: $Q_{mo} = F_o \cdot \gamma = 60 \cdot 1,38 = 82,8$ t/m'

Effective working time of the machine for the destruction of 1m' excavation chamber: $t_{ro} = 120$ min

Excavation chamber progress: $L_{ns} = T_{smj.}/t_{ro} = 450/120 = 3,75$ m/ shift

Due to operational downtime, we adopt 70% of the calculated excavation shift progress: $L_{nso} = 2,63$ m/ shift

Daily excavation progress: $L_{ndo} = 3\ L_{ns} = 3 \cdot 2,63 = 7,89$ m/day

Coal production per meter of chamber excavation: $Q_{mo} = F_o \cdot \gamma = 60 \cdot 1,38 = 82,8$ t/m'

Daily coal production from mining: $Q_{mdo} = Q_{mo} \cdot L_{ndo} = 82,8$ t/m'$\cdot 7,89$ m/day = 653,3 t/day

Monthly coal production from mining: $Q_{mmo} = 30 \cdot Q_{mdo} = 30$ day$\cdot 653,3$ t/day = 19.600 t/mon.

Coal production indicators refer to 1 mining mechanized chamber. For a layer of great thickness (20 m), 4 excavation chambers are calculated in simultaneous operation.

Utilization of the coal seam

The utilization coefficient represents the ratio of coal produced from the mining unit per m' of the mining chamber in relation to the calculated amount of coal per m' (according to the geometry of the mine).

$$I_u = \frac{Q_{mo} \cdot N_{ok}}{Qg_{mo}} = \frac{82{,}8\ \text{t/m'} \cdot 4}{16{,}2 \cdot 20} = \frac{331{,}2}{447{,}12} = 74{,}1\ \%$$

Effects

Monthly coal production from preparation: $Q_{mmp} = 30 \cdot Q_{mdp} = 30$ day$\cdot 134,9$ t/day = 4.047 t/month

Monthly coal production from mining: $Q_{mmo} = 30 \cdot Q_{mdo} = 30$ day$\cdot 653,3$ t/day = 19.600 t/month

Total monthly production of coal from preparation and mining: $Q_{mmu} = Q_{mmp} + Q_{mmo} =$ 4.047+19.600= 20.647≅ 20.650 t/month. Monthly and annual output per employer:

$$U_{mr} = \frac{Q_{mmu}}{N_{rad}} = \frac{20.650}{128} = 161{,}32 \text{ /empl./mon.} \quad = 1.935{,}8 \text{ /empl/year.}$$

Table 8. Parameters of the borehole blasting method and the mechanized method

Parameter – Indicator	Modified chamber excavation method with deep borehole blasting	Mechanized chamber method of excavation with multifunctional machines		
The method of making preparatory rooms	Classical method (drilling and blasting method)	Mechanized method of production (machine)		
The length of the dissolution process	L=52 m	L=120 m		
Excavation width	Š=90 m	Š= 52 m		
Cross profile of the excavation unit (chamber) - for hz=17 m	F_o=(23x17)m; $F_o \cong$ 390 m^2	F_o= (8,6 x 8,1)m; $F_o \cong$ 70 m^2 za 2 pojasa (2x2)x70 m^2; $F_o \cong$ 280 m^2		
Excavation processing and management	By drilling and blasting in three fans of mine boreholes (I, II i III)	A multifunctional machine with a combinat. of attachment mechanisms (tools)		
3 fan wells (1 cycl.- 1,6 m')	DOH / GOH / 3 fan wells (1 cycl.- 1,6 m') / DOH	GOH		
Surface [m^2] - 591,6; A well N_w/L_w; [/m] - 110/288 Explosive [kg] - 256,6 ; Lighters [kom] - 329				
Production parameters	(1 cycle - 1,6 m')	(1 cycle - 2,4 m')		
Time - 1 cycle on excavation	t_c= 27 hours za 1,6 m' excavations	t_c= 7,3 hours za 2,4 m' (per chamber- mach.)		
Broj smjena u ciklusu	B_{sm}= T_c/T_{ef}= 27/6= 4,5 smj./cikl.	B_{sm}= T_c/T_{ef}= 7,3/7= 1,04 smj./cikl.		
Coal production per cycle	$Q_{ug/cik}$= $D_z \cdot P \cdot \gamma$ = 1,6·313·1,38 = 691 t	Q_{ug} = $D_z \cdot P \cdot \gamma$ = 232 t (per chamber- mach.) -for one belt- (2 machines)- 464 t/cycle) - for two belts - (4 machines - 928 t/cycle)		
Coal production per shift	$Q_{m'}$ = $Q_{ug/cik}/B_{cik}$= 156,3 t.r.u./shift	232	Coal production per shift	$Q_{m'}$ = $Q_{ug/cik}/B_{cik}$= 156,3 t.r.u./shift
Coal production per month	14.067 t.r.u./month	20.880	Coal production per month	14.067 t.r.u./month
Number of excavation employers	14 empl./day (po OH)x 3= 42 empl./day	8 empl./day (po OH)x 4= 32 empl./day		
Productivity (t.r.u./employ./month)	335	653	Productivity (t.r.u./employ./month)	335

CONCLUSION

- At the time of the challenges of the European energy transition, the decarbonization of the BiH energy sector, but when the political circumstances are rapidly changing and there are no strategic political decisions, considering the opening of new underground mining facilities and the modernization of methods and technologies, there are enough rational reasons.
- In the complex mining-geological conditions of the „block deposit structure“, there are significant limiting factors and influences that need to be adequately addressed and are key to the choice of method and technology for the exploitation of a complex deposit such as the „Brezje“ pit.
- The application of chamber excavation methods with borehole blasting, in various technical solutions of this method in the previous period, although semi-mechanized methods adaptable to the conditions of the deposit, was technically and technologically justified, but not economically.
- In all applied solutions, the degree of mechanization of the method was not significantly improved and all modifications of the chamber method remained at the level of the semi-mechanized method.
- Adequate selection of flexible equipment and mechanization in the „Brezje“ pit will reduce the share of manual work, improve the level of mechanization, the level of deposit utilization and economic effects of work and reduce the risk of injuries at work, which are key requirements of modern business. Exploitation of a coal seam with variable characteristics is possible only by using equipment that is to the greatest degree flexible and adaptable to the changing conditions of the deposit.
- The mechanized chamber method conceptually represents a solution and a possible application in complicated conditions using modern multifunctional combined machines. The advantage of these machines is a very high degree of adaptability to the elements of the coal seam with the possible application of different working mechanisms (tools) that can be changed in a very short time depending on the need in

the existing/specific working conditions.
- Multi-purpose combined multi-functional mining machine (multipurpose mining machine – multipurpose dinting loader type KL-PSU9000-II-EN) with quickly replaceable working tools and organs (mechanisms with loading bucket, cutting head, impact hammer, hydraulic drilling mechanism), contributes to easier making decisions about application in the stages of the technological process in a pit with complex mining-geological conditions.
- The production and economic indicators of the concept of the excavation method and technology confirm the justification of investing in the purchase of a multi-purpose combined multifunctional mining machine (one or more of them) depending on the planned volume of production and/or the life of exploitation in the area/ pit „Brezje“ in the future.

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