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BLOCK METHOD OF EXCAVATION WITH BACKFILLING THE EXCAVATED SPACE OF THE BOR RIVER DEPOSIT[**]

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Abstract

The position of deposits and ore bodies for the underground mining in the underground mine Jama Bor, in relation to the terrain surface, old works of the Jama and Open Pit in Bor, and in relation to the mining infrastructure limits the selection of excavation methods with the applied technologies up to now. This paper presents the block method of excavation with backfilling the excavated space with the paste backfill of the Bor River deposit.

Keywords: *Bor River deposit, block method of excavation, paste backfill*

INTRODUCTION

The partially filled the old Open Pit Bor is situated above pit works and ore bodies, with the possibility of accumulating large amounts of water. The geological-mineralogical and chemical specificities of the ore sites with the goals of required productivity and economy of ore exploitation, as well as safety at work, additionally narrow a selection of mining methods. There are a settlement, roads, city and industrial sewerage and infrastructure, railway with a tunnel, cemetery, collector for several surface watercourses as well as the industrial facilities are located above the deposit of the terrain surface.

The excavation methods with caving, in addition to the characteristics of low ore utilization from the deposit, high metal depletion and environmental damages for use in the ore excavation in the underground mine Jama Bor, require large investments for relocation the buildings and infrastructure on the terrain surface or are completely inapplicable due to the risk of inflow the accumulated water [1].

The excavation methods with hydrofilling with cycloned flotation tailings have the low productivity and economy. The costs of transport and installation of backfill with drainage are high. The bearing capacity of the backfill for excavation the pillars and movement of machinery is insufficient [1].

The ore excavation using the empty space methods ensures the high capacities and productivity without ore depletion. The disadvantages of these types of methods are

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the high losses of ore in safety pillars and plates, static uncertainty and endangering the stability of entire system. By sub-building the excavation, the economy is lost, and the problem is not solved permanently. Leaving the empty spaces in the underground mine Jama Bor is a great danger for the mine operation of and safety of employees. The disadvantages of these methods are solved by a subsequent filling of excavation with solidifying backfill. By backfilling the excavation, the system stability is ensured and enables the excavation of pillars, formed in the first phase, and achieves a high ore utilization from the deposit [1].

The ore excavation using the methods with backfilling of empty spaces with appropriate physical-mechanical and technological characteristics, in the existing conditions of location the ore bodies, layout of infrastructure and industrial plants, is solved by the underground exploitation of copper ore in the Bor deposit.

Backfilling of excavation with a high-density backfill, which has the property of hardening and then suitable load-bearing capacity, becomes a condition for selection the modern excavation methods with highly productive equipment and high capacities in an environmentally friendly way, i.e., for excavation the Borska River deposit.

EXCAVATION METHOD

A correct selection of the excavation method, as well as a strict application of the designed technology, enables the optimal technical and technological parameters to be achieved, where a care should be taken to ensure that the excavation is carried out cleanly, without leaving ore in the form of islands, edges, pillars, etc. [2]. Based on the available data on the ore body and set boundary elements in selection the excavation method, it is necessary to determine the possible excavation method in principle and to pay a special attention to the following important conditions.

- High productivity,
- Application of highly productive equipment,
- Low preparation coefficient,
- Matching the excavation geometry with the working environment,
- High degree of utilization the available ore reserves,
- Minimum depletion (dilution) of mined ore,
- Realization of designed production capacity,
- Flexibility at work,
- High safety of the employed personnel during excavation,
- Low operating costs,
- Minimum investment costs.

Taking into consideration the previous principles, analysis of the working environment and experience in the field of underground exploitation, the method of block excavation with backfilling of the excavated space was adopted [3].

Excavation preparation consists of development the excavation corridors. The number of excavation corridors to access the block is usually in a function of the block size, but in this particular case, two excavation corridors were designed (at the bottom and at the top along the block axis). The excavation corridors are permanent and reinforced with appropriate subgrade, and the minimum costs per unit of mined ore are achieved with them. Access to the block on each upper floor is required for drilling and blasting as well as filling, and on the lower floor for loading.

Division is necessary on each floor, through the floor corridors that are developed in the deposit itself, forming the sectors for the phased "attacking" the pit field, which significantly reduced the start of excavation in the pit field.

The ore knocking down in the block is carried out by crushing using the drilling and blasting. Access to the block is achieved by development the excavation corridors longitudinally in relation to a direction of deposit excavation. The first phase is to create a vertical opening (notch) between the floors that define the planned surface of the block front. The block formation is achieved by blasting a fan of boreholes between two levels, but for the initial front opening or block face, it is necessary to make an initial opening, i.e. an expansion that gives a sufficient gap for ore compensation by blasting the initial fan of boreholes. An opening or compensation chamber is usually located vertically in the block center or side at the initial strike point in the orebody. The compensation chamber is formed in the full height of block and, in this case, it connects the upper drilling corridor with the lower loading corridor.

Using the appropriate explosive charge ensures a disintegration over the entire vertical surface of the block face and formation a free surface for the next blasting sequence. The number of blasting sequences (production rings) mainly depends on the geomechanical characteristics of the working environment. That length ranges from a minimum of 30 to a maximum of 50 meters. In principle, the length of block excavation must be in a function of preserving the stability of walls. After reaching the designed block length and removing the blasted ore, that block segment is filled with backfill paste and after hardening the same according to the certain excavation dynamics in the block, the excavation continues.

In the same way, the block formation is initiated in the continuation of excavation, with the fact that care must be taken not to damage the backfill in the previous segment of block. This can be achieved by leaving a so-called clear ring (belt) between the cut-off zone in which a compensation hole is created (drilled) as well as drilling a fan of blasting boreholes. The blasting is then carried out in the order starting from the boreholes in the immediate vicinity of the drilling and ending with blasting the boreholes in the cleaning ring. This procedure ensures a minimum dilution with backfill from the previous segment of the filled block.

The shape of a designed block is achieved by blasting the rows of fans from the initial fan next to the compensation chamber, and then the block is cut from the upper to the lower floor with the other rows of fans. The blasting boreholes are blasted in sequences with a synchronized loading at the loading level. The rows of fans must be drilled parallel to each other. In this case, the vertical direction of rows of blasting boreholes in fans was chosen. The filling of fans must be fully respected to prevent the formation of oversized pieces of ore or endanger the cement paste backfill which would lead to the ore dilution of and reducing the stability of pillars. With proper blasting, the pillars remain undisturbed enabling the extraction of clean ore from the block.

The auxiliary rings consist of belts drilled parallel to the regular blasting boreholes. The purpose of the auxiliary rings is to prevent the destruction of cemented backfill mass. Experience in the world has shown that even if a part of the ore from backfill wall does not fall, it does not lead to anexcessive dilution, but prevents a great depletion in the case of blasting directly next to the backfill leading to the large deformations. However, when the backfill remains intact, a clean and complete ore extraction from the block is possible. Figure 1 presents this excavation method.

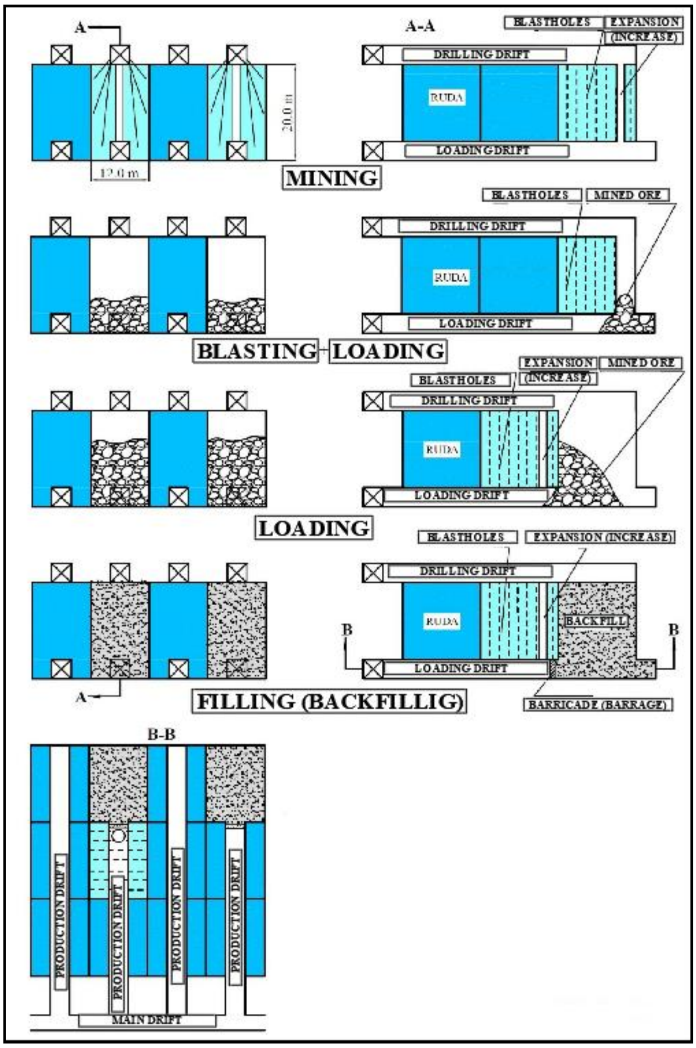


Figure 1 *Method of block excavation with backfilling the excavated area of the Borska reka deposit*

BASIC CHARACTERISTICS OF THE TECHNOLOGY OF EXCAVATION WORKS

The ore excavation by this method is carried out in the mining blocks oriented perpendicular to the ore body. The base of mining blocks is rectangular with dimensions of 12 m wide x 20 m high, and the block length depends on the width of the ore deposit, i.e., on contours of the same, so that it ranges from a minimum of 20 m to 400 m. The excavation of blocks along their length is carried out in segments (stages) from 30 m to 50 m long, depending on geomechanical characteristics in the part of ore deposit where the block is excavated [4, 5].

As soon as a certain segment is excavated to a critical length, according to data provided by geomechanics on the basis of continuous monitoring the stress conditions in the massif [6,7,8], the excavation is stopped and after the block is emptied by removing the mined ore with remote-controlled loaders, the excavation corridor is shielded that is, the loading corridor at the bottom of the block. The corridor at the very exit from the excavated block is armored by installing a suitable barricade (barrage) which, as soon as it reaches a certain level of strength, allows the backfilling of the excavated block to begin from the excavation corridor on the upper floor, which has the current function of a drilling corridor.

The distribution of backfill paste is carried out by the pipelines through the floor corridors and excavation corridor of drilling to the roof part of excavated block segment of the block and fills it up to the floor level of corridor. After filling to the level of the upper floor and hardening of backfill, the next segment of block can be continued in the established order, and until the block is excavated along its entire length. The block excavated and filled in this way represents a pillar for excavation the adjacent blocks according to the same excavation principle.

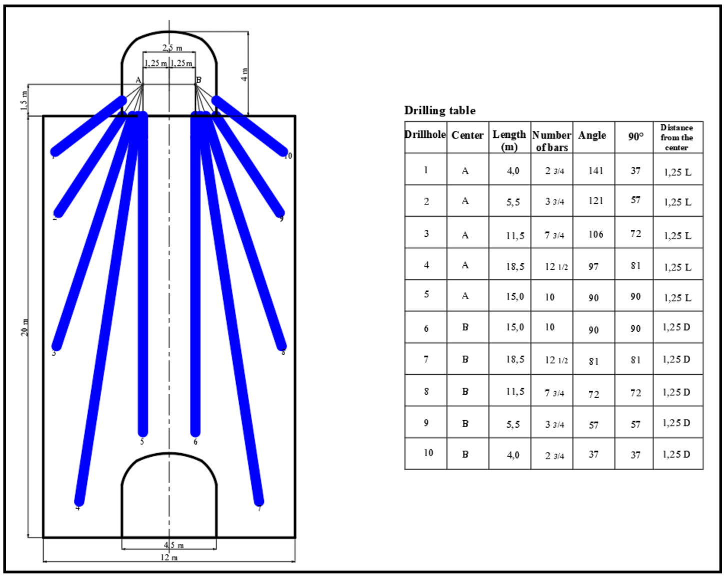
The basic procedure of this method is excavation in an open block where the size and shape of the block are limited by two levels (sub-levels). Drilling and blasting are carried out on the upper floor, and production, i.e., loading and unloading, on the lower floor. Access to the blocks is through parallel transverse excavation corridors, connected to the multi-level corridor, which is parallel to the ore deposit. This method requires moving of transport as the drilling of blocks progresses upwards, where each lower block drilling corridor for the upper block becomes a loading corridor. After filling the excavated (empty) block, the previous level of drilling becomes the next level of production, i.e., transport.

The method requires very good stability control both above the blocks and at the front due to the stress redistribution in the open sequences of block, especially if cracks and faults are present in the surrounding massif. Due to the formation of such stresses in the blocks, it is necessary to minimize the potential leaks on each (location) floor. Full coverage (insurance) is required, i.e., substructure with a suitable subgrade (sprayed concrete + anchor + mesh). In the event of a weaker working environment, the block length must be minimized in order to carry out the work safely.

The order of excavation the mining blocks is from bottom to top. The drilling level for the previous (lower) mining block becomes the loading level for the next (upper) mining block. The ore excavation in mining blocks is carried out in two phases: primary (P, every other block - pillar) and secondary (S). In the first primary phase, every other block is excavated, and the unexcavated blocks have the function of pillars, and a temporary self-supporting structure is formed. The excavated blocks in the first phase are filled with paste backfill, which after hardening the backfill become an integral part of the supporting structure. In the second secondary phase, the remaining blocks, which had the function of pillars, are excavated and, after excavation, they are filled with backfill.

There is no special preliminary preparation the bottom of blocks. A flat section of the block bottom is made by drilling and blasting the deep mine holes from the drilling corridor, where a loading corridor has already been made at the bottom. Therefore, a flat section of 4.5 m has already been formed in the middle of block and remains 3.5 m, to the left and right of the corridor, to form the bottom across the entire block width.

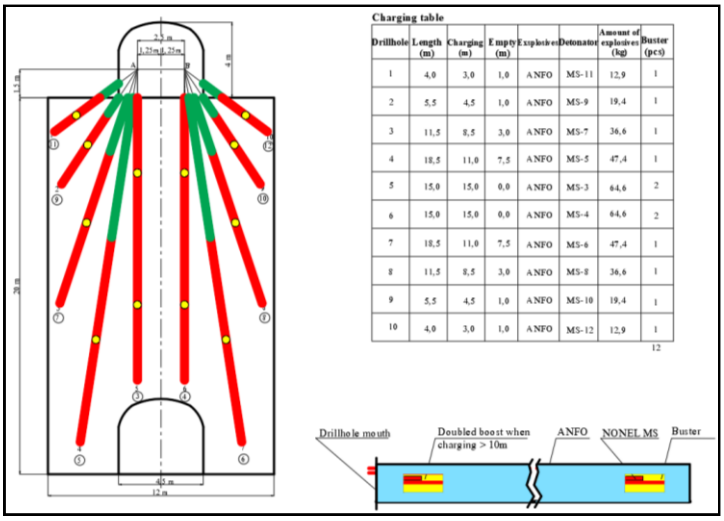
Drilling of deep exploitation drillholes, diameter of 76 mm, is carried out from the excavation corridor of the upper next excavation level in a fan arrangement in the vertical plane. The "fan" drilling is done from two centers at a distance of 2.5 m. The distance between the "fans" is 2 m. Drilling is done from top to bottom. The fans of blasting boreholes are charged with the ANFO explosive mixture. Initiation must be performed with a nonel system with boosters for the process safety. Charging of the blasting boreholes is mechanized [3]. The schemes of drilling and charging the blasting boreholes are presented in Figures 2 and 3.



Drilling table

Drillhole	Center	Length (m)	Number of bars	Angle	90°	Distance from the center
1	A	4,0	2 3/4	141	37	1,25 L
2	A	5,5	3 3/4	121	57	1,25 L
3	A	11,5	7 3/4	106	72	1,25 L
4	A	18,5	12 1/2	97	81	1,25 L
5	A	15,0	10	90	90	1,25 L
6	B	15,0	10	90	90	1,25 D
7	B	18,5	12 1/2	81	81	1,25 D
8	B	11,5	7 3/4	72	72	1,25 D
9	B	5,5	3 3/4	57	57	1,25 D
10	B	4,0	2 3/4	37	37	1,25 D

Figure 2 *Scheme of drilling the blasting boreholes*



Charging table

Drillhole	Length (m)	Charging (m)	Empty (m)	Explosives	Detonator	Amount of explosives (kg)	Buster (pcs)
1	4,0	3,0	1,0	ANFO	MS-11	12,9	1
2	5,5	4,5	1,0	ANFO	MS-9	19,4	1
3	11,5	8,5	3,0	ANFO	MS-7	36,6	1
4	18,5	11,0	7,5	ANFO	MS-5	47,4	1
5	15,0	15,0	0,0	ANFO	MS-3	64,6	2
6	15,0	15,0	0,0	ANFO	MS-4	64,6	2
7	18,5	11,0	7,5	ANFO	MS-6	47,4	1
8	11,5	8,5	3,0	ANFO	MS-8	36,6	1
9	5,5	4,5	1,0	ANFO	MS-10	19,4	1
10	4,0	3,0	1,0	ANFO	MS-12	12,9	1
							12

Figure 3 *Scheme of charging the blasting boreholes*

To start the ore excavation in each block, a compensation space (notch) is made in height by making a compensation shaft using the specialized ROBINS type drills or the latest EASER L Atlas Copco self-propelled sets.

The blasted ore is loaded in the loading corridors with a diesel loader with a bucket volume of 5 m^3 with remote control, and on the loading ramps it is loaded into the pit diesel trucks with a box volume of 10 m^3, which are used for transport unloading into unloading stations or mine shafts. Loaders with remote control are used for loading in blocks. Loading ramps for ore loading into trucks are made at the junction of excavation and floor corridors. Ramps are made in the multi-storey corridors with a height of 6 m [3]. Figure 4 shows a schematic representation of opening and elaboration the exploitation project above the XIX horizon.

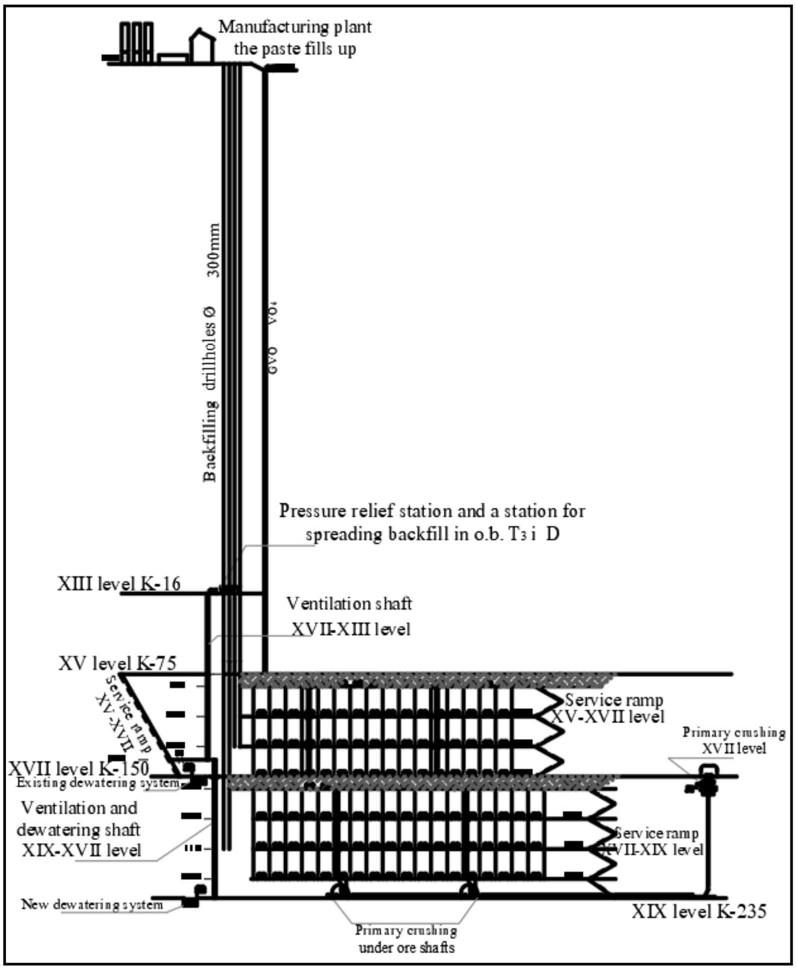


Figure 4 *Schematic presentation of opening and elaboration the exploitation process above the XIX horizon to the surface*

The excavated fields are defined by the exploitation contours of excavated blocks at the floor levels with a height distance of 20 m between floors. The exploitation contour of the mining blocks is divided into chambers with a width of 12 m, oriented transversely (east - west) in relation to the provision of the ore deposit, which is in the north - south. The numbering of chambers is unique for every three mining blocks in both mining operations. The maximum number of chambers is located on the lower excavation blocks, because they have the largest area, while some chambers are excluded on the upper excavation blocks as a result of reduction the excavation fields on them. According to the height of mining operation, the same numbering is kept for all excavation blocks vertically, regardless of the excluded chambers, due to easier monitoring the order of excavation in chambers.

FILLING THE EXCAVATED SPACE WITH BACKFILL PASTE

Backfill paste is defined as a mixture of fine binder particles and water. It contains between 72 and 85% solids by weight. The Portland cement (type 10) is the most often used as a binder. Cement is usually added in a percentage of 2 to 6%, in order to achieve the required strength. Adding slag and fly ash can partially replace cement and reduce costs. At least 15% of particles smaller than 20 microns are required in the paste mass [9].

The location for construction the plant for backfill paste productionon on the surface is above the Borska reka deposit due to as mini9mum as possible transport of backfill paste. On the ground, the location is between the rear buildings of the Sever settlement and the VO4 ventilation shaft plant for making the backfill paste and technical drillholes for backfill distribution.

The plant consists of paste thickeners, thickener feeding system, component dosing system (flocculants-binding agents), water tank, pumps for paste transport, device for density regulation, power plant, compressor, counter for measurement and regulation instruments and system management. A pipeline for delivery of flotation tailings and a pipeline for return water are being installed from the Flotation Plant Bor to the plant. The four technical drillholes are built up to the K-205 level for distribution of backfill past distribution from the level of plant for preparation of backfill pastes from the field surface to the exploitation of the Borska reka deposit. A pipeline is installed for transport of backfill paste from the plant to the drillholes.

The basic raw material for making backfill paste is the flotation tailings from the Flotation Plant Bor. The man-made RTB raw materials (slag, ash, mine waste) can be used as additives. Binding components, flocculants or cementing agents are added in the appropriate ratio to harden the backfill in a certain time and with the designed strength. Pastes are of high density, over 80% solid. A plant with a capacity of 900,000 m^3 of backfill paste in a hardened state is being built on an annual basis, with the possibility of expansion.

The floor corridors and excavation corridors at the drilling level, i.e. from the top of excavation level of each excavation level, will be used for distribution of backfill and backfilling of excavated blocks. Distribution of backfill is achieved by the pipelines from the drillholes of backfill through the floor corridors and then through the excavation corridors to the end of excavated block, where it is released by gravity into the open pit. The transport system consists of the two-by-two vertical drillholes from the field surface to the -130 or -205 level and pipeline along the floor corridors and other excavation corridors that will transport the backfill paste, Figure 5.

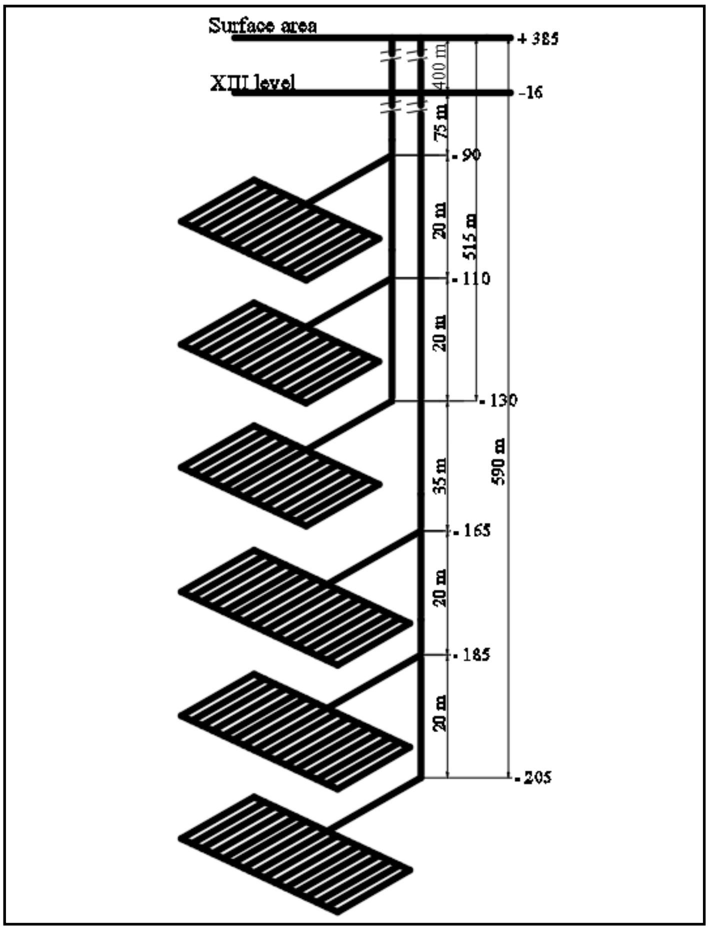


Figure 5 *Transport scheme for delivering the backfill pastes by pipelines through boreholes and corridors to the designed backfill levels*

Transport or distribution of materials in the underground mine on the floor levels out of which the backfilling or filling the excavated blocks is carried out via steel pipes installed in the ceiling of the access floor corridors.

CONCLUSION

Applying the high-capacity and high-productivity methods of excavation with the ore and overburden massif destruction, it is necessary to relocate the facilities, infrastructure, and settlements from the terrain surface, and this requires the large investment funds, a long period of realization and high initial investments. Its negative impact on the environment is evident, especially on population of the Brezanik settlement, which would have to be displaced due to the possible terrain deformation.

Continuing the underground mine production in exploitation the Borska Reka deposit, adopting the block excavation of ore with subsequent filling of the empty space with the high-density backfill and excavation the out pillars, it is possible to ensure the minimum depletion, high utilization, above all the safety of employees during excavation, compatibility the geometry of the open pit with the working environment, while preserving all the facilities, infrastructure on the terrain surface with minimizing the impact of performed underground exploitation works on the environment.

Considering the impact of exploitation method on the environment and facilities, it is minimal due to the fact that the underground method of excavation using the current method is the best way to protect the natural environment so far. This method of deposit exploitation will not affect the environment and facilities, because the proposed block excavation method with backfilling the excavation is the best way to protect the environment. Regarding the deposition of tailings, obtained by the flotation ore processing, more than 80 % of them will be used as theraw material for making backfill pastes and filling excavations in the underground mine Jama, and only a small part will be disposed on the tailing dump.

The costs of construction a tailing dump and deposition of tailings on the surface mostly cover the costs of building a plant for making the backfill pastes and costs of backfilling the excavations.

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