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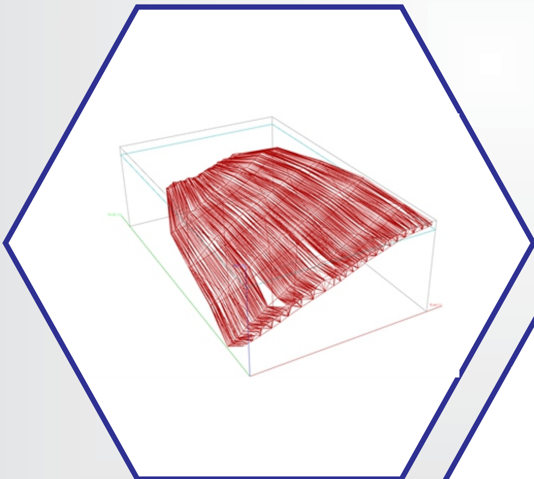

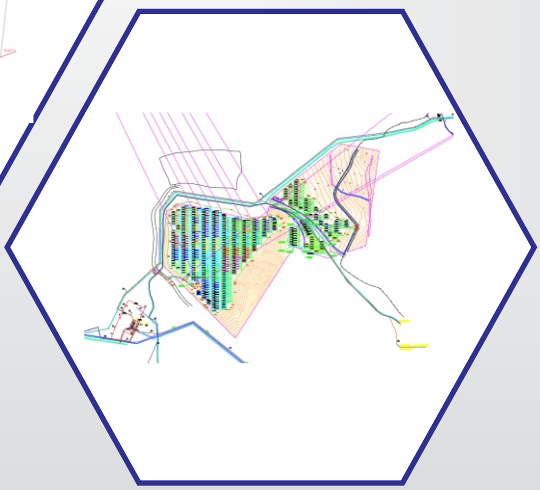

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Aleksandar Doderović[*1], *Miljan Gomilanović*[*2], *Nikola Stanić*[**3],
Saša Stepanović[*4], *Daniel Kržanović*[*5]

TECHNOLOGICAL BENEFITS OF RELOCATION AND EXTENSION A CONTINUOUS PART OF THE COAL TRANSPORT SYSTEM[***]

Orcid: 1) https://orcid.org/0000-0003-3665-6784 2) https://orcid.org/0000-0002-1209-7423
3) https://orcid.org/0000-0002-6620-8563 4) https://orcid.org/0000-0003-3485-201X
5) https://orcid.org/0000-0003-3841-8667

Abstract

Due to the changing conditions of the working environment or its insufficient knowledge, the coal exploitation takes place with smaller or larger deviations from the designed or planned activities. Depending on which segment of the entire exploitation system the deviation occurred, it will also depend on the extent to which the deviation will affect the profitability and efficiency of exploitation. If major accidents are excluded, the technological process of transport has the greatest impact on the efficiency and economy of exploitation. The newly created situation at the open pit Gacko – Central Field in terms of coal transportation was analyzed in the presented paper. Also, the benefits are presented that arise as a result of reconstruction the combined coal transport system, continuous and discontinuous part. The system reconstruction included the extension of continuous part of transport and relocation the crusher closer to the front of the works, in order to reduce operating costs. On the other hand, discontinuous transport is reduced to the zone where the works are carried out, in order to reduce the operating costs and use the maneuverability of discontinuous equipment. This paper explains the technological-organizational, economic and ecological benefits of reconstruction the coal transport system, for the short and long term.

Keywords: *open pit exploitation, combined transport systems, coal exploitation, benefits*

1 INTRODUCTION

The open pit exploitation of mineral deposits is becoming more and more challenging, especially when it comes to the open pit coal mines. This complexity arises from the deeper deposit, presence of overburden interlayers in the coal seams, and steeper bedding of the seams, all of which together lead to an increase in the overburden coefficient and varying quality [1,2,3]. An important parameter that characterizes the exploitation in these conditions is an increase transport costs with increasing depth of the open pit, while in the case of decreasing depth, these costs decrease [4].

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnstajna 1, 19210 Bor, Serbia,*
E-mail: aleksandar.doderovic@irmbor.co.rs
[**] *RB Kolubara, EPS, Svetog Save 1, 11550 Lazarevac, Serbia*
[***] *This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, contract number 451-03-66/2024-03/200052*

The application of high-capacity continuous systems reduces the unit costs of transport and thus the total costs of exploitation. In accordance with the different and specific conditions that prevail in the modern open pit mines, very complex machinery is used, which is dimensioned according to the special requirements, in order to be able to respond to the specific working conditions [5]. These systems are structurally and constructively complex and reflect a strong interdependence between elements [6]. They play a key role at the coal open pits where the homogenization process is carried out. This process is aimed to meet the set requirements in terms of minimum costs and environmental impact, as well as ensuring the optimal coal quality by mixing multiple seams with different quality from multiple levels [7].

The case study, presented in this paper, included an analysis of benefits resulting from changing the configuration of the existing DTD system at the open pit Gacko – Central Field. In technological terms, there are clear differences between continuous and discontinuous loading and transport systems. Continuous systems provide a continuous flow of material, while discontinuous systems operate with interruptions in the process. Combined systems, as their name suggests, represent a combination of elements of both groups of systems, with the aim of utilization the potential advantages of both continuous and discontinuous technological solutions [1].

Coal mining in the area of the Gacko coal basin takes place in the area of the open pit Gacko – Central Field in two separate exploitation zones, namely:

- Central Exploitation Zone (CEZ), and
- Roof Exploitation Zone (REZ).

In addition to these two zones, the active execution of works is also being carried out in the area of the Great External Landfill, as well as in the western part of the basin in the area of the former Field B, where the excavated waste is disposed of. From an organizational and functional point of view, carrying out the exploitation is not simple due to the great distance between the work sites. The spatial arrangement of the work sites and problems that arise have already been described by the authors of this paper in earlier publications [8,9].

After the earthquake that occurred in April 2022, the exploitation was first partially, and during 2023, completely moved to the REZ. Due to the very unfavorable situation in the CEZ, primarily the large amounts of overburden that need to be excavated, for a certain period of time the coal exploitation will be realized exclusively in the Roof Exploitation Zone.

1.1 Description of Geology and Working Conditions in the Roof Exploitation Zone

The natural conditions prevailing in the REZ are characterized by a lower coefficient of overburden but also by the complex structural and qualitative characteristics. Spatial arrangement of the seams, more precisely the absence of clear boundaries between the seams and their non-uniformity with characteristically small thickness do not make the process of exploitation simple.

In addition to the structural characteristics of the deposit, the process of exploitation, i.e. provision the necessary quantities of coal of appropriate quality, is influenced by the already mentioned seam thickness and relatively short front of works. The seam thickness in certain parts of the REZ is below the possible level of selection the existing mining equipment. Half of the total number of seams is 0.5 m thick, while about 75% of seams are below 0.9 m [10].

Figure 1 *Overview of working slopes within the REZ with spatial arrangement and seam thickness [11]*

In such working conditions, it is realistic to expect that the exploitation process takes place with losses in production, in the form of losses in both mass and quality of coal. The authors said a little more about losses in the exploitation process in the paper "Analysis of Losses in a Function of Selection the Level of Roof Coal Series - Coal Deposit Gacko" [10]. From the above, it is clear that the entire exploitation process must be carried out selectively [12] and that on this occasion the excavators with a bucket volume of 3 - 6 m^3 should be used as the excavation equipment [13].

2 CONFIGURATION OF THE COAL TRANSPORT SYSTEM AND DESCRIPTION OF TECHNOLOGY

The coal mining system is organized on the principle of a combined system with application the selective mining. According to the existing project documentation, the coal mining is to be realized with the bucket excavators with a bucket volume of up to 6 m^3, and transport of mined coal is to be carried out by trucks with a capacity of 55 t to the crusher. After crushing, coal is transported by the belt conveyors to the secondary crusher, from where it is further delivered either to the landfill or directly to the thermal power plant block.

As a part of the DTD system, there are two crushers SB1515 and SB1315 and 4 conveyors with a belt width of 1200 mm (PTU, TU-1, TU-2, TU-3). Figure 2 shows the spatial arrangement of zones where coal exploitation is planned, network of transport roads and position of facilities within the DTD system for coal transport.

2.1 Description of the problem

The problem that arises in the new situation is that the current position of a crusher and layout of a conveyor is configured as a compromise solution for the balanced or majority exploitation of coal from the Central Exploitation Zone. Due to the lack of equipment and delay in excavating the necessary amounts of overburden, even before the aforementioned earthquake, most of the coal mining was carried out from the REZ. This deviation from the general method of exploitation was reflected in several aspects of exploitation process, in such a way that one problem led to another, and so on until the complete change of work organization, a domino effect.

The reliance of entire production on coal from the REZ required the excavation of significantly larger quantities of coal of lower calorific value. In order to ensure larger quantities of coal, but also due to the lack of trucks with a capacity of 55 t, the entire amount of coal that was mined was transported by trucks with a capacity of 110 t. On the other hand, in order to ensure the efficient selective exploitation of coal, the excavators with a bucket volume of up to 6 m^3 were retained. From the technological side, the excavator-truck sys tem in this configuration is less efficient, primarily due to the long loading time of truck.

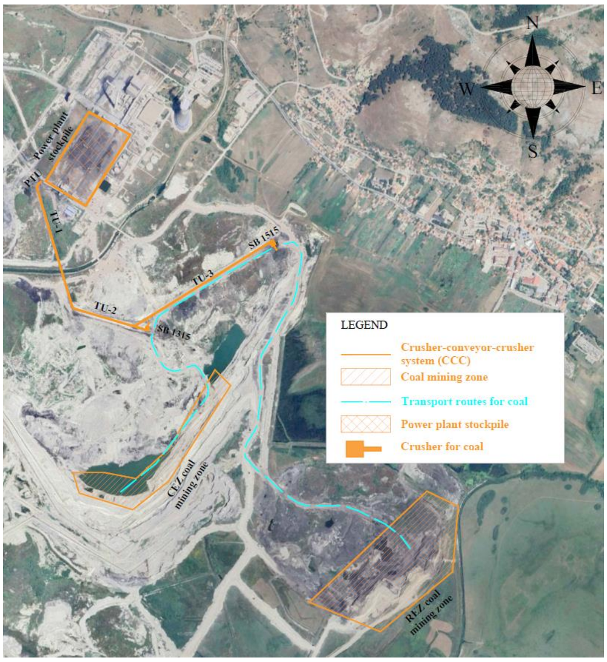

Figure 2 *Spatial arrangement of zones where the coal exploitation is planned, network of transport roads and positions of facilities within the continuous part of coal transport system [14]*

In addition to the impact on excavation technology, a more significant problem arising in the newly created situation is the length of transportation. As it can be seen in Figure 2 currently, the position of a coal crusher is significantly away from the center of mass of the coal mining within the REZ. The length of the route shown in Figure 2 was about 2400 m.

The increase in the transport length affected the increase in normative costs. Which is expected in accordance with the fact that transport is a technological operation that generates the largest part of costs, within operating costs [15, 16]. In addition to the operational costs, it is necessary to hire an additional number of trucks in an organizational sense, both due to the increase in transport lengths and increased need for larger quantities of poor quality coal.

The impact of transport, in addition to the necessary requirements for redistribution the equipment and increase in production costs, also occurs in the environmental aspect. The position of the main part of transport communication from REZ from the crusher position is for the most part at the level of a mining field, which adversely affects the emission of dust and noise to the environment. These impacts are not dramatic and on a larger scale, but they are present; the reduction of which requires the additional attention.

Continuation of the coal exploitation in the future will be realized from the eastern part of the basin, which will result in an inevitable shift of the center of mass to the east. Accordingly, it is realistic to expect that the existing configuration of the DTD system will undergo a certain number of changes.

3 CHANGING THE COAL TRANSPORT SYSTEM

Reconstruction of the DTD system for coal transport is a topic that the authors have dealt with before [17]. Based on that solution, as well as the new findings and plans, the previously defined system was supplemented. Relocation of the coal transport system implies the following technological operations:

- Relocating and changing the configuration of the existing TU-3 conveyor.
- Construction of the route and formation of the new TU-4 conveyor.
- Construction of the route and formation of the new TU-5 conveyor.
- Moving the primary crusher to the REZ.
- Construction of a protective embankment towards the city from excavated materials.

In addition to the work on changing the configuration of the coal transport system, it is possible to reorganize the drainage system with the aim of collecting water from the northern catchment area.

In accordance with the previously stated, Figure 3 shows the conceptual solution for changing the configuration of the DTD system for coal.

Reconstruction of the DTD system included relocation of the existing conveyor TU-3 at the level 936. Introduction of the new conveyors will be realized beyond the reached limits of the open pit mining works. The TU-4 transport route runs in the west-east direction, while the TU-5 transport route runs in the north-south direction. Parallel to the TU-5 conveyor on the western side, there is also a transport road for trucks with a capacity of 110 tons. The plateau of the primary crusher is positioned at level 936 within the REZ.

During the previous period, a major problem in the coal transport and crushing was its wetting during transport on conveyors. In addition to the problems that occurred at the secondary crusher, due to the coal wetting during transport, a problem with a drop in quality was also observed. In order to eliminate the negative effects in the process of reconstruction the DTD system, it is planned to cover all conveyors.

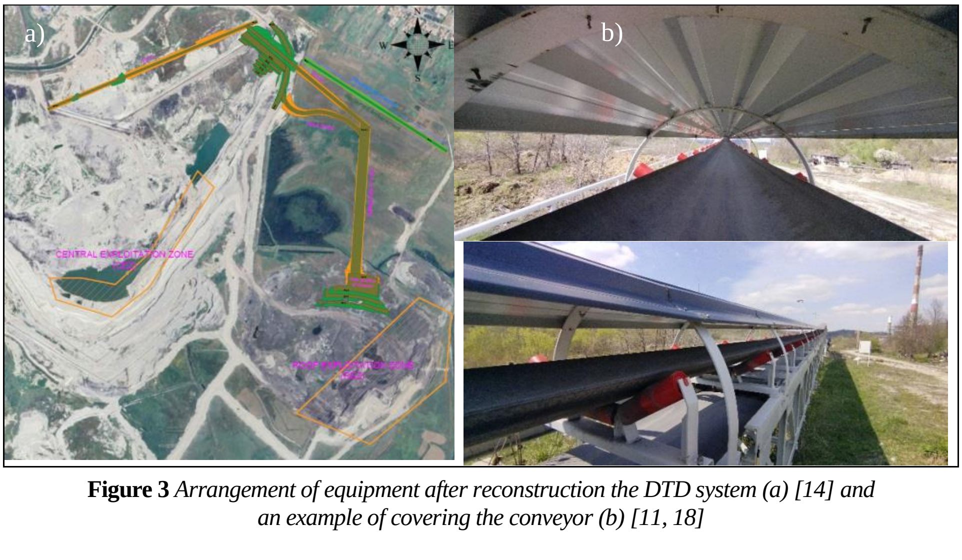

Figure 3 *Arrangement of equipment after reconstruction the DTD system (a) [14] and an example of covering the conveyor (b) [11, 18]*

4 ANALYSIS OF BENEFITS

Reconstruction and upgrading of the DTD system provides technological and organizational benefits for the entire exploitation system. In addition to these advantages of changes in technology or organization, and in addition to improving the working conditions, there is an increase in the economy of the entire exploitation system. For such an undertaking, such as the relocation of the DTD system, it is necessary to allocate certain investment funds. The positive effects of investment do not necessarily manifest as a direct net profit, but their effects can manifest in the form of better use the existing equipment, possibility of more efficient quality management, extension of exploitation time, etc. Also, the realized works can provide benefits in the ecological sense.

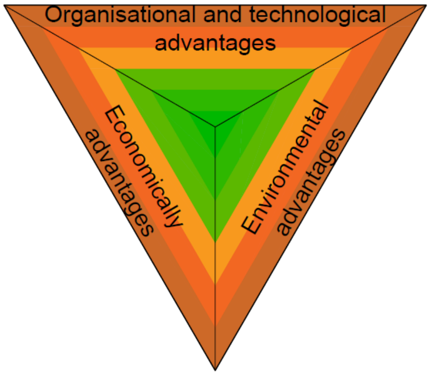

Figure 4 *Triangular scheme of benefits of the system reconstruction benefits*

4.1 Organizational and Technological Benefits

The technological and organizational benefits of reconstruction at the open pit exploitation can be expected primarily in relation to the mentioned disadvantages and aggravating circumstances of the newly created situation. So, it is possible to provide with these works:

- Reduction of transport lengths.
- Re-introduction of the 55 t capacity trucks with excavators with a bucket volume of 6 m^3.
- Increasing the efficiency of coal exploitation technologically and qualitatively.
- Return the trucks with a carrying capacity of 110 t to their original function of transporting overburden transport.

Accordingly, an analysis of a discontinuous part of coal transport from the REZ to the coal crusher before and after the reconstruction of the DTD system for transport with trucks carrying capacity of 110 t (variants V1 and V2) and 55 t (variant V3) was performed. During the analysis in all variants in the excavator-truck system, the excavators with a bucket volume of 6 m^3 were used. The calculation results are shown in Table 1, and the entire analysis was done for the annual coal exploitation capacity for 4 different cases.

Table 1 *Engaged equipment of a discontinuous part of the combined system at the REZ coal mining*

Capacity	Variant					
	V1		V2		V3	
t/year	Excavator	Truck Belaz 75135	Excavator	Truck Belaz 75135	Excavator	Truck Belaz 7555
1,000,000	1	3	1	2	2	3
1,500,000	2	4	2	3	2	4
2,000,000	3	5	2	4	3	5
2,500,000	3	6	3	5	3	6
3,000,000	4	7	**3**	**5**	**4**	**7**

As it can be seen, the two most favorable variants based on the criterion of the number of engaged equipment involve transport over a shorter distance, i.e. from variant solutions with relocation the DTD system. And if, in terms of reserve, it is more favorable to use the trucks with a capacity of 110 t, there is no reason not to use the trucks with a capacity of 55 t. Seen from the point of view of organization the exploitation system, the introduction of trucks with a capacity of 55 t in combination with excavators with a bucket volume of 6 m^3 provides a necessary formation of the system, that is, equipment for coal exploitation. In addition, the trucks with a carrying capacity of 110 t are returned for exclusive operation as a part of the combined system.

4.2 Reorganization Plan of Exploitation

The dynamics of introduction the 55 t trucks can be realized gradually, and Figure 5 shows the Gantt chart of the dynamics of equipment replacement and reorganization of the entire operation.

Ist year - during this period, it is planned to start the process of moving, reorganizing and equipping the DTD system. Also, in addition to the procurement of equipment during this year, it is necessary to start the procedure for procurement the trucks with a capacity of 55 tons.

IInd year - during this period, it is planned that the coal transport system will operate with full or majority exploitation of coal from the REZ. During this period, trucks with a capacity of 110 t are working to transport coal within the REZ, which on average requires a reduction of the truck fleet compared to the first year by 1-2 trucks, depending on capacity, as well as 1 excavator, depending on capacity.

IIIrd year - during this period, it is planned to introduce the 55 t trucks for coal transport, while the 110 t trucks will be fully returned to work with overburden as a part of the combined system.

IVth year - during this period, it is possible to consider reducing the amount of coal from the REZ and starting the exploitation of coal from CEZ as well. This type of exploitation would entail reloading up to 2 trucks with a capacity of 55 t and transferring them to the CEZ.

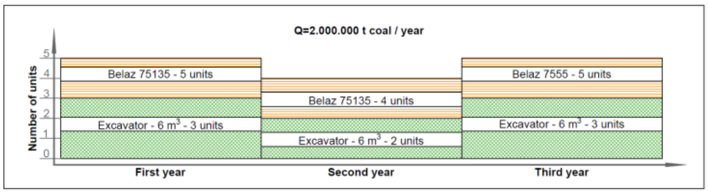

Figure 5 *Gantt chart of work realization for capacity of 2,000,000 tons of coal per year*

4.3 Environmental Benefits

By returning the truck transport to the limits of exploitation zones, the possibility of reducing noise and dust emissions on the surrounding land is achieved. In addition to these benefits, the introduction of the new conveyors, primarily the TU-4 conveyor, whose position is parallel to the urban zone of the municipality of Gacko, it is possible to expect the increased noise generation due to the conveyor operation. In order to reduce noise, the formation of a protective embankment and its greening are planned. Also, in addition to the creation of an embankment that only partially follows the route of the TU-4 transporter, the reconstruction of the transporter implies their covering. In this way, a reduction in the impact of atmospheric precipitation on coal quality is achieved, as well as a reduction in noise and dust emissions.

4.4 Economic Benefits

The economic benefits of changing the configuration of the DTD system are of a long-term nature and primarily relate to the reduction of operational production costs. The fact is that the distance from the location of exploitation to the end consumer is not small and that as exploitation progresses, the distance will grow more and more. The new position of a crusher, as well as introduction the two new conveyors for coal transport, primarily reduce the volume of discontinuous transport, which by its nature is more expensive, but also more suitable for the conditions prevailing inside the open pit. On the other hand, most of the transport has been redirected to the continuous transport, which is more convenient from the economic point of view.

By realization the selective coal exploitation on a larger scale, it is possible to ensure significantly more efficient exploitation, and above all, a longer period of exploitation.

CONCLUSION

The process of surface exploitation THE mineral deposits is a dynamic process that requires periodic progress and displacement of work site (work front). When it is taken into account that the entire process takes place in order to supply consumers such as the thermal power plants, landfills or preparation and processing facilities with excavated mineral raw materials which, as a rule, are fixed and objects of a stationary character, a periodic increase in the length of transport appears as an inevitability. This results in an increase in the costs of entire process, as well as an increase in product price of product delivered to the end users.

The way in which this problem has been solved in practice so far is the introduction of combined transport, i.e. a combination of discontinuous and continuous transport. In this way, the heavy-duty mining trucks are limited to work within the contour of the open pit, while continuous transport is realized from the crusher located on the rim or inside the open pit to the landfill or plant for preparation the mineral raw materials.

In the presented case study that dealt with the newly situation at the open pit Gacko – Central Field, the problem of increased discontinuous transport led to a non-conformity of individual technological operations and equipment operation in the entire coal transport system. From this new situation, it is clear that the existing configuration of the coal transport system must undergo certain changes. The best solution, especially when taking into account that the work front will progress further towards the east, is to extend the continuous part of this system. Applying the existing combined system, along with the extension of its continuous part of transport, the positive elements of both types of transport are used in the most favorable way, while the negative impacts are reduced to a minimum.

For an undertaking like this, it is necessary to set aside two very important resources, namely money and time. The investments are a necessary part of the entire exploitation process, in order to ensure efficient and economical exploitation. From this point of view, time is a significant resource, primarily because the realization of any investment requires the investor to commit the time resources for investment realization. Also, the investment return time is significant because it should be as short as possible. In the specific situation, the investment return is not considered primarily as a net value, but rather as a way that will ensure as soon as possible the most favorable working conditions and increase the efficiency of the coal mining system. Of course, with the provision of these conditions, the economic profit is also expected through reduction the operating costs.

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Original Scientific Paper
Mining Engineering

*Ivica Vojinović[*1], Igor Svrkota[*2], Miloš Stojanović[*3], Dragan Šabaz[*4], Radmilo Rajković[*5]*

SLOT DEVELOPMENT USING THE CONTROLLED BLASTING IN THE ORE BODY "BORSKA REKA"[**]

Orcid: 1) https://orcid.org/ 0009-0006-3658-6922 2) https://orcid.org/0000-0002-3779-6327
3) https://orcid.org/0000-0003-0044-5491 4) https://orcid.org/0000-0002-1373-413X
5) https://orcid.org/0000-0001-5905-6613

Abstract

The occurrence of deviations in the drilling of long blast holes can negatively impact the quality of blasting and safety of personnel and pillars in the room and pillar mining methods. The application of controlled blasting through a two-step blasting process for creating a compensation chamber (slot) is presented due to the occurrence of blast hole deviations. Initiation sequences of holes in the two-step blasting process were determined by surveying the holes and simulating blasting in the Datamine Aegis software. Blasting the lower and upper parts of the slot created a free space of approximately 840 m³ with an approximate specific explosive consumption of 2.25 kg/m³.

Keywords: *controlled blasting, slot, room and pillar, Datamine Aegis, powder factor*

INTRODUCTION

Blasting refers to the technical use of the destructive force of explosives, which is used in mining for breaking rocks and mineral raw materials during underground and surface mining operations [1].

For this purpose, a cavity of appropriate dimensions (blast hole, blast chamber) is created in the rock mass or mineral raw material to accommodate a corresponding amount of explosive, known as explosive charge, and prepared for detonation using an appropriate initiation device. Such an amount of explosive, placed and prepared for detonation, is known as a mine.

Drilling of holes is to a greater or lesser extent accompanied by deviations, which can negatively impact the quality of blasting, ore dilution, and the safety of personnel, excavations or safety pillars [1].

The arrangement of blast holes can vary depending on the applied blasting method, type of cut, hole deviations, physical and mechanical properties of the rock mass in which the mining object is being constructed, and dimensions of it. The arrangement of blast holes at a particular worksite, which includes all blast holes for a single blasting operation, is called a blasting pattern [1].

This paper provides a detailed description of application the controlled blasting in creation a compensation chamber, specifically a slot, for the purposes of room-and-pillar mining in the "Borska reka" ore body.

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia,
E-mail: ivica.vojinovic@irmbor.co.rs*

[**] *This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract No. 451-03-66/2024-03/ 200052.*

MINING METHOD IN THE “BORSKA REKA“ ORE BODY

The planned mining method in the 'Borska Reka' ore body is the room and pillar block method of excavation with backfilling of excavated space using the paste backfill.

The basic parameters of adopted excavation method are: room (chamber) width 12 m, pillar width 12 m, room height 20 m, and room length variable from 30 to 50 m [2,3].

The number of access drifts to the room is typically related to the room size, but in this case, two access drifts are planned. Dimensions of the access drifts are 4.5 x 4 m and they are constructed along the room axis. The factor influencing the planned dimensions of access drifts includes the equipment used, ventilation requirements, as well as considerations the stability of excavations. The stability and safety of the drifts are primarily ensured by appropriate ground support using shotcrete, anchors, and mesh [2,3].

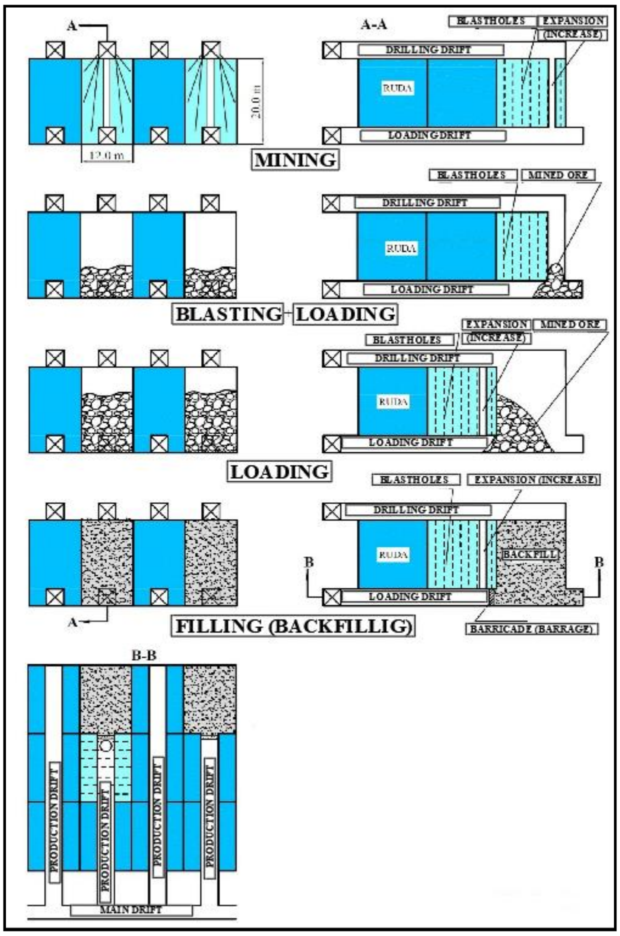


Figure 1 *Mining method in the “Borska reka“ ore body [2,3]*

Division is necessary on each level through level drifts constructed within the ore body itself, forming sectors for the phased excavation of the mining area, significantly reducing the start-up time of excavation in the mining field [2,3].

The ore excavation in the room is achieved through drilling and blasting. Access to the room is obtained by constructing the access drifts longitudinally relative to the direction of ore body excavation [2,3].

The first phase involves creating a slot between levels that define the planned face area of the room, with a height of 20 m and width of 12 m [2,3].

The room formation is achieved by the blasting ring-shaped blast holes between two levels, but for the initial opening of the face of the room, it is necessary to create an initial opening or expansion that provides sufficient void for ore compensation by blasting the initial ring of blast holes. The compensation chamber or slot is formed at the full height of the chamber, in this case connecting the upper drilling access drift with the lower loading access drift [2,3].

After achieving the planned length of the room and removing the mined ore, that segment of the room is backfilled with the paste fill. After it has hardened according to a specified schedule, excavation in the room continues [2,3].

The rings must be drilled parallel to each other, and in this case, a vertical direction for the rows of blast holes in the rings was chosen. It is crucial that the filling of the rings is done completely accurately to prevent the formation of oversized ore pieces or jeopardize the cement paste fill, which could lead to the ore dilution and reduce the stability of pillars or rooms. Proper blasting ensures that the pillars remain undistorted, allowing for the extraction of clean ore from the room, as well as ensuring their stability and safety [2,3].

SLOT DEVELOPMENT METHOD

In the mentioned ore body in the underground mine 'Jama', four methods for creating slots for initial blasting in the sublevel caving method have been tested: creating a conventional raise bore (ALIMAK), using a ring drilling at various angles, drilling parallel blast holes for controlled blasting to form the cut, and creating raises through the two-stage blasting [2].

The new method of slot development is very similar to the previous one (creation of raises through two-stage blasting), where the raise drilling pattern remains the same (Figure 2), and the number of blasts is also two. The difference lies in drilling the additional 24 holes arranged in a ring pattern across three rows and their initiation sequence.

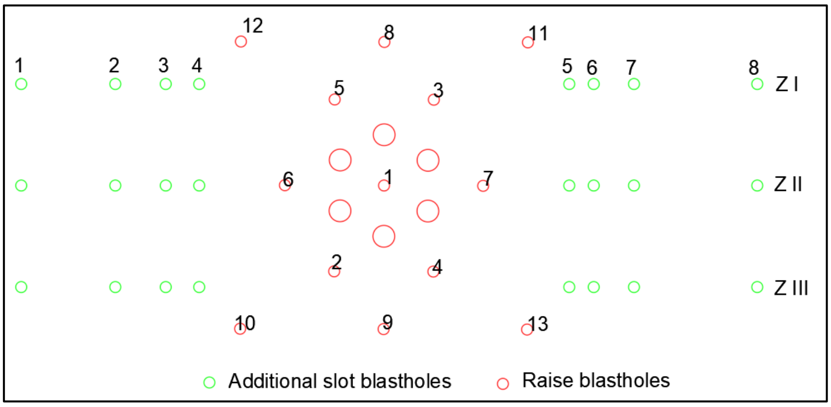


Figure 2 *Slot blastholes pattern*

The holes in the raise are drilled vertically downwards, while the additional holes are drilled at the predefined angles. Drilling is performed using the Atlas Copco Simba 1354 drilling rig. Prior to the drilling phase, surveying work is conducted to mark the central hole and azimuth of the other rows of blast holes. After drilling is completed, top and bottom surveys of the drilled blast holes in the raise are conducted to determine the potential deviations.

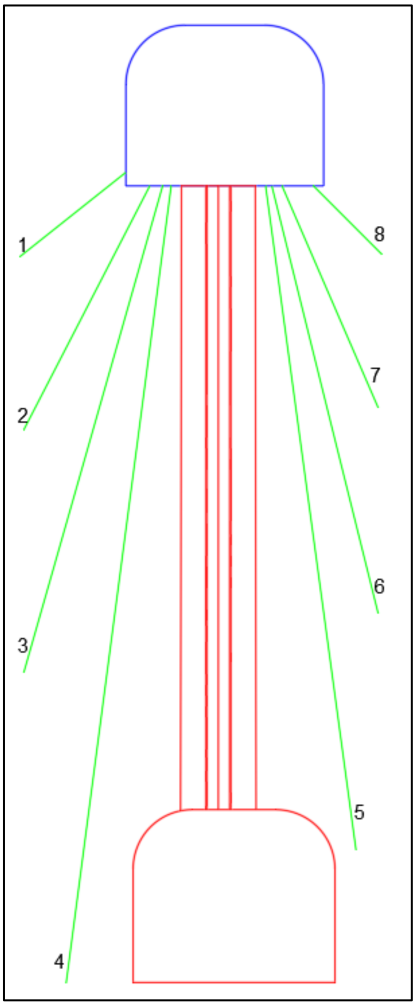


Figure 3 *Cross-section of the raise and ore body blast holes*

It can be seen from Figure 3 that the raise holes are drilled down to intersect the lower drift. This allows for surveying the blast holes after drilling is completed to determine their deviations (Figure 4). This information is crucial for establishing the initiation sequence.

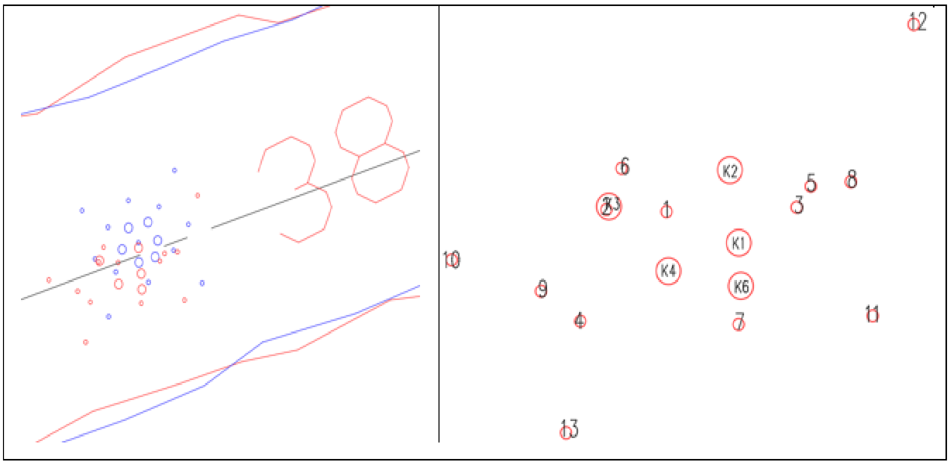
After conducting the survey of blast holes and determining the initiation sequence, the blasting operations follow.

First, the raise holes are initiated to create free space for blasting the rows of blast holes in the side, thus achieving the necessary width of the slot. Upon completion of blasting and ventilation, the operational phase of loading the blasted material follows. Planning for the upper part of the excavation is done similarly, using the same blast hole survey for determining the initiation sequence, with the order now adjusted.

SLOT DEVELOPMENT IN THE DRIFT OH38L

The application of a new method for creating a slot using controlled blasting in the 'Borska Reka' ore body is further described using the example of slot development in the access drift OH38L between two levels, K-110 and K-130.

After marking the central blast hole and azimuth of the other rows of blast holes, they are drilled accordingly. Deviations of the blast holes are determined by surveying the top and bottom of the blast holes in the raise (Figure 4).



a) b)

Figure 4 *Surveyed holes: a) location of blast holes at the level K-110/K-130; b) location of blast holes at the level K-130 due to the deviation*

For a better understanding of the issue, planned and surveyed blast holes were input into the Datamine Aegis software package.

This program helps to clearly visualize the direction and magnitude of blast hole deviations both in 2D and 3D views (Figure 5).

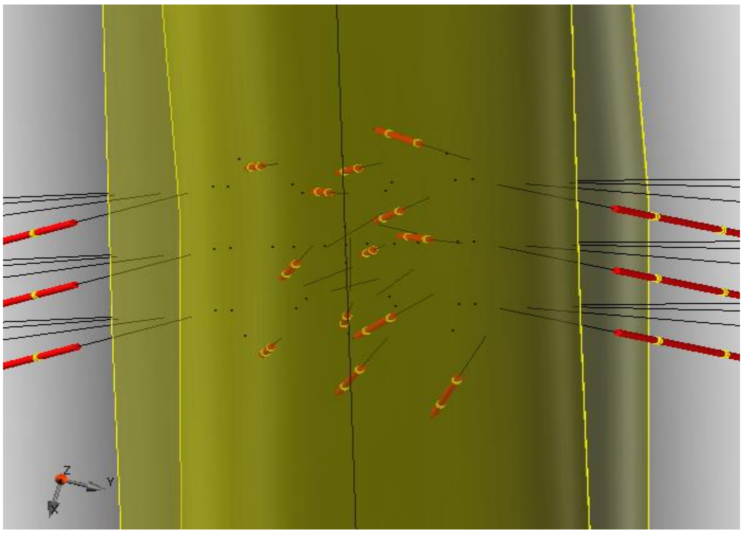


Figure 5 *3D representation of blast hole deviations in Datamine Aegis software (plan view)*

Deviations of the blast holes can also be displayed in 2D views on vertical profiles. Figure 6 shows an example of vertical profiles with surveyed blast holes (left) and planned blast holes (right), clearly illustrating the extent of blast hole deviations.

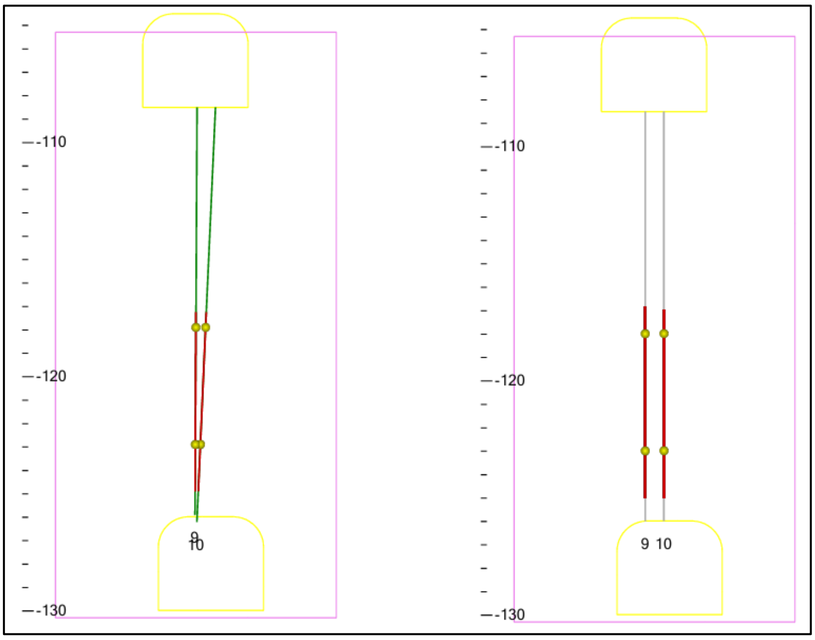
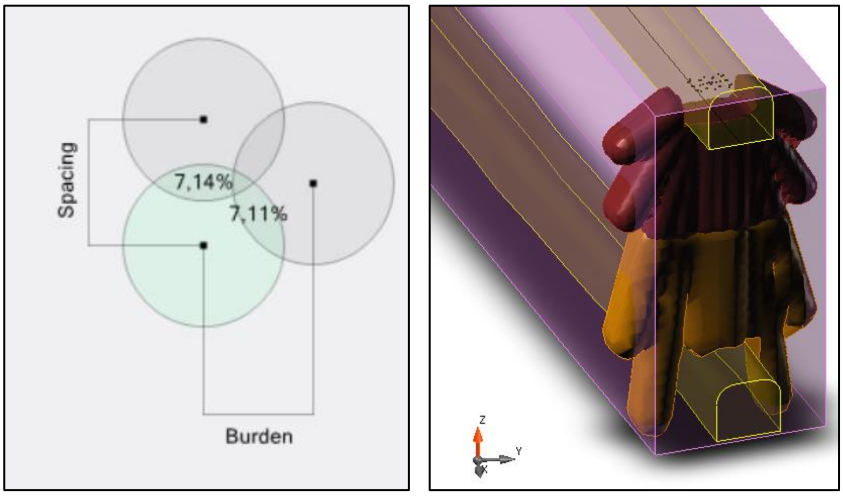


Figure 6 *Vertical profile of surveyed (left) and planned (right) blast holes 9, 10*

Deviation was observed only in the raise blast holes, due to the current lack of instruments for measuring deviations in the side blast holes. These side holes are not drilled to intersect the drift at the lower level; instead, their bottom remains in the rock mass.

Based on the provided data, the initiation sequence was determined graphically using the software, and a mining model was created in the Aegis software. Through simulation in the software for each blast hole, an approximate radius of explosive effect was obtained, and the initiation sequences of the lower part of the drift were determined due to the overlapping of these radii (Figure 7), as shown in Table 1.



a) *b)*

Figure 7 *Determining the blast radius (a) and simulation of the slot blasting (b)*

Table 1 *Blasting parameters of the slot bottom part*

Slot blasting bottom part OH 38L -110/-130				
Blast hole ID	**Series**	**Delay (ms)**	**No. of det. + bust.**	**Explosive amount per series (kg)**
1	1	100	2	30.61
2,3	2	800	4	61.22
6,7	3	2500	4	61.22
4, 5	4	4500	4	61.22
8, 9, 10, 11, 12, 13	5	5000	12	183.66
ZIII - 4, 5	6	5500	2	93.05
ZII - 4, 5	7	6025	2	93.05
ZI - 4, 5	8	6525	2	93.05
ZI - 3, 6	9	7050	2	33.06
ZII - 3, 6	10	7575	2	33.06
ZIII - 3, 6	11	8500	2	33.06

Schematic representation of a detonator conection in the bottom part of the slot is shown in Figure 8.

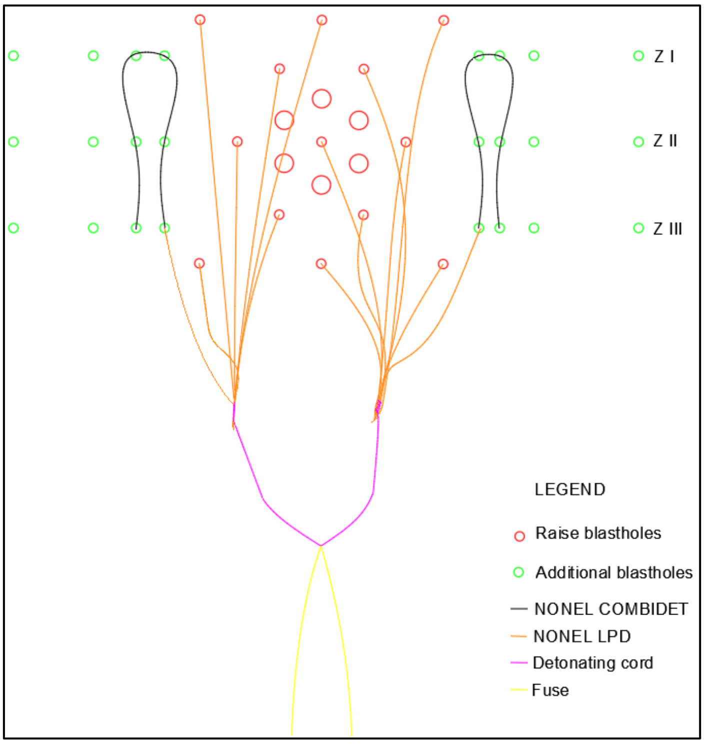


Figure 8 *Schematic representation of detonator conection in the bottom part of the slot*

Table 2 *Blasting parameters of the slot upper part*

Slot blasting upper part OH 38L -110/-130				
Blast hole ID	**Series**	**Delay (ms)**	**No. of det. + bust.**	**Explosive amount per series (kg)**
1	1	100	2	30.61
2,3	2	500	4	61.22
4, 5	3	700	4	61.22
6, 7	4	900	4	61.22
8, 9, 10, 11, 12, 13	5	1200	12	183.66
ZI - ZIII 4, 5	6	1600	6	230.16
ZI - ZIII 3, 6	7	2500	6	236.28
ZI - ZIII 2, 7	8	4500	6	170.16
ZI - ZIII 1, 8	9	6000	6	77.13

Schematic representation of a detonator conection in the upper part of the slot is shown in Figure 9.

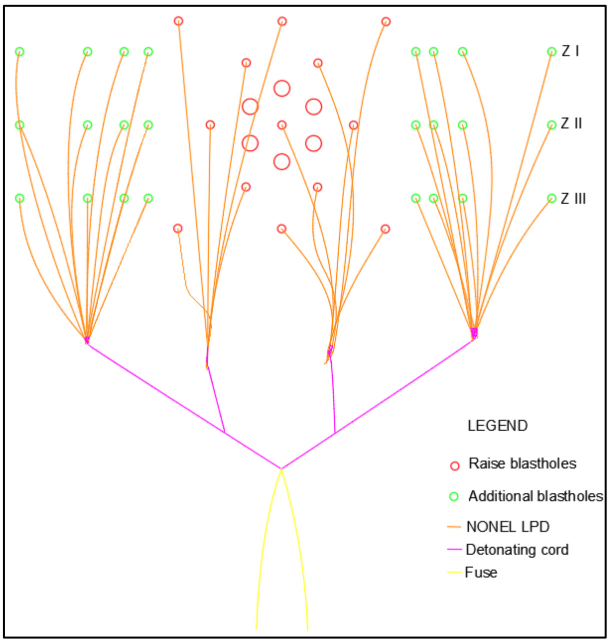


Figure 9 *Schematic representation of a detonator conection in the upper part of the slot*

RESULTS AND DISCUSSION

Slot blasting was carried out according to the method described above. The blasting of the upper and lower parts of the slot was successfully completed without any issues. A free space approximately 3.5 m x 12 m x 20 m was opened, resulting in approximately 840 m³ of rock mass being blasted. These dimensions are approximate due to the inability to measure more precisely.

Based on this, the approximate specific consumption of explosives can be calculated as follows [4]:

$$PF = \frac{W_e}{V_o, W_o}$$

where:

PF – powder factor,

We – weight of explosive used in blast,

Vo, Wo – volume or weight of blasted ore (in this case, volume).

PF = 2.25 kg/m^3

There were no occurrences of the oversize pieces in the muck pile, while in the surrounding rock mass, there were no major damages or occurrences of the hanging rock pieces.

CONCLUSION

The new method of slot development has proven to be successful and fast. The difference in construction speed between the new and old methods is 1 day, or 3 shifts.

It has been demonstrated that this approach can efficiently and safely create the required slot for further successful blasting of the rings.

To further study the slot construction, consideration should be given to blasting the slot in one blast using an appropriate combination of delays and connection schemes.

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Radmilo Rajković[*1], *Miljan Gomilanović*[*2], *Daniel Keržanović*[*3],
Saša Stepanović[*4], *Miomir Mikić*[*5], *Milenko Jovanović*[*6]

DETERMINATION OF SAFETY DISTANCES DUE TO THE SEISMIC EARTHQUAKES DURING BLASTING AT THE OPEN PIT NORTH MINING DISTRICT OF THE MAJDANPEK COPPER MINE[**]

Orcid: 1) https://orcid.org/0000-0001-5905-6613 2) https://orcid.org/0000-0002-1209-7423
3) https://orcid.org/0000-0003-3841-8667 4) https://orcid.org/0000-0003-3485-201X
5) https://orcid.org/0000-0001-7659-769X 6) https://orcid.org/0000-0002-6757-4143

Abstract

Majdanpek is located right next to the mine, so blasting at the Open Pit North Mining District could have an impact on the environment. If the intensity of that impact exceeds the prescribed limits, the harmful and dangerous consequences could be for people and facilities. In order to protect the environment from the harmful effects of blasting, the standards for protection and limits for the intensity of manifestation the certain effects of blasting at a certain distance are prescribed. This paper shows the determination of safety distances during blasting due to the seismic waves.
Keywords: *Open Pit North Mining District, blasting, seismic earthquakes, safety distance.*

1 INTRODUCTION

Excavation at the open pit North Mining District started in 1977, while the ore processing in the Flotation Plant began in 1989. By 2024, about 60 million tons of copper ore and about 200 million tons of waste were excavated

Discontinual excavation technology is applied at the open pit North Mining District. The excavation of waste is performed using the drilling - blasting works with vertical drill holes, loading with bucket excavators with and truck transport to the truck landfill of the North Mining District.

Drilling of exploitation blast holes, diameter 138 mm and 152 mm, is performed with the diesel drive drills, and loading of blasted rock mass is performed using the hydraulic backpack excavators of 5.6 m^3 and 8.0 m^3 on diesel drive. The waste and ore transport are performed with the load capacity trucks of 75 t and 85 t. The ore transport is to the primary crusher, located on the southeastern perimeter of the open pit, and waste to the truck landfill of the North Mining District, west of the open pit.

The designed floor level at the open pit is 15 m, while the designed roads of 7-8% are 15 m wide for one-way and 25 m for two-way roads. The roads of slope of 8-10%, were performed in the field. The current highest spot of the open pit is K + 770 m in the northeastern part of the open pit, while the bottom of the

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia,*
E-mail: radmilo.rajkovic@irmbor.co.rs
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open pit is at K + 326 m. The planned annual capacity of ore excavation, based on internal long-term plans of the company, is 3.3 million tons of ore per year.

As the town of Majdanpek is located right next to the mine, blasting at the open pit North Mining District can have an impact on the environment. If the intensity of that impact exceeds the prescribed limits, it can have the harmful and dangerous consequences for people and objects. In order to protect the environment from the harmful effects of blasting, the protection standards and limits for the intensity of manifestation the certain effects of blasting at a certain distance are prescribed.

In recent years, an increasing number of experts in the field of blasting have been engaged in research related to the seismic earthquakes during blasting. Through research, conducting experiments and proposing measures, the authors try to reduce the negative impact of earthquakes on people and environment. The largest number of works in recent years is related to the prediction of earthquakes using the artificial intelligence methods [1-4]. In addition to research related to the application of artificial intelligence methods, a large number of authors are engaged in research on the impact of blasting parameters on the intensity of seismic earthquakes [5-7]. In this paper, a special care was taken to calculate and optimize the blasting parameters that affect the seismic earthquakes, all with the aim of reducing the negative effects of earthquakes.

2 BLASTING TECHNOLOGY

Blasting technology at the open pit North Mining District was processed through development the following blasting procedures: preparatory works, primary blasting, and oversize crushing / secondary blasting.

The works on drilling and blasting process needs to be planned, designed and optimized with a great care so that the effects and results are as good as possible. In addition to the positive effects, it is necessary to harmonize and reduce the negative effects such as disintegration of the rock massif, emission of harmful gases and seismic effects of blasting.

In order to achieve the designed capacity of a certain granulation while controlling the secondary effects of primary blasting, it is necessary to set and harmonize the three groups of parameters:

- The amount of explosive energy required for desired degree of rock mass crushing;
- Spatial distribution of energy in the mine field;
- The time scedule of communication the energy to the massif, defined by the initiation scheme and deceleration times.

In order to achieve the required effects of primary blasting, in addition to the properly selected explosive, it is also important to determine, i.e. adjustment of the blasting geometry parameters. The goal of determining the appropriate parameters is to maximize the use of explosion energy, and to reduce the negative effects of blasting, primarily the seismic effect. In the limited area intended for exploitation, in the engineering-geological sense, three units can be distinguished, the characteristics of which are shown in Table 1.

Table 1 *Charging scheme of blast holes*

Medium	1. Gneiss	2. Limestone	3. Andesite
Volume mass (g/cm^3)	2.7	2.7	2.66
Pressure strength (MPa)	38.8	44	24.5
Spreading speed of longitudinal wave (m/s)	2,800-4,600	5,100-5,900	3,800-4,200

The maximum size of blasted mass is determined on the basis of bucket volume of the loading means 5.6 m^3 and 8.0 m^3:

- Oversize when loading with an excavator: $D\_max \leq 0.75 \cdot \sqrt[3]{5.6} = 1.33$ m
- Mean mass diameter $D\_sr = (0.15\text{-}0.20) \cdot \sqrt[3]{E} = 0.35$ m

During the calculation of blasting parameters, a special attention was paid to the following blasting parameters, which significantly affect the seismic earthquakes:

1. Selection of explosive and its quantity, both total and quantity per deceleration interval.
2. Initiation scheme and deceleration time between the mine charges.
3. The application of split charging was considered.
4. Alignment with the current blasting technology was also carried out.

Selection of explosives: Based on a long-term experience in the application of ANFO and emulsion explosive mixtures and positive effects, achieved by the use of these explosives for the primary blasting at the open pit North Mining District, the use of ANFO J.1 and emulsion explosive (Detolit) was adopted.

The amount of explosives per deceleration interval: By reducing the amount of explosives per deceleration interval, the seismic effects during blasting are reduced.

Initiation scheme: With an appropriate initiation scheme, the amount of explosives in connected charges can be reduced by reducing the number of charges that are initiated in the same time interval [8]. The appropriate initiation scheme achieves the management of explosion effect, and thus the reduction of seismic effect [9].

The initiation of explosive charges will be carried out by the NONEL Dual Delay system, which is already successfully applied at the open pits of the Majdanpek Copper Mine. The Nonel system provides the adequate safety during initiation, reduction the seismic effects of blasting, combination of different magnitudes of deceleration, use in the aquatic environment, etc.

The use of separated charges in the borehole can reduce the earthquakes. Separation of charging is done by intermediate plugs, the dimensions of which must be adequately calculated so that the impulses between charges are not transferred and initiated at the same time. The intermediate plugs vary from 0.4 m for 34-36 mm boreholes, up to 2 m for a 150 mm diameter borehole [8].

Drilling and blasting technology is harmonized to a large extent with the previous experiences at the open pit, which gave the good results in terms of obtaining the necessary granulation, safety and achieving the optimal costs in the exploitation phase.

Calculation of the primary blasting parameters was made for a floor height of 15 m, different environments, vertical boreholes and different explosives. For different environments, the calculation took into account different physical-mechanical parameters of the present engineering-geological environments. Different explosives are used in dry and wet environments, where the ANFO mixtures are used in dry environments, and the Detolit emulsion explosives in wet environments. The mining technical characteristics are given in Table 2. The blasting parameters were calculated, wherever possible, on the basis of several patterns taken from the literature and frequently used in the mining practice [10, 11].

Table 2 *Blasting - technical characteristics of explosives*

Characteristic	ANFO J.1	DETOLIT
Density (g/cm^3)	0.85-0.95	1.1-1.25
Detonation speed (m/s)	2.000	4.000
Gas volume (dm^3/kg)	1045	1090
Oxygen balance (%)	Balanced	Balanced
Explosion heat (kJ/kg)	3872	2805
Explosion temperature (K)	2544	
Min. usage diameter, mm	50	100
Initiation	Min. pentolite enhancer 250g	Min.pentolite enhancer 500g

Calculation was made according to the characteristics of three different engineering-geological environments (gneiss, limestone and andesite) and for explosives of the characteristics of explosives ANFO J.1 and Detolit (6 variants). Figure 1 shows the structural elements of the mine charge for one of the six variants [13].

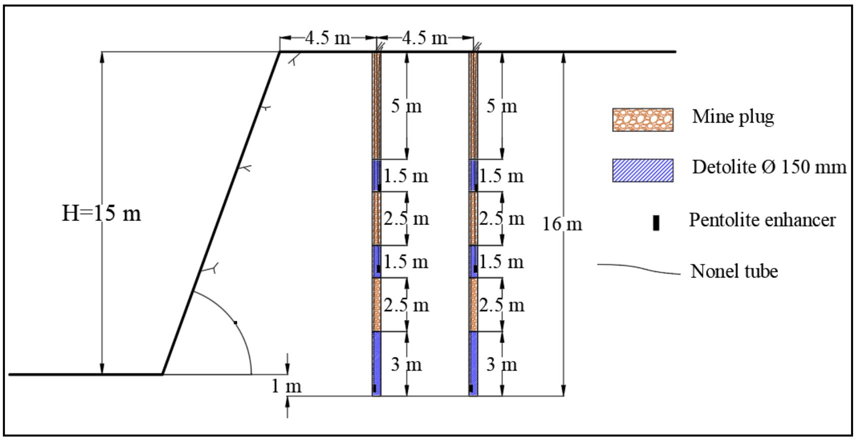


Figure 1 *Construction of blasting charge – 1 middle - gneiss (Detolit explosive)*

The blasting charge in boreholes H_e = 15 m, that is, for the borehole length of 16 m, consists of separate (lower-main and two upper-separated) charges with a proportional ratio of 50%:25%:25%. The maximum mass of explosives in one blasting borehole is 137 kg for all six variants.

Initiation of explosive charges is carried out by the NONEL Dual Delay system, which is successfully applied at the open pits of the Majdanpek Copper Mine. The Nonel system ensures the adequate safety during initiation, reduction of seismic effects of blasting, combination of different sizes of deceleration, use in the aquatic environment [10,11,13].

During planning and execution of blasting at the work site, the initiation schemes with such deceleration values must be calculated, as well as carried out, in order to minimize the possible harmful effects of seismic waves on the natural environment and existing buildings. The initiation scheme should ensure, in addition to reducing the seismic effect, an increase in degree of rock crushing, as well as obtaining the required shape of a pile of blasted material.

When blasting on floors 15 m high (H_e = 15 m), the initiation scheme is with the split charge. Initiation of blasting series is done depending on the situation on the ground, i.e. from the needs in relation to the increase in a degree of rock crushing or reduction the seismic effect. When planning and carrying out the connection of blasting charges, it is necessary to take into account the length of blasting of the rock mass.

For all variants, the drilling geometry of the blasting series is 4.5 x 4.5 m. The deceleration is 25 ms between the boreholes in a row and 42 ms between rows [13].

Scheme of initiation is shown in Figure 2.

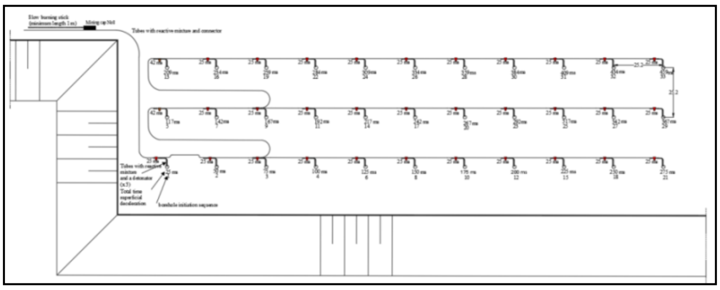


Figure 2 *Scheme of blasting field initiation with separated charge for floors H = 15 m*

3 PERIMETER BLASTING

Perimeter blasting has the task of crushing the rock mass in the peripheral parts of the floor, while ensuring:

- ➢ Preservation the stability of the open pit sides,
- ➢ Proper cutting of the floor slope according to the design, i.e. to the given floor contour.

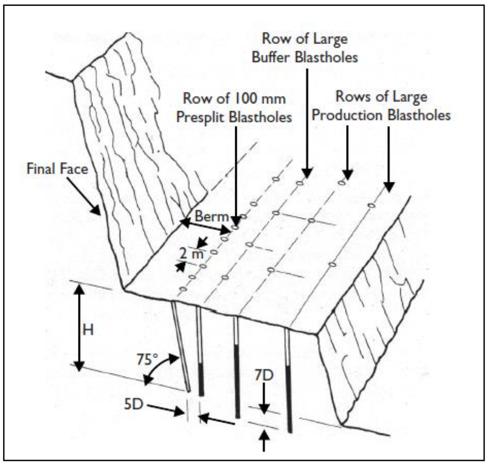


Figure 3 *Example of perimeter blasting [14]*

These effects are achieved by controlling the level of shaking the open pit sides and by appropriate blasting along the contour in order to cut it off properly. [10, 11]. At the same time, two different blasting methods or techniques are most often applied at the same time:

- ➢ Buffer blasting,
- ➢ Contour blasting.

In the specific case, the so-called smooth blasting technique will be performed when the contours of boreholes are activated as the last row in the series, what is typical for preserving the surface stability. This blasting is applied in the zone of final slope in order to preserve it [10,11].

The last row of boreholes is drilled at an inclination of 70° (floor inclination). The diameter of boreholes, as well as for the primary blasting, is adopted as 150 mm. The last row of boreholes is drilled without piercing. In addition to the contour boreholes according to the intended geometry, the contour boreholes without explosives are also drilled at a half of distance between the boreholes (the role of these contour boreholes is to form a line of weakened resistance along which a crack will be formed during blasting). Each row of boreholes is drilled at a certain angle. The borehole scheme for the smooth blasting method is shown in Figure 4.

The layout of the blasting charge construction for the ANFO explosive for the first middle in the floor contour for the smooth blasting method is given in Figure 5 [13].

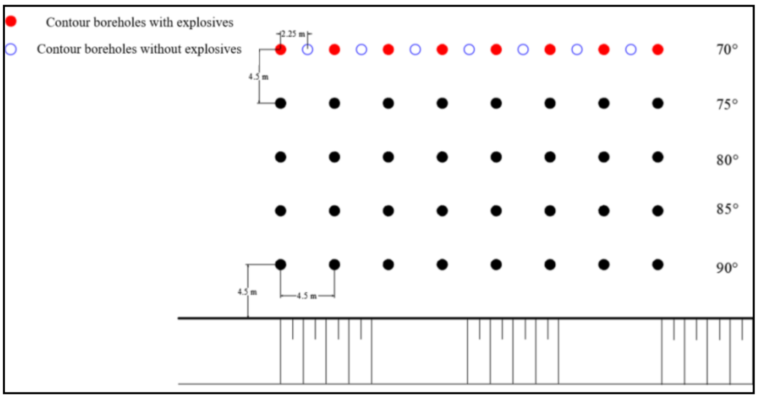


Figure 4 *Scheme of boreholes for the smooth blasting method*

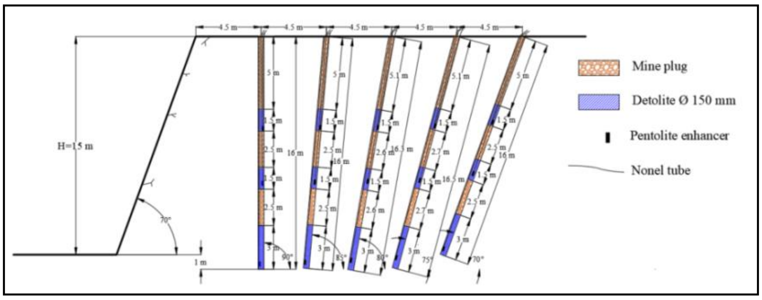


Figure 5 *Layout of the construction of the ANFO explosive charge for the first middle in the floor contour (for the smooth blasting method)*

4 DETERMINATION OF SAFETY DISTANCES DUE TO THE SEISMIC EARTHQUAKES

Determination of safety distances when performing the blasting works refers to:

- Determination of safety distances due to the seismic earthquakes;
- Determination of safety distances from flying pieces during blasting;
- Determination of safety distances due to the effect of air shock waves;
- Determination the gas hazard zone.

The shock wave, which moves through the rock mass from the blast site, gradually loses energy on its way - it weakens (causes less and less strain in the rock) until it is completely attenuated, that is, lost at a certain distance from the blasting site.

In the vicinity of the explosion site, the shock wave has such energy that it causes the compressive strains greater than the compressive strength of the rock mass, then due to the loss of energy from a certain distance it can cause only tensile stresses greater than the tensile strength of the rock, and finally only the elastic deformations in the rock mass until it disappears. In the area where it causes the creation of cracks in the rock mass, the wave has a destructive character, and beyond that it causes only elastic deformations of the rock mass and has the character of a seismic wave, so it is called that.

The seismic ground oscillations, caused by blasting, are very similar to the oscillations caused by an earthquake, and the difference between them is manifested mainly in duration and length of oscillation time. During earthquakes, the oscillations occur that last a long time and in which the length of oscillation period is from 0.5 to 5 s, while during blasting, the duration of oscillations is significantly shorter and ranges from 0.004 to 0.25 s. As a rule, the blasting is carried out frequently, so the object affected by seismic tremors is significantly exposed to their influence. That is why, depending on the condition of the object, during blasting, the permissible tremors are usually one to two degrees lower than in the case of earthquakes.

When a seismic wave hits a soil particle, it throws it out of equilibrium at that point, whereupon it begins to oscillate around its equilibrium position for a certain time until it completely settles. The oscillation of particles of the rock mass (terrain or soil) is what manifests itself or is felt as an earthquake, that is, the ground.

While the seismic waves travel at significantly higher speeds through the rock mass, provoking the oscillations of particles at points found on their path of propagation, the oscillation of material particles of the mass around its equilibrium position is at much lower speeds, on the order of mm/s - cm/s.

In seismic earthquakes, two types of waves are distinguished:

- Volume
- Superficial

There are two basic types of volume waves. The first is longitudinal, under the influence of which the particles move forward - back along the line that determines the direction of wave propagation. Considering that in this way the elastic deformations are transmitted by the shortest path and that longitudinal elastic waves reach the measuring point first, these waves are also called the primary waves and are denoted by (P). The propagation speed of longitudinal elastic waves [10,11] on sample can be determined from the ratio:

$$V_u = \sqrt{\frac{E \cdot g}{\gamma}}, \quad \text{m/s}$$

where:

V_u - propagation speed of longitudinal waves, m/s

E - modulus of elasticity, dN/cm^2

g - acceleration of the earth's gravity, cm/s^2

γ - volumetric weight, g/cm^3

When the longitudinal wave reaches the free surface or boundary of the layer with other physical and mechanical properties, then at an angle of incidence of 90^o it is reflected back, forming a transverse wave in which the particles of the excited medium oscillate in a plane perpendicular to the direction of wave propagation. maintaining a mutual distance and thereby causing the elastic deformations that are parallel to the direction of wave movement. Due to this property, the transverse elastic waves are also called the shear waves. Their speed of propagation is lower than that of longitudinal waves, and they reach the measuring point later, so they are sometimes called the secondary waves and are denoted by (S). The ratio of the speeds of longitudinal and transverse waves is:

$$V_u = \sqrt{3} \cdot V_p$$

The propagation speed of elastic waves in the rock depends on the elastic properties of rock and its density, shown in Table 4.

Table 4 *Propagation speeds of longitudinal elastic waves for some media*

Type of rock	V_u (m/s)
Granite	5.000 – 5.700
Limestones, Sandstones	2.500 – 4.500
Marl, Gypsum	1.700 – 2.300
Gravel	900 – 1.100
Sandy soil	600 – 1.600
Clay soil	500 -1.500
Loose soil	200 - 500
Water	1 430
Air	340

The speed of transverse wave propagation [1, 2] can be determined from the relationship:

$$V_p = \sqrt{\frac{E \cdot g}{2 \cdot \gamma \cdot (1+\mu)}}, \text{ m/s}$$

where:

V_u - propagation speed of longitudinal waves, m/s

E - modulus of elasticity, dN/cm^2

g - acceleration of the earth's gravity, cm/s^2

μ - Poisson's ratio, which most often ranges from 0.20 - 0.40.

While the longitudinal elastic waves (P) propagate through the solid, liquid and gaseous media, the transverse waves travel only through the solid media.

The surface waves got their name from the layer thickness over which they spread, which is approximately equal to their wavelength and in most cases is 100 - 200 m, so that at a depth of twice the wavelength, the wave oscillation is practically not felt. There are several types of surface waves depending on the trajectory of movement the medium particles:

1. Type (R) waves - in this type of wave, the oscillation of material soil particles is carried out along an elliptical path, the main axis of which is vertical. In the upper part of ellipse, the particles move in a source direction, and in the lower part, away from the source of explosion.
2. Type (Q) waves - in this type of surface waves, the particles move perpendicular to the direction of wave propagation, where the movement takes place in the horizontal plane.
3. Waves of type (C) - this wave is created by combination of (R) and (Q) waves and material particles move along a diagonal path.

The (C) waves usually arrive at the measuring point first, then the (Q) and finally the (R) waves. From the aspect of seismic earthquakes, the surface waves are more interesting because they lead to the damage of objects that are one or more wavelengths away from the site of explosion.

There are three important factors that determine the intensity of earthquakes during blasting [8]:

1. Characteristics of the rock massif
2. Distance from the blasting site
3. The amount of explosives initiated

In addition to obtaining the loose rock mass of required granulation that is the subject to further technological processing, the most important task in the process of primary blasting is the need to preserve the residential buildings in the vicinity of the open pit North Mining District from the seismic impact. Therefore, it is necessary to determine the law of ground oscillation for directions towards the critical objects, and then to define the zones with precisely determined amounts of explosives per deceleration interval, which must not be exceeded under any circumstances.

The protection of buildings against earthquakes is carried out with limitation the amount of explosives that is initiated in one time interval, whereby the time interval must not be shorter than 8 ms, taking into account the possible deviation of deceleration time from the nominal retarder times.

The earthquake protection comes down to limiting the speed of soil oscillation and with it the foundations of residential buildings. The permitted oscillation speeds for certain types of objects are regulated by the standards. Since there is no such standard in Serbia, the German standard DIN 4150-3 is most often used, Figure 6. The maximum permissible ground oscillation speeds according to the DIN 4150-3 are given in Table 5.

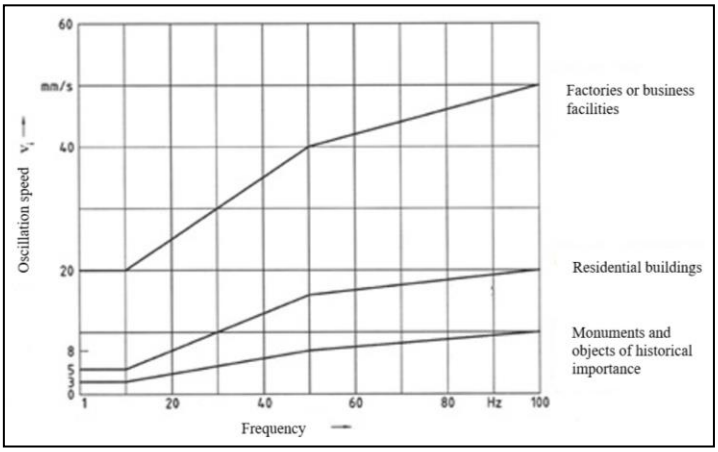


Figure 6 *Maximum permissible oscillation speeds according to DIN 4150-3 [8]*

Table 5 *Oscillation speed size limits in mm/s according to the DIN standard 4150 [8]*

Type of Buildings/site measurement	**Foundations**			**Floors on the highest floor of building**
	<10 Hz	**10-50 Hz**	**50-100 Hz**	**all frequencies**
1. Factories or business facilities	20	20-40	40-50	40
2. Residential buildings	5	5-15	15-20	15
3. Monuments or objects of historical importance	3	3-8	8-10	8
Vibrations in the frequency range higher than 100Hz can have a higher value				

A real-time monitoring system was introduced at the open pits South and North Mining District in order to monitor and realistically assess the impact of seismic earthquakes during blasting and determine the laws of soil oscillation.

After looking at the measurement results of the ground oscillation speeds as the blasting results at the open pits North and South Mining District [12], the following was concluded:

1. Measuring points were placed on the outskirts of the city, and the vast majority of blasting was carried out at relatively long distances (700 and more meters).
2. The maximum oscillating speeds (and the used maximum speeds in all

three directions x, y and z) are small (< 2 mm/s).

3. The laws of soil oscillation, obtained on the basis of performed measurements have a low correlation with the measurements themselves due to the large deviations of the measured values from the mean value. In the submitted analyses, the laws of oscillation are given for 50% and 95% reliability and the total amount of explosives that are simultaneously initiated and initiated in a time interval of 8 ms. Taking into account the dispersion of the measured values for practical application, the ground oscillation law would be acceptable for a reliability of 95% and the amount of explosives that is initiated in an interval of 8 ms.

In order to see the analysis results specifically for the North Mining District, the results of measurements during blasting in the North Mining District and for the closest measured places (MM-5 and MM-6) were used in the course of 2023, i.e. in the reports for January, February and March. In February, there was only one blasting in the North Mining District, and it was carried out in an uncharacteristic place, and due to this reason, it was not considered. A significantly larger number of blasting in these reports was carried out in the South Mining District, but the general conclusions about the oscillation speeds as a function of the amount of explosives that are simultaneously initiated and the distance are similar, that is, the low oscillation speeds were measured at the measuring points.

Based on all of the above, the dependence of distance on the amount of explosives that is initiated from 8 ms, based on the given law of oscillation in the aforementioned Report was not given, but the safety distance due to the effect of seismic earthquakes was determined on the basis of literature [10].

The Mercalli-Cancani-Seiberg (MSC) scale, which contains 12 seismic degrees, is most often used to assess the seismic effect, and is used to assess the earthquakes. The Mercalli-Cancani-Seiberg (MSC) scale provides the modified Mercalli scale intensities, commonly observed at locations near the earthquake epicenters, Table 6.

Table 6 *Mercalli-Cancani-Seiberg (MSC) scale [8]*

Oscillation speed cm/s	Degree of seismic intensity (IFZ)	Description of effect
Up to 0.2	I	The earthquake is felt only by the instruments
0.2 – 0.4	II	The earthquake is felt only in some cases in complete silence
0.4 – 0.8	III	The earthquake is felt by very few people or only by those who expect it
0.8 – 1.5	IV	The earthquake is felt by many people, the clinking of window glass is heard
1.5 - 3	V	Lime shedding, damage to buildings in poor condition
3 - 6	VI	There are fine cracks in the plaster, damage to buildings that have already developed permanent deformations
6 - 12	VII	Damage to buildings in good condition, cracks in plaster, parts of plaster falling off, cracks in brick ovens, collapse of chimneys
12 - 24	VIII	Significant damage to buildings, larger cracks in the supporting structure and walls, falling factory chimneys, falling ceilings
24 - 48	IX	Demolition of buildings, larger cracks in walls, dismantling of walls
> 48	X - XII	Greater destruction, destruction of entire buildings

In terms of resistance to the earthquakes due to the blasting, the buildings can be divided into three basic categories:

1. Buildings made of rough stone, village buildings, buildings made of unbaked bricks and houses made of clay.
2. Ordinary brick buildings, large block buildings and buildings made of prefabricated materials, buildings with partially wooden construction, as well as buildings made of natural hewn stone.
3. Reinforced concrete buildings and ordinary wooden buildings.

The safety distance [10] can be determined from the relationship:

$$r_s = K_b * K_p * K_z * R_{red} * Q^{1/3}$$

where:

r_s – danger zone radius due to the effect of seismic waves

K_s – coefficient calculated as: $K_s = K_b * K_p * K_z$

K_b – coefficient depending on the condition of the object, Table 7

K_p – coefficient depending on the method of initiation the internal filling, Table 8

K_z - coefficient depending on the physical and mechanical characteristics of the working environment, Table 9

Table 7 *Coefficient Kb*

Building categorization	Building state	Seismic intensity degree (cm/s)	Coefficient K_b
A	Dilapidated building made of broken stone	4	2,5
B	Buildings built with brick blocks with previous deformations	5	1.6
C	Strong stable buildings made of reinforced concrete or wooden structures	6.7	1

Table 8 *Coefficient Kpb*

Initiation method						
Degree of seismic intensity cm/s	Currently			Milliseconds		
	Rk	Ri	Rp	Rk	Ri	Rp
1	100	91	72	80	83	63
2	63-100	68-91	46-72	50-80	82-83	50-63
3	40-63	37-58	29-46	32-50	34-52	25-16
4	25-40	23-37	12-18	13-20	13-21	10-16
5	16-25	15-23	12-18	13-20	13-21	10-16
6	10-16	9-15	7.3-12	8-13	8.3-13	6.3-10
7	6.3-10	5.8-9	4.6-7.3	5-8	5.2-8.3	4-6.3
8	4-6.3	3.7-5.8	2.9-4.6	3.2-5	3.4-5.2	2.5-4
9	2.5-4	2.3-3.7	1.8-2.9	2-3.2	2.1-3.4	1.6-2.5
10-12	2.5	2.3	1.8	2	2.1	1.6
K_p	1.0	0.91	0.72	0.8	0.83	0.63

Table 9 *Coefficient Kz*

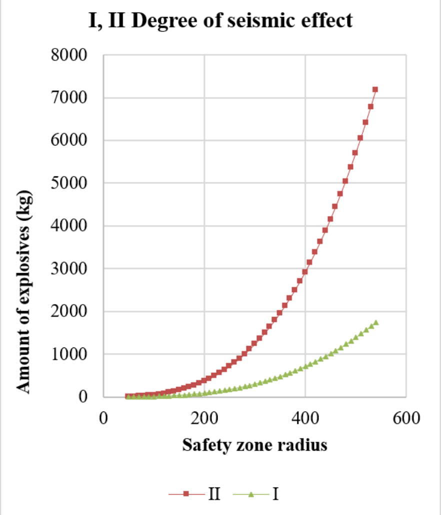
Soil type	K_z
Solid rock	0.5
Solid cracked rock	0.7
Semi-solid rock (gypsum, marl, sandstone)	0.8
Gravel soil	0.9
Sandy clay soil with water at a depth of 10m and more	1
Sandy clay soil with water at a depth of 5-10m	1.2
Sandy soil and clay with water up to a depth of 5m	1.4
Muddy soil	1.8

- The adopted values: K_b-1, K_p-0.8, K_z- 0.7
- R_{red} – reduced distance for various degrees of earthquakes at current and millisecond blasting
- Q – quantity of used explosive (kg)

For an individual assessment of the object resistance to earthquakes due to blas-ting, it is necessary to determine which level of seismic intensity is dangerous for a given object, and then what is the seismic intensity of the observed earthquake. Table 10 presents the safety distances and permitted quantities of explosives for the I, II and III degrees of seismic effect.

Table 10 *Amount of explosives (kg) at different safety distances for the I, II and III degrees of seismic effect*

R, Safety distance m	Degree of seismic effect		
	III	II	I
50	22	6	1
60	38	10	2
70	60	16	4
80	89	23	6
90	127	33	8
100	174	46	11
110	231	61	15
120	300	79	19
130	382	100	24
140	477	125	31
150	586	154	38
160	712	187	46
170	854	224	55
180	1013	266	65
190	1192	312	76
200	1390	364	89
210	1609	422	103
220	1850	485	118
230	2114	554	135
240	2402	630	154
250	2715	712	174
260	3054	801	195



Amount of explosives at different safety distances for I and II degree seismic effects

The nearest residential buildings, which represent the most threatened buildings from the perspective of blasting operations at the North Mining District, are over 250 m away from the nearest blasting site. In order to determine the maximum amount of explosives that can be initiated simultaneously, a distance of 240 m was adopted, and the mentioned objects should be located in the zone of the first or second degree of seismic effects [13].

Based on a large number of measurements of earthquakes during floor blasting on different terrains, the USA Bureau of Mining determined the average law of soil oscillation, which could also be used in our country for the first approximation, whose constants are k=750 and n=-1.67. that is, it reads [11]:

$$V_o = 750 \cdot R_{r.8ms}{}^{-1,67}$$

The width of the zone of seismic impact of blasting (R_{gr}) can be determined by the expression:

$$R_{gr} = \sqrt{Q_{8ms.sr}} \cdot \left(\frac{k}{V_{doz}}\right)^{\frac{1}{n}}$$

For the maximum permissible speed of ground oscillations $V_{doz} = 5\ mm/s$ and average value of the maximum masses of explosives that were initiated within the time interval of 8 ms $Q_{8ms.sr} = 137\ kg$ of explosives, the zone width of seismic impact of blasting at the open pit North Mining District [4], amounts to:

$$R_{gr} = \sqrt{137} \cdot \left(\frac{750}{5}\right)^{\frac{1}{1,67}} = 234\ m$$

CONCLUSION

In this paper, it was repeatedly emphasized that blasting can have an impact on the environment if the intensity of that impact exceeds the prescribed limits, which can have the harmful consequences for people and environment.

The main effects of blasting, from which people and objects should be protected, are:

- Seismic earthquakes;
- Pieces flying apart;
- Air shock waves;
- Gases.

Earthquakes are the primary impact of blasting on the environment because they cause the sudden vibrations of ground and structures. In case of inadequate control, the earthquakes can cause serious damage of buildings and installations. The use of mass blasting increases the problems related to the earthquakes. Due to this reason, the open pits must have an earthquake control system in order to avoid the aforementioned damages.

In order to control the impact of blasting on the environment, it is necessary to determine the law of ground oscillation for directions towards the critical objects, and define the zones with determined amounts of explosives per deceleration interval. Earthquake protection is reduced to limiting the speed of ground oscillation and with it the foundations of residential buildings according to the standards.

Since there is already a real-time seismic effects monitoring system with six measuring points, it is recommended to introduce one or more measuring points (aligned with the designed position of the works) into the monitoring system. The introduction of one or more measuring points will improve the already existing real-time monitoring system.

The authors would like to point out that after each blasting, it is necessary to analyze the obtained results and effect of blasting. Based on the obtained results and phenomena that follow the blasting, further activity must be planned in advance in order to prevent any bad effects of blasting.

At the open pit North Minng District, the calculation of explosive amount by boreholes and series, as well as the deceleration and initiation intervals, were done so that all blasting influence zones are below the object distance limit. Blasting is carried out according to the calculated parameters with the application of special protective measures, i.e. placing the protective coverings on minefields.

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*Srđana Magdalinović*1, Silvana Dimitrijević*2, Aleksandra Ivanović*3, Sanja Petrović*4, Slađana Krstić*5*

APPLICATION OF THE MINERAL PROCESSING METHODS IN RECYCLING THE WASTE PRINTED CIRCUIT BOARDS**

Orcid: 1) https://orcid.org/0000-0002-2916-2850 2) https://orcid.org/0000-0003-1670-4275
3) https://orcid.org/0000-0002-0562-2824 4) https://orcid.org/0000-0001-5197-1614
5) https://orcid.org/0000-0002-4342-3842

Abstract

Development of the modern society has resulted in the production of various electronic equipment that becomes obsolete very quickly. This outdated equipment has been dumped on the landfills for many years. Electronic waste contains a significant amount of useful elements, so it represents a real resource for valorization. The presence of harmful elements classifies it as a hazardous waste, why a disposal in a specific area with special conditions is necessary. On the other hand, the massive exploitation of primary deposits has led to their depletion, creating an escalating demand for the new exploitation and concentration methods. Development of the recycling methods for such material is necessary from an economic and ecological point of view. Waste printed circuit boards can conditionally be viewed as a complicated mineral raw material. In mining, a methodology has been developed by which samples are tested to determine the concentration procedure. The same or similar approach is used during recycling. In this paper, an overview of the preparation methods of mineral raw materials that can be or are used in the recycling of waste printed circuit boards was carried out.

Keywords: *mineral processing, printed circuit board recycling*

PRINTED CIRCUIT BOARD RECYCLING: A REVIEW

It was estimated [1] that 23.6 million tons of e-waste were generated in the world in 2019. In Europe, on average, 11 out of 72 electronic devices are not being used or are broken. It is estimated that 4-5 kg of e-waste per inhabitant is stored before being discarded. In France, there are between 54 to 113 million cell phones that are currently stored in homes, drawers and other storage space. These cell phones have a total estimated weight of 10 to 20 tons.

Mir and Dhawan [2] describe the printed circuit boards as the basis on which various electronic components such as the

* *Mining and Metallurgy Institute Bor, Alberta Ajnstajna 1, 19210 Bor, Serbia,*
E-mail: srdjana.magdalinovic@irmbor.co.rs
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This work was the result of the India-Serbia Bilateral Scientific and Technological Cooperation: Recycling of Valuable Metals from Discarded Printed Circuit Boards.

monolithic ceramic capacitors, tantalum capacitors, integrated circuits and central processing units are mounted. On average, the printed circuit boards contain 30–35% metal, 35–42% refractories, and 24–30% resin. The metal fraction of printed circuit boards consists of 8–38% Fe, 10–27% Cu, 2–19% Al, 1–3% Pb, 0.3–2% Ni, 200–3000 ppm Ag, 20–1200 ppm Au and 10–300 ppm Pd depending on the plate origin. The organic content of printed circuit boards consists of various polymers, such as the polycarbonate, polyvinyl chloride, polyvinyl acetate and refractory materials, such as silicon and alkaline oxides.

Printed circuit boards make up about 3-8% of the total electronic waste and contain 40% metal, 30% organic matter and 30% ceramic [3]. The bare PCB platforms represent about 23% of the weight of the whole boards. However, there is a large difference in the composition of waste printed circuit boards from different devices, different manufacturers and different ages. For example, after the removal of dangerous batteries and capacitors which, according to the current laws, must be separated for the special recycling. The organic fraction is about 70% in motherboards from computers and televisions and 20% in those from cell phones.

Eswaraiah et al. [4] claim that the printed circuit boards have a large share in the electronic waste and that the typical composition is the non-metals (plastic, epoxy resin, glass) more than 70%, copper about 16%, solders about 4%, iron, ferrite about 3%, nickel about 2%, silver about 0.05%, gold about 0.03%, palladium about 0.01% and others (bismuth, antimony, tantalum etc.) less than 0.01%.

The procedures for recycling the printed circuit boards are as follows:

- Waste sorting, separation of the printed circuit boards
- Manual disassembly of panels and separation the parts that can be reused or hazardous components that are separately disposed of or recycled (batteries, capacitors).
- Characterization of the waste printed circuit boards
- Release of certain materials, i.e. reducing the size of plates to a size where the components are separated or released by the type of material so that they can then be separated (plastics, resins, metals).

The assessment of freedom can be determined in the same way as it is present in mineralogy. After sieving the material by the size classes, the degree of liberations and intergrowth is determined by studying with a microscope. A chemical analysis should be done on each class to determine the participation of elements. Sometimes, the sieving phase can be partially also the concentration phase, if in certain size classes the pure components such as metal, plastic or resin have been separated. The sieving phase is often necessary if the subsequent concentration process involves the methods of concentration in water or air current, because in these fluids the grains are separated according to the speed of their fall in the fluid. Thus, it can happen that large grains of low density and small grains of high density go into the same product, and they should have been separated into separate products. In that case, the material should first be sieved into smaller size classes and then treated separately in concentration devices, thus avoiding the phenomenon of equally falling grains in the fluid. The same is true for magnetic and electrostatic separation, where the pre-sieving is required for the same reasons, only the forces acting on the grains are the magnetic or electrostatic instead of gravity.

After the characterization of waste plates, it is possible to choose a method for separation or concentration based on the differences in the physical and chemical properties of the components.

The physical and chemical properties that distinguish the components of printed circuit boards and that can be used for separation and concentration are the same ones that are already used for separation and concentration the minerals in the preparation of mineral raw materials:

- Density
- Magnetic susceptibility
- Electrical conductivity
- Hydrophobicity, hydrophilicity

By reviewing the literature, it was determined that some of the mentioned properties are used for extraction, independently or in combination, but to a lesser extent than is the case with the hydrometallurgical and pyrometallurgical methods.

Veit et al. [5] shredded the printed circuit boards on a chopper to -1 mm and then sieved the material into narrow classes of size. These classes were analyzed for the metal content and distribution of metals by the size classes. After that, the concentration was carried out on a dry magnetic separator at a magnetic field strength of 6,000-6,500 G. In the magnetic class, iron and strongly magnetic amalgams were concentrated. The nonmagnetic fraction was treated on an electrostatic separator. Copper, tin and some lead were mostly concentrated in the conductive fraction, and mostly polymers and ceramics in the non-conductive fraction. This last fraction requires processing in terms of lowering the metal content for the possibility of disposal of this material or for some other type of recycling.

Cui and Forssberg [6] described a detailed characterization of TV waste, and it is described here because the same procedure can be applied to waste printed circuit boards.

- Manual separation
- Shredding on a shredder to a size of -12 mm
- Sampling was carried out using the cup ring and quartering method
- Sampling on a rotary sampler
- Grinding to the fineness for chemical analysis was done on a turbo-rotor mill
- Chemical analysis
- Determination of the grain composition on a series of ASTM Retsch sieves using a shaker
- Determining the grain shape using the image process system
- Grain liberation
- Floating-sink test in liquids with densities ranging from 1,000 to 2,970 kg/m^3
- Identification of plastics by the FTIR spectroscopy

The authors conclude that a good characterization is the guide in choosing the process of separation or concentration by the methods of preparation of mineral raw materials.

Guo et al. [7] performed tests on a sample of the computer printed circuit boards from different manufacturers. First, they removed the toxic parts for further use. Then they disassembled the motherboards and cut them into 10 cm pieces. The material was crushed to a size of -1.25 mm. The sample was sieved into several size classes and then the liberation was determined by the observation using a digital camera and metallographic microscope. Metals were separated from the material using the physical methods of concentration, namely the pneumatic, electrostatic and magnetic separation. In this way, they obtained a metal fraction with about 71% Cu.

Cui and Forssberg [8] summarized literature data on the electronic waste recycling. The authors emphasize many advantages of electronic waste recycling such as: saving energy, saving raw materials, reducing air pollution, saving water, reducing water pollution, reducing mining waste, reducing consumer waste. They also showed percentages of energy savings when the recycling instead of using the natural resources, ranging from 60% for zinc to 95% for aluminum production. They noted that the hazardous components from electronic waste must be separated and separately recycled, as is the case with the capacitors containing highly toxic polychlorinated biphenyl. The authors also stated the values of some characteristic sizes of materials based on the differences of which can be separated using the physical methods of concentration such as density, magnetic susceptibility and electrical conductivity.

Das et al. [9] describe the procedure, where the accessories such as cables, frames, wires were first manually removed from the motherboards. The boards are cut into 1.5 cm pieces. They were ground in a ball mill up to -0.5 mm. Sieving was done into narrow size classes and the analysis of material liberation was carried out. The -44 µm class, which did not contain metal, had a pycnometer density of 1.49 t/m^3. In the initial sample, the density was 3.32 t/m^3. Based on these data, a sink-float test was performed in bromoform, which has a density of 2.81 t/m^3. This test indicated the possibility of successful separation by the gravity separation. This paper also shows some properties and differences on the basis of which metals can be separated from non-metals by the physical methods of concentration and flotation, and they are shown in table 1.

Table 1 *Differences in material properties that favor separation [9]*

PCB parts	Density	Electrical Conductivity	Hydrophobicity	Occurrence in Input	Concentration Criteria
Metallic	High	Very High	Very Low	Large in coarse size classes	Desliming, gravity concentration, flotation, electro-static separation
Non-metallic	Low	Very Low	Very High	Large in fine size classes	

Eswaraiah et al. [10] described the recycling of waste printed circuit boards in an air classifier. The authors say that recycling can be considered as the separation of metal and plastic from printed circuit boards and their reuse. The lack of non-polluting methods to separate metals and plastics from these sources forces many researchers to resort to the mechanical separation methods. The air classification is a cleaner separation method that does not use any polluting separation medium. In this paper, the authors presented the separation of metals and plastics from the ground PCBs using an air classifier and analyzed the results of this process using the sink-float method. The authors passed the ground PCBs through an air separator and then analyzed the concentration results using the sink-float procedure (characterization). The choice of medium for separation was influenced by the medium density, but also by the requirements that it be cheap, non-toxic and non-corrosive. The density of non-metals in the PCB ranges from 1-1.8 g/cm^3. The density of metals present varies from 2.6 (aluminum) to 19.3 g/cm^3 (gold). A saturated zinc chloride solution with a density of 1.85 g/cm^3 was used for separation. The mechanical methods of recycling consist in shredding the plates to a suitable size and then they are treated on the eddy current separators or separators in a dense medium. In addition to the good separation of metals with these methods, the environment is also minimally polluted in this way. The material is first crushed to -2 mm in an impact crusher with hammers. After that, sample was sieved on a series of sieves, each class was separated into a floating and a sinking part in a saturated solution of zinc chloride with a density of 1.85 g/cm^3. Validation of the sink-float method was performed analyzing with the AAS method. Validation was also done by melting in a furnace at 650°C and then measuring the product. Based on validation, it was confirmed that the sink-float method can be used as a fast method for evaluating the concentration results.

Li et al. [11] described a corona electrostatic concentration. The high voltage field is generated by a corona electrode and an additional electrostatic electrode. Sample is added to a rotating roller where it is charged using the corona electrode, the metal grains exchange the charge via the grounded electrode and fall off the rotating roller, and the non-metallic grains, depending on the amount of charge, remain on the roller and fall off the roller due to the force of gravity or are physically removed. Depending on the strength of charging force, the place where grains fall off the roller is different, and that is how the separation is achieved. Corona electrostatic separation is an efficient and environmentally friendly method for recycling metals from the printed circuit boards. Coarseness classes from 0.6 to 1.2 mm are suitable for separation on an industrial scale.

Duan et al. [12] described the separation process in a water stream on the Falcon SB40 centrifugal separator. They stated the advantages of wet crushing that preceded the separation process, such as preventing the formation of dust, avoiding the heating of machine parts, no separation of gases due to the pyrolysis during crushing, the process of crusher emptying is accelerated, which further leads to the prevention of over-shredding because the material passes through the crushing chamber faster. Water, used in the process, can be reused which means that the water consumption is low.

Zhou and Qiu [13] stated that many researchers have used various mechanical methods to separate metals and non-metals from the waste printed circuit boards, such as the multiple crushing, grinding, electrostatic separation, gravity separation, separation based on density, and magnetic separation. However, a lot of dust and harmful gases are produced in the crushing process due to a high resistance to pulverization, and non-metallic powder, obtained by the mechanical processes, can only be used as a low-value product (paints, paving material, plastic filler material, etc.). In addition, precious metals can remain with nonmetals because they tend to adhere to the nonmetal grains during the grinding process.

Williams [14] desribed that in the previous period, most of the discarded electronic waste was destined for disposal on the landfills and incineration or was taken to the developing countries despite the international agreements limiting deliveries. This paper presents the procedures, used in the recycling of electronic waste.

- Decomposition processes refer to the separation of ferrous metals, non-ferrous metals and precious metals.
- Manual sorting into product groups,
- Shredding on the shredder and extracting on the magnet
- Grinding in the mills and extracting metals such as copper, aluminum and others
- Mass recycling and separation of metals

The purpose of shredding is to release material for separation to separate out unnecessary material that would increase the cost of transportation from the recycling stations to the smelters.

Separation can be the magnetic, electrostatic, based on differences in density, visual or based on some other characteristics. Using permanent magnets instead of electromagnets can reduce the energy costs. The multi-phase chopping and treating on magnets can increase the iron recovery. After magnetic separation, larger pieces of glass or plastic can be separated by selection on the belts.

The mills and sieves are often used to separate the material by the size classes before the material is sent to separation on the Eddy current separators, electrostatic separators, air current separators, sink-float tanks or separation in centrifuges.

The Eddy Current Separators are used to separate non-metals from non-ferrous metals from mixtures with a size of 4-100 mm with a capacity of 18-30 t/h. Even in that case, it is possible to separate 92% of copper grains with a size of 2-4 mm. The Eddy current separators can be adapted to sepa rate non-ferrous metals such as aluminum and copper. In order to further improve the utilization rate in the separation process on the Eddy current separators, the effect of particle size, shapes and materials in the concentration space as well as the concentrator operating parameters such as the conveyor speed, drum speed, separator position and magnetic roller position angle can be investigated. The author says that the separation of ferrous and non-ferrous metals is relatively well researched, but the separation of plastic and glass is not. In this field, several techniques have given results, namely the hydrocycling, electrostatic separation and rotor delamination, which combines a centrifugation at high temperatures. The author says that the separation of ferrous and non-ferrous metals is relatively well researched, but the separation of plastic and glass is not. In this field, several techniques have given results, namely the hydrocycling, electrostatic separation and rotor delamination, which combines centrifugation at high temperatures.

The printed circuit boards are essential components in the electronic waste, as highlighted by Mir and Dhawan [2]. The authors emphasize the significant challenge of valorizing these boards due to their highly heterogeneous composition. There is no suitable characterization technique that quantitatively assesses the distribution and liberation/association of different components that are spatially distinct/heterogeneous without multiple fragmentation. In categorization, it is necessary to perform an identification using various instrumental techniques such as the X-ray diffraction, inductively coupled plasma spectroscopy (ICP) and scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and Fourier transform FT-IR.

Ghosh et al. [15] assessed the state of printed circuit board recycling. The paper analyzes more than 150 related articles mostly published in recent years and covering the broad areas such as the characterization of printed circuit board waste, health hazards associated with processing and different recycling routes to provide a comprehensive overview on this topic. In the physical separation processes, the electrostatic separation, magnetic separation, and flotation concentration are mostly described in the works. In the paper, the authors referred to various hazardous elements including the heavy metals, flame retardants that pose a serious threat to the eco-system during conventional waste treatment from landfilling and incineration. Consequently, the e-waste including waste printed circuit boards are either stored in the stores or sent to the developing countries where the poorest sections of population are engaged in the primitive recycling. The Yard operations in Asia and Africa, particularly in China, India and Ghana, are of concern because they involve the primitive recycling techniques that result in most hazardous elements being discharged into nearby watercourses or soil. In some processes, the hazardous compounds such as dioxins are released, and furans can also be produced during the thermal degradation of waste. As a result, the living and working environment of the recycling population is greatly affected.

Some of the conclusions are [15]:

- Waste printed circuit boards are a diverse and complex material in terms of type, size, shape, components and composition. The composition of printed circuit boards is continuously changing, which makes it difficult to achieve a stable material composition.
- The assembly of plastic, ceramic and metal in the printed circuit boards is very complex, so there are great difficulties in releasing and separating each fraction.
- The presence of various metal elements requires a complex exploitation process.
- In the recycling of printed circuit boards, the most interesting is the metal content, which is about 30%. The non-metallic part (~70%) has a significantly lower economic value.

The goal of most recycling processes is to maximize the use of metal fraction from the waste printed circuit boards, but sometimes these processes are not very environmentally friendly.

Several procedures have been patented in the field of recycling the waste printed circuit boards [16]. Based on the literature review of these authors, the stages of recycling and procedures for preparation the mineral raw materials, applied in those stages, were systematized:

- Dismantling – manual selection
- Liberation of components - shredding on shredders in crushers and mills
- Characterization – sieving into the narrow size classes, separation in the sink-float procedure
- Concentration or separation – sink-float, separation in a fluid stream in cyclones, centrifugation in a fluid, magnetic separation, eddy current separation, electrostatic separation, flotation concentration
- Validation of separation results – float-sink procedure

CONCLUSION

A rapid development of the modern society results in generation the large amounts of electronic waste, out of which 3-8% are the printed circuit boards. Printed waste plates represent a very heterogeneous material depending on the type of device and from time period of their origin. This fact makes recycling difficult, which has become an economic and environmental necessity. It is believed that the amount of electronic waste at the annual level is measured in tens of millions of tons. This type of waste is a hazardous waste for which the strict norms are applied. In the Western countries, the electronic waste is either deposited or burned, and most of it is sent to the developing countries for treatment with primitive techniques, as a result of which the dangerous chemicals end up in the soil and watercourses, thus posing a danger to the population. The modernization and development of recycling techniques is imposed as an imperative in preservation the natural resources and healthy environment.

Waste printed circuit boards can be conditionally viewed as a very complicated mineral raw material. Also, the well-established rules and methodology and processes for preparation the mineral raw materials can be applied in the electronic waste recycling. Many of them are used in the recycling, or possibility of their application at the laboratory level is investigated.

During disassembly of the printed circuit boards, the unwanted parts are selected manually. To liberate the components into separate particles, a shredding is used to the required size. The characterization of samples takes place after sieving the crushed samples into the narrow size classes, using the classic or instrumental chemical methods. Separation of components can take place using the float-sink process, classification in fluids water and air, centrifugation in fluids, magnetic concentration, eddy current separation, electrostatic separation, flotation. The float-sink procedure can be used for rapid validation of separation techniques.

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Dragan Ignjatović[*1], *Snežana Ignjatović*[**], *Vanja Đurđevac*[*2], *Lidija Đurđevac Ignjatović*[*3], *Dušan Tašić*[*4]

LIME SOIL STABILIZATION[***]

Orcid: 1) https://orcid.org/0000-0003-2333-6853, 2) https://orcid.org/0000-0002-7973-0916
3) https://orcid.org//0000-0002-1113-5360, 4) https://orcid.org/0000-0001-8005-9640

Abstract

Soil stabilization represents process for improvements physical-mechanical and deformation feature of soil, adding binders. There are two basic kinds of stabilization: mechanical and chemical. Chemical stabilization of soil refers on addition binders to basic material of soil. The most common materials in chemical stabilization soil are lime and cement. In this work will to be shown the results stabilization soil with lime, for access roads on territory of the city of Bor.

Keywords: *stabilization soil, access road, soil, lime, cement*

1 INTRODUCTION

Physical, mechanical and deformation characteristics of subsoil, on place of future construction of the object, are very important factor. If the subsoil does not satisfy conditions prescribed in Project of construction, it should be replaced or stabilized. Most often, soil stabilization is performed by using two kinds of binders: lime and cement. Which one will be used depends from a lot of factors, such as mineralogical composition of subsoil, grain size distribution curve, organic matter content, etc. After completed selection of binders, its implementation is achieved.

To make everything realized, it was, previously, necessary to carry out laboratory tests of subsoil, for determination of all necessary factors.

It is also necessary to perform laboratory examines to see how the stabilized ground will behave, and will it fulfill the requirements of the Project.

In this paper will be shown the results of laboratory examinations of subsoil, to whom, as a binder material, is added a lime in different rates, 5% and 8%.

2 PHYSICAL MECHANICAL AND DEFORMATION PROPERTIES OF SUBSOIL MATERIALS

In the area of Bor city, access roads should be built, in order to connect certain areas with the main roads.

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnstajna 1, 19210 Bor, Serbia, E-mail: dragan.ignjatovic@irmbor.co.rs*
[**] *AG Institut DOO Novi Sad, Dr. Đorđe Jovanovića 4, Novi Sad, Serbia*
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That is why it was necessary to carry out a geomechanical test of the subsoil material, in order to see if it meets the requirements of the project for the construction of such roads.

According to the terms of the Project, the material should have the following properties:

- Classification per AASHTO A6 and better ,
- Maximum laboratory compactness for E = 600 kNm /m ^{3} larger than 1600 kg/m ^{3}
- Optimal humidity w_{opt} = 14-16%.

Classification per AASHTO, Class A6, implies dusty-clay material with the next one granulometric and consistency characteristic:

- More of 35% of the material passes through Sieve opening 0.075mm,
- That the liquid limit is max 40%,
- The index plasticity is min 11%

2.1 Subsoil properties

Subsoil properties, which are laboratory examined, are shown in Table 1.

Graphic representation of the grain size distribution of the subsoil material, are shown in Fig. 1.

Table 1 *Grain size distribution and consistency limits of subsoil*

GRAIN SIZE DISTRIBUTION						PLASTICITY			
-	Gravel	Sand	Silt	Clay	Passing through the sieve 0,075mm	Limits		Plasticity Index	Soil classifi-cation
>60	60-2.0	2.0-0.063	0.063-0.002	<0.002		W_L (%)	W_p (%)	I_p (%)	
(%)					(%)				
-	28,82	54,62	16,56	-	18,00	30,65	19,02	11,63	CL

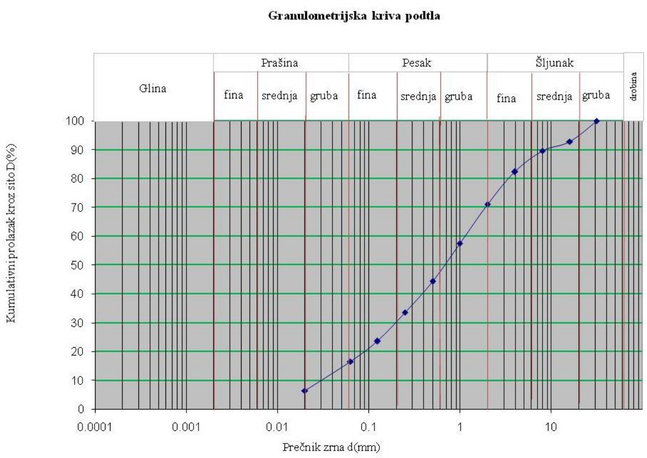

Figure 1 *Graphic representation of the grain size distribution of the subsoil material*

In addition to those shown properties, subsoil material was tested by the Proctor test, the CBR test and the determination of the compressive strength of the soil after the Proctor test.

Tests have shown the following:

- Maximum dry density from Proctor test, at a compaction energy of E = 600 kNm /m ^{3}, is 1732 kg/m ^{3},
- Optimal humidity w_{opt} = 12.53%,
- CBR = 11.68%,

- Uniaxial compressive strength of the material from Proctor test σ_p = 0.275 MPa

After the basic tests of the subsoil were completed, it was homogenized with lime in different proportions: 5% and 8%, Figure 2.

Figure 2 *Homogenization material of subsoil with 5% lime*

The homogenized material was then compacted in the Proctor apparatus under the same conditions as the base soil, with an optimal moisture content of 12.53% and a compaction energy of E = 600 kNm/m^3. Three test bodies were created from the compacted material in order to be tested after 7, 14 and 28 days of ripening, Figure 3.

Figure 3 *Uniaxial compressive strength of soil material*

The results of testing the compressive strength of the homogenized material are shown tabularly (Table 2) and graphically (Figure 4).

Table 2 *Presentation of compressive strengths of homogenized materials with 5% and 8% lime*

Time maturation mixtures, (day)	UCS of material with 5% lime, (MPa)	UCS of material with 8% lime, (MPa)
7	0.396	0.587
14	0.491	0.778
28	0.572	0.927

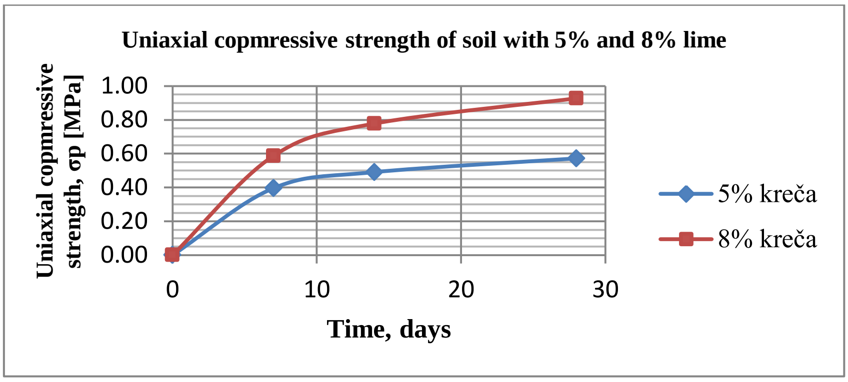

Figure 4 *Graphically display UCS of homogenized material, after 7, 14 and 28 days*

Comparing the value of compressive strength of the base material and given mixtures, it is concluded that there was an increase in compressive strength, especially in the mixture with 8% lime.

3 CONCLUSION

The use of lime as a binder for fine-grained, coherent or partially coherent materials results in an increase in the compressive strength of the soil and a decrease in the plasticity index. This method is one of the more economical methods, considering the availability of cement on the market and its price.

In the paper, it can be seen that the compressive strength of homogenized mixtures, with different lime content, increases with maturation time. As expected, the mixture with a higher lime content achieved, after 28 days, a higher compressive strength ($\sigma_{p\ (8\%\ lime,\ 28\ days)}$ = 0.927 MPa) than the mixture containing 5% lime ($\sigma_{p\ (5\%\ lime\ ,\ 28\ days)}$ = 0.572 MPa). Which of these mixtures will be applied on the field, depends on the characteristics of the stabilized soil and requirements of the Project.

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Vanja Đurđevac[*1], *Snezana Ignjatović*[**], *Dragan Ignjatović*[*2], *Dragana Savić*[***3]

DIFFERENT TYPES OF SOIL STABILIZATION TECHNIQUES[****]

Orcid: 1) https://orcid.org/0000-0002-7973-0916 2) https://orcid.org/0000-0003-2333-6853
3) https://orcid.org/0009-0002-3396-9435

Abstract

Soil stabilization is the process of improving physical, mechanical and dynamical properties of soil and increasing the bearing capacity. During the construction of a structure (road, building, etc.), it is necessary that the soil, where the structure will be located, meets the designed characteristics (physical, mechanical and deformation). In case, during the examination of the said soil, it is determined that it does not meet the given criteria, the improvement of the soil is started. This paper will describe the basic principles and types of soil stabilization.

Keywords: *soil stabilization, bearing capacity, structures, soil, soil characteristics*

1 INTRODUCTION

The basic ground, on which some of the construction objects will be located, must meet the requirements of the construction project. If it does not meet the prescribed conditions and qualities, soil improvement should be done. There are two ways: ***complete soil replacement*** and ***soil stabilization.***

The complete replacement of the soil is more expensive and time-consuming process, and in particular care should be taken to use the nearest loan site with material of the required characteristics, due to the economic effect. That is why soil stabilization is used in most cases.

Soil stabilization is a procedure that involves changing the properties of the basic soil, in order to obtain a substrate that meets the requirements of construction projects.

Depending on the type of soil to be stabilized, two methods of stabilization are applied: mechanical and chemical.

Mechanical methods are usually used with incoherent soils. With such types of soil, the granulometric composition is changed and such a mixture is mechanically acted upon until the required properties of the material are obtained (required load capacity, water permeability, etc.).

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnstajna 1, 19210 Bor, Serbia,*
E-mail: vanja.djurdjevac71@gmail.com
[**] *AG Institut DOO Novi Sad, Dr. Đorđe Jovanovića 4, Novi Sad, Serbia*
[***] *Geoing Group doo, Kraljice Marije 25, 11000 Belgrade, Serbia*
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With the chemical stabilization method, depending on the type of soil, cement and lime are used. By adding these materials, the physical, chemical and mechanical properties of the base soil are improved and changed.

2 THEORETICAL BASIS OF SOIL STABILIZATION

Soil stabilization is a process in which the soil's resistance to the effects of traffic and climatic influences is improved by adding binders, so that it can continuously receive the traffic load and its resistance to the effects of water and frost is increased in the medium and long term [1].

Soil stabilization is a group of earthworks technologies for improving soil characteristics during the construction process and for improving mechanical and load-bearing properties. The two main technological methods are soil improvement and soil consolidation [2].

Stabilized soil is any natural material that has been processed in such a way that its bearing capacity is improved and maintained, as well as to acquire resistance to the action of atmospherics (weather influences) [3].

These are just some of the definitions of soil stabilization, which scientists have been dealing with for many years. Almost all definitions of soil stabilization imply the use of additional materials, all with the aim of improving the characteristics of the basic soil.

Soil stabilization is very often applied in places where the basic soil has unsatisfactory physical and mechanical characteristics and where replacing the material is an extremely expensive solution.

The main methods of soil strengthening are: ***physical-chemical, mechanical and structural.***

Physico-chemical methods of soil strengthening are considered highly effective. We distinguish:

1. Mechanical stabilization
2. Stabilization using different types of mixtures:
   - lime stabilization,
   - cement stabilization,
   - chemical stabilization,
   - stabilization with fly ash,
   - bitumen stabilization,
   - stabilization using geotextiles and fabrics.

Mechanical soil stabilization is mainly used for non-coherent or weakly coherent types of soil. Adding certain fractions to the existing soil changes the initial granulometric composition. Some of the materials can be brought to a state of good geo-mechanical properties by the compaction process.

Chemical soil stabilization is associated with modifying soil properties by adding chemically active materials. It is important to know two facts: the property of the materials included in the mixture and the result after mixing and how the material will behave after stabilization [4].

The most commonly used binders used in soil stabilization are lime and cement. Which binder to use depends on the type of soil. Lime is used for fine-grained, bound soil, while cement is used to stabilize incoherent and weakly coherent soils.

In order to make it easier to determine which type of binder to use, depending on the granulometric composition and consistency limits of the base soil, Mirko Stanković, M.Sc., gave a tabular representation of the decision-making process, Figure 1.

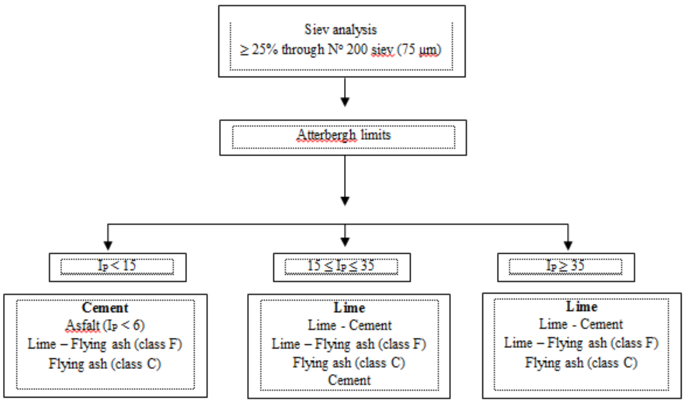

Figure 1 *Some of the decision-making elements on soil stabilization [4]*

2.1 Stabilization with cement

Stabilization with cement is suitable for coarse-grained soils and soils on the transition to fine-grained. Depending on the amount of cement, they differ:

1. **Cement soil**, which is a homogeneous material containing 5-15% cement in relation to the mass of the soil. The cement fills the pores and a cement lattice is formed in which the soil grains are trapped. Stabilized soil has a high strength of 2-7 MPa, is resistant to erosion, moisture and frost. It is applied to the bearing layer of traffic roads;
2. **Cement-improved soil** contains 2-5% cement. Soil grains are connected by cement only on part of the surface and no cement grid is formed. It is used to stabilize the placenta.

The process of stabilizing the base soil with cement in the field is shown in Figure 2.

Figure 2 *The process of stabilizing the base soil with cement in the field [2]*

2.2 Stabilization with lime

This type of stabilization is suitable for fine-grained soils. Stabilization is done by adding 2-8% of slaked lime in relation to the soil mass. A chemical reaction occurs between slaked lime and clay minerals and changes the properties of the soil. The mineralogical composition of the clay affects the strength of the reaction, soil moisture decreases, a solid skeleton is formed and the granulometric composition changes (clumping occurs). Over a longer period of time, a pozzolanic reaction occurs - the reaction of lime with active silicates and clay minerals. The grains stick together and thus increase the strength of the soil. The plasticity index, I_P, decreases . This method is more economical than cement stabilization. There is a noticeable effect of stabilization on increasing the bearing capacity of the soil.

The process of stabilizing the base soil with lime in the field is shown in Figure 3.

Figure 3 *The process of stabilizing the base soil with lime in the field [2]*

2.3 Chemical stabilization

The principle of chemical soil stabilization is to prevent the chemical binding of absorbed water or to provide the necessary water content, which will provide the material with the necessary cohesion. Various chemical additives are used for this purpose. The problem is that these funds are, in the main, very expensive and relatively unavailable to the broad market.

2.4 Bitumen stabilization

This type of stabilization is applied to all types of materials. It causes the effect of particles sticking together, thus increasing cohesion. The amount of bitumen used ranges from 2-4%, exceptionally in some cases up to 10%.

2.5 Stabilization with ash

Ash is a product of coal combustion in thermal power plants. Depending on the type of coal, class C ash is obtained, which has self-binding properties, i.e. only water is needed to start the reaction, and class F ash, which has only pozzolanic properties, i.e. in addition to water, an activator is also needed for the reaction to occur. The optimal ash content in the mixture is 10-30%, which depends on the type of soil and ash. The stabilization effect is reflected in an increase in strength and load capacity, while the plasticity index and swelling decrease.

The problems of soil stabilization, which arise when using the mentioned materials, are reflected in the following:

- Dosing of these supplements is done in small quantities, so even distribution on the field is difficult to implement.
- Depending on the mineralogical composition of the soil material being stabilized, the chemical reaction that takes place between the stabilizer and the base soil also depends. Therefore, the effectiveness of using stabilizers is called into question.
- Before starting the stabilization process in the field, it is necessary to conduct a series of laboratory tests, in order to prove the effectiveness of the stabilizer. In addition to laboratory tests, field tests are also very important, which will confirm the results obtained in the laboratory. All this requires a longer time period of testing [4].

3 CONCLUSION

Soil stabilization is applied in the case when the complete replacement of the soil is economically unprofitable (e.g., the distance of the loan site with quality material from the construction site, etc.).

Soil stabilization aims to improve the basic characteristics of the soil, such as: bearing capacity, shear resistance, compressive strength, and plasticity and swelling of the material are reduced.

In order to determine exactly what type of stabilization we will apply, it is necessary to determine the basic physical parameters of the soil material (granulometric composition and Atterberg consistency limits).

It should be borne in mind that, although a good amount of stabilization material is made, there are problems that arise during the process itself, such as: uneven dosing and small amounts of soil stabilization material, mineralogical composition of the basic soil, and the like.

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Metallurgical Engineering

*Aleksandra Ivanović[*1], Silvana Dimitrijević[*2], Stevan Dimitrijević[**3], Shaila Mir[***]*

THE IMPACT OF ANNEALING TEMPERATURES AND CHEMICAL ASSAYS ON THE MECHANICAL PROPERTIES AND ELECTRICAL CONDUCTIVITY OF CuNi9Sn2[****]

Orcid: 1) https://orcid.org/0000-0002-0562-2824 2) https://orcid.org/0000-0003-1670-4275
3) https://orcid.org/0000-0002-6507-0259

Abstract

The interest in copper-based alloys with nickel and tin is constantly increasing. In this regard, certain tests were performed on CuNi9Sn2 alloy samples. In this work, the influence of annealing temperature and chemical composition on the mechanical properties and electrical conductivity of CuNi9Sn2 was investigated. Tensile strength (Rm), yield strength (Rp0,2) and elongation (A) were determined in the function of annealing temperatures and content of added elements (Li and B) at a constant deformation degree.

Keywords: *CuNi9Sn2, mechanical properties, tensile strength, yield strength, elongation, electrical conductivity*

1 INTRODUCTION

The interest in copper alloys with nickel and tin constantly increases, because new areas of application continuously being discovered. Today, copper-based alloys with nickel and tin are used mainly as connector materials because of their suitable mechanical properties, their excellent relaxation behavior, and their high corrosion resistance.

The ternary Cu-Ni-Sn system was investigated by Ghosh [1] and covering practically all available literature. Schmetterer et al. [2] were investigated the phase equilibria in four isothermal sections at 220, 400, 500, and 700^0C of the Cu-Ni-Sn system and the existence of (βCu3Ti-type structure) was confirmed. The CuNi9Sn2 (in wt%) alloy exists as a two-phase alloy and has the ability to thermally precipitate. Also, it is well processed in a warm and cold condition. As with all metallic materials, tensile strength, yield strength and hardness increase with increasing cold deformation of wrought CuNi9Sn2 alloys, while elongation decreases (Fig. 1) [5].

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia, E-mail: aleksandra.ivanovic@irmbor.co.rs*
[**] *Innovation Center of the Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia*
[***] *Indian Institute of Technology, Roorkee, Uttarakhand 247667, India*
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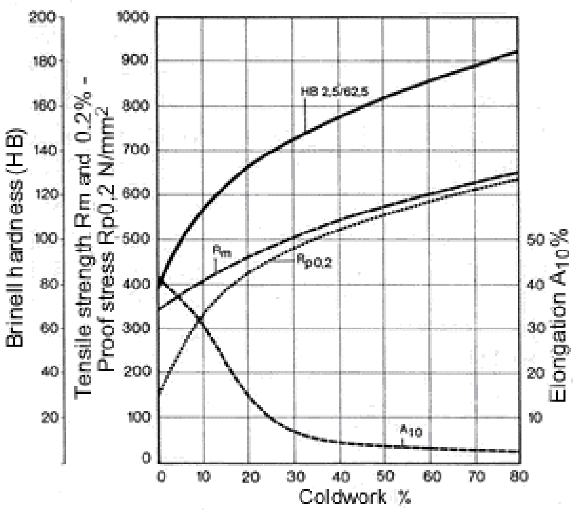

Figure 1 *Work hardening characteristics of CuNi9Sn2 [5]*

In addition to phosphorus for deoxidation, other elements are also used. Especially in use is Li, where besides deoxidation, lithium hydride is formed [6]. Zn is also used in small quantities since Zn acts negatively on electrical properties, but on the other hand, Zn improves the ability to process in a cold state. It is similar to the effect of Sn. Both of these elements are used to deoxidize the strip for cooler production. Also, Be and B are used for deoxidation. Bor reduces electrical conductivity but contributes to the fine-grained structure.

This paper presents the results of the influence of B and Li on the mechanical properties and electrical conductivity of the CuNi9Sn2 (in wt%) alloy.

2 EXPERIMENTAL WORK

2.1. Materials and Procedures

Results of all experimental testing presented in this paper were performed on the samples by mass 0.600 kg. The composition of the samples is given in Table 1.

Table 1 *Chemical Composition of investigated samples*

Sample	Ni % wt	Sn % wt	B % wt	Li % wt
CuNiSn + B	9.5	2.3	0.001	
CuNiSn + Li	9.5	2.3		0.0001
CuNiSn	9.5	2.3		
CuNiSn + (B, Li)	9.5	2.3	0.0005	0.001

Melting of CuNi9Sn2 alloy was carried out in the frequency induction furnace under a vacuum atmosphere (0.13 Pa). The melting process itself took place by putting all the material in a pot so that B and Li were placed on the bottom of the pot, then tin, nickel and at the end copper. Bor was added as Cu-B with 10% Bi, and Li wrapped in copper foil, pressed and then added to the batch. The casting was done in mold size 14x50x100 mm. Homogenization annealing of samples was carried out in an electric resistance furnace at 750^0C for 10 hours. Plastic processing of samples included rolling from 14x14x100 mm to the dimensions of ∅ 6.3 mm. The temperature of the hot processing was 900^0C. After the rolling, samples in the form of wire, with the deformation degree of 84%, were subjected to recrystallization annealing (750^0C, 1 h).

Samples were drawn to the dimensions of ∅ 2 mm with a total deformation degree of ε = 90%. After reduction, all samples were exposed to the recrystallization annealing at 750^0C during the 60 minutes in an electric resistance furnace of chamber type LP08.

2.2 Mechanical properties and electrical conductivity tests

Chemical analysis of samples was performed by an atomic absorption spectrophotometer. Mechanical characteristics were tested at a universal device for tensile testing of materials, by manufacturer Karl Frank, type 81221. First, mechanical tests (Rm, Rp0.2, A) of cold-deformed samples were performed and then samples were tested at the temperature range 20-500^0C. The time of holding the sample at the test temperature was 15 minutes. Electroconductivity tests were performed on wire samples ∅ 2mm in cold-deformed and annealing state by Thomson Bridge.

3 RESULTS AND DISCUSSION

3.1 Mechanical properties

Mechanical properties of samples after recrystallization annealing were presented in Table 2.

Table 2 *Mechanical properties of samples after recrystallization annealing*

Sample .	Rm, N/mm^2	$Rp_{0.2}$, N/mm^2	A, %
CuNi9Sn2 + B	324.8	137.2	28.93
CuNi9Sn2 + Li	339.0	145.5	37.94
CuNi9Sn2	330.6	140.4	29.57
CuNi9Sn2 + (B, Li)	357.2	165.4	31.17

Based on the data presented in Table 2, it can be concluded that the material is suitable for plastic processing in a cold state. Figures 1 -4 graphically present the effect of the annealing temperature (20-500^0C) to mechanical properties (Rm, Rp0.2, A) of cold-deformed samples

Figure 2 shows the effect of the annealing temperature (20-500^0C) to the tensile strength. From the results shown in Figure 2, it can be concluded that the tensile strength decreases with the annealing temperature increase. Analysing the tensile strength, depending on the presence of the alloying elements, it can be concluded that B and Li present in the alloy together affect the increase in the tensile strength in relation to the tensile strength of the CuNi9Sn2 alloy, which is retained at elevated temperature. Also, the values of the tensile strength of the alloy with Li are higher than the alloy with B.

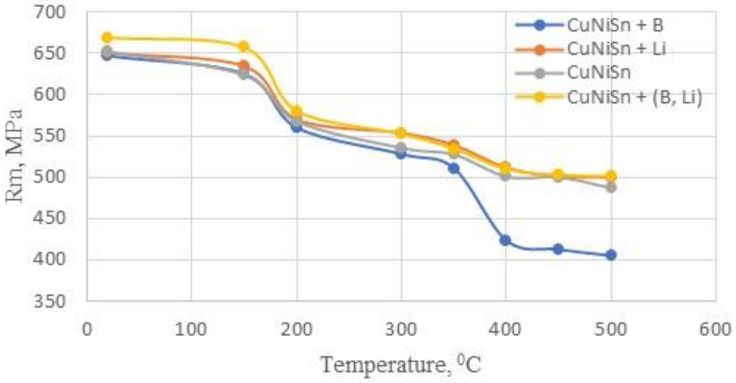

Figure 2 *Dependence of tensile strength of cold-deformed samples from temperature and content B and Li*

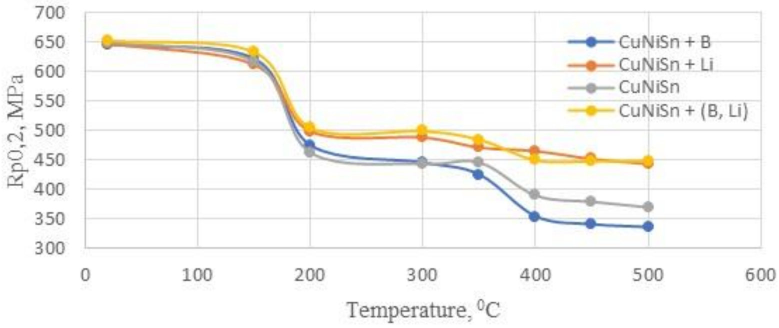

Figure 3 *Dependence of yield strength of cold-deformed samples from temperature and content B and Li*

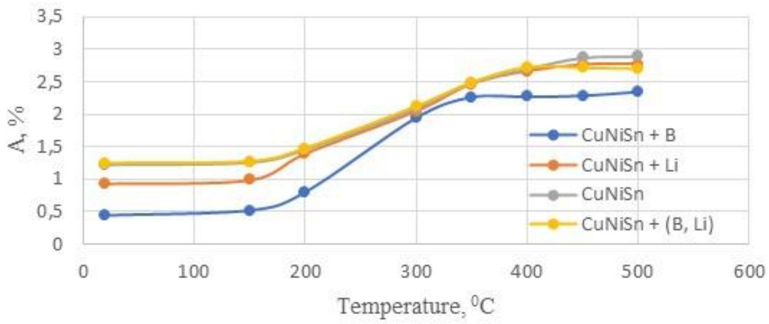

Figure 4 *Dependence of elongation of cold-deformed samples from temperature and content B and Li*

Figure 3 and Figure 4 shows the effect of the annealing temperature (20-500^{0}C) to the yield strength and elongation. From the results shown in Figure 3, it can be concluded that the yield strength decreases uniformly with increasing temperature, following the tensile strength. It is characteristic that the values of the stretching boundary and tensile strength are very close when it comes to cold-deformed samples. This phenomenon leads to the conclusion that the material in the solid state is very elastic. The elasticity is retained at elevated temperature. From the results shown in Figure 4, it is noticeable that Li has a little more effect on the increase in elasticity compared to B, while together they more favorably influence the increase in mechanical properties.

3.2. Electrical conductivity

Electrical conductivity and resistance after recrystallization annealing were presented in Table 3.

Table 3 *Electrical conductivity and resistance of samples after recrystallization annealing*

	Cast condition			
	CuNiSn + B	CuNiSn + Li	CuNiSn	CuNiSn + (B, Li)
Resistance (Ω)	0,03435	0,0412	0,04105	0,036
Conductivity (S)	9,32	7,75	7,8	8,81
	Annealed condition			
Resistance (Ω)	0,03567	0,041	0,04077	0,036
Conductivity (S)	9,923	8,338	8,378	9,375

From the results shown in Table 3, it can be concluded that the presence of B gives slightly higher electrical conductivity. By contrast, comparing the electrical conductivity data of the samples in annealed and cast state, it can be noticed a certain increase in electrical conductivity by annealing samples without B.

4 CONCLUSION

Based on the study it can be concluded:

- The results showed satisfactory values of mechanical properties at room temperature.
- Tests at elevated temperatures show a drop in the mechanical properties of all samples to a temperature of 400^{0}C.
- Li and B have a positive influence on the mechanical properties of CuNi9Sn2 alloy. It is noticeable that Li has a little more effect on the increase of mechanical properties than B, but together they more favorably influence the increase in mechanical properties of this alloy.
- Presence of B gives slightly higher electrical conductivity. By contrast, comparing the electrical conductivity data of the samples in annealed and cast state, it can be notice a certain increase in electrical conductivity by annealing samples without B.

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Branko Drndarević[*]*, Petar Nedić*[**]*, Dušan Vulović*[***]*,*
Aleksandar Milovanović[****]*, Ivana Čeković*[****1]

IMPACT OF SELECTING THE CUTTING TECHNOLOGY ON PRODUCTION TIME AND COST

Orcid: 1) https://orcid.org/0000-0002-5332-2965

Abstract

This paper analyzes the technology of cutting processing for supports the mold clamping jaws made of 1C60 material. The number of clamping moves, required to produce the workpiece, is defined, as well as the adoption of necessary cutting tools with appropriate cutting modes on the basis of used material and CNC machine. A detailed analysis is provided for the circumferential milling of pockets with diameters of Ø250 mm and height of 30 mm, Ø200 mm and height of 30 mm, and Ø100 mm and height of 40 mm. This is due to the material volume processed per unit of time, which significantly affects the production time of a workpiece. The impact of selecting the offered circumferential milling operations in the HSMWorks software package on production time and tool life is analyzed, using the 2D Pocket and 2D Adaptive Clearing software options. A comparative analysis of the workpiece production time and cost is provided.

Keywords: *circumferential milling, cutting modes, processing technology, production time, CAM programming*

1 INTRODUCTION

Milling is a cutting process involving a chip removal. The tools used in milling operations are called the milling cutters, and machines for processing are called the milling machines. The main rotational motion is performed by the tool, while the auxiliary linear motion is performed by the workpiece [1]. In a circumferential milling, the used milling cutter has the cutting edges arranged around its circumference, with at least two cutting edges. Face milling is used for processing larger surfaces, and in this process, the cutting edges are located on the tool face. The cutting modes in the milling process are determined by the cutting speed. The main processing time is calculated using equation (1) [1]:

$$t_g = i \cdot \frac{L}{n \cdot S} [min]. \qquad (1)$$

The cutting speed in the milling process represents the circumferential speed of the milling cutter (2):

$$V = \frac{D \cdot \pi \cdot n}{1000} \approx \frac{D \cdot n}{320} [m/min] \qquad (2)$$

The removal rate is calculated by equation (3):

[*] *Rad Raso d.o.o., 31000 Užice, Serbia, E-mail: branko.drndarevic@gmail.com*
[**] *NIDEC ELECTRIC MOTOR d.o.o., 21000 Novi Sad, Serbia*
[***] *Elektrotermija d.o.o., 31000 Užice, Serbia*
[****] *Academy of Applied Studies Western Serbia, 31000 Užice, Serbia*

$$q = a \cdot b \cdot V_s [mm^3/min] \quad (3)$$

The support of the mold clamping washers is made of the material 1.0601.

The mechanical properties of material and its chemical composition are presented in Tables 1 and 2 [2].

Table 1 *Mechanical properties of material 1.0601[2]*

Designation	Tearing strength (Rm) $[N/mm^2]$	Yield strength (Re) $[N/mm^2]$	Elasticity modulus (E) $[N/mm^2]$	Toughness $[MN/m^{3/2}]$	Hardness (HRc)
1C60/1.0601	$1250 \div 1450$	460	$(2{,}1 \ldots 2{,}2) \cdot 10^5$	5.5 ± 0.4	20.3

Table 2 *Chemical composition [2]*

Chemical composition (expressed as %)								
Designation	C	Mn	P	S	Si	Cr	Mo	Ni
1C60/1.0601	0.57÷0.65	0.60÷0.90	≤0.045	≤0.045	≤0.4	≤0.4	≤0.1	≤0.4

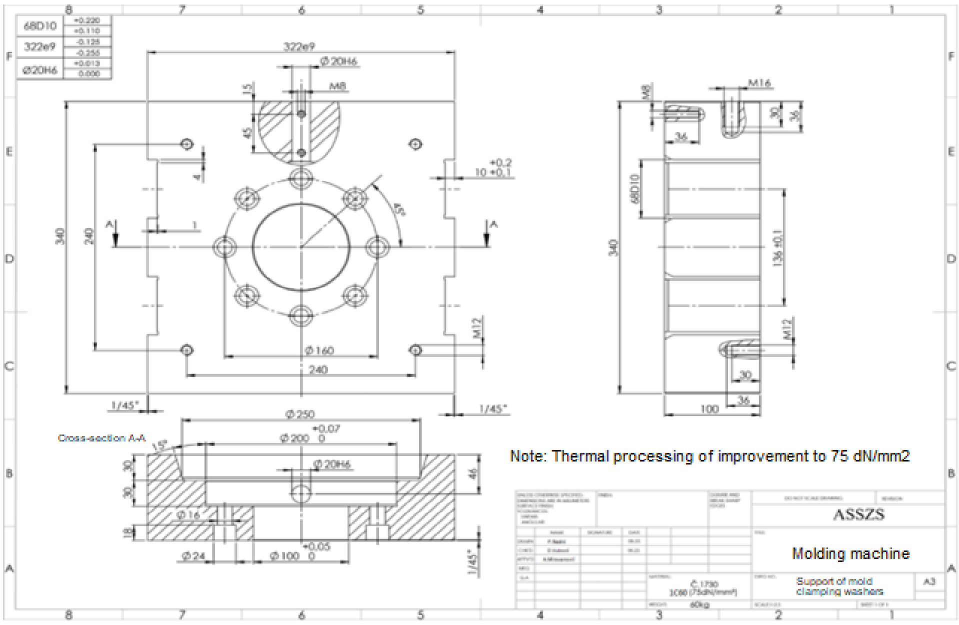
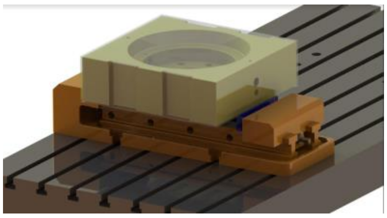
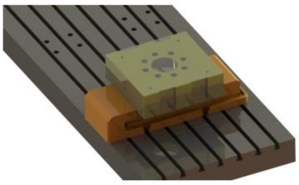
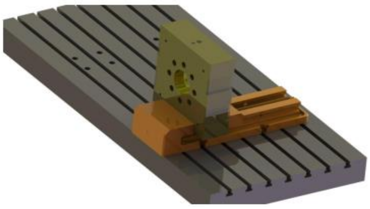
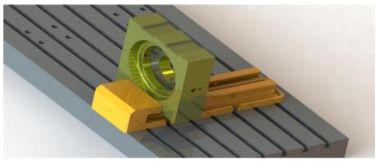
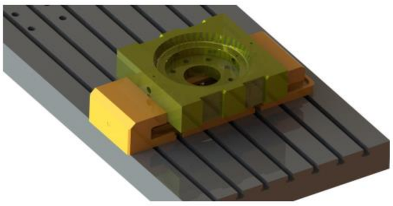


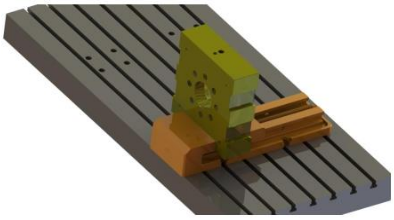
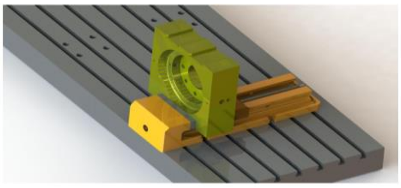
Figure 1 *Support of mold clamping washers [3]*

2 CLAMPING AND TOOL SELECTION

By analyzing the supports of clamping washers, a minimum of 11 clamping moves necessary for the proper production of a clamping washer has been defined. Table 3 provides an overview of clamping, along with description of operations involved in each clamping move [3].

Table 3 *Presentation of clamping and description of operations involved [3]*

	Clamping move no. 1 Face milling, circumferential milling, the operation of interior contour milling of Ø250 mm diameter, the production of a conical part at an angle of 15^{o} by the internal circumferential milling operation, contour milling of the radius R5 mm, interior contour milling of Ø200 mm diameter with an additional 0.3 mm for further processing, interior contour milling of Ø100 mm diameter with an additional 0.3 mm for further processing, drilling 12 holes, drilling 4 threaded holes using a Ø6.4 mm drill, M8 thread cutting, and drilling 8 holes using a Ø16 mm drill.
	Clamping move no. 2 Face milling, interior contour milling of a pocket with diameter of Ø24 mm and height of 18 mm, drilling 4 holes, drilling 4 threaded holes using a Ø9.6 mm drill, and M12 thread cutting.
	Clamping move nos. 3 and 4 As the workpiece is symmetrical, only one clamping move is shown. The operation includes tapping the Ø20H6 pocket and M16 threaded hole, drilling the Ø20H6 pocket using a Ø16 mm drill, widening the Ø20H6 pocket with an additional 0.3 mm left for fine processing, drilling the Ø12.8 mm threaded hole using a Ø12.8 mm drill, and M16 thread cutting.
	Clamping move nos. 5 and 6 As the workpiece is symmetrical, only one clamping move is shown. Circumferential milling of the 68D10 slot with an additional 0.3 mm for further processing, and production a relief channel using a Ø3 mm milling cutter.
	Clamping move no. 7 Additional processing after thermal treatment. Additional processing of the Ø200 mm diameter to the required dimension using interior contour milling, additional processing of Ø100 mm diameter to the required dimension using interior contour milling.

	Clamping move nos. 8 and 9 Additional processing after thermal treatment. As the workpiece is symmetrical, only one clamping move is shown. Additional processing of the Ø20H6 pocket to the required dimension.
	Clamping move nos. 10 and 11 Additional processing after thermal treatment. As the workpiece is symmetrical, only one clamping move is shown. Contour milling of the 68D10 slot to the required dimension.

By analyzing the supports of clamping washers, the minimum number of necessary cutting tools was defined. A detailed description of the cutting tools, along with the cutting modes determined on the basis of recommendations of the tool manufacturer, material from which the support of clamping washers is made (1C60/1.0601), and the CNC machining center used, is shown in Table 4. To produce this workpiece, the "HAAS VF5/50" CNC milling machine (three operational axes: x, y, and z) was used [4].

Table 4 *Description of cutting tools and cutting modes [5]*

No.	Tool name	Manufacturer	Tool and plate ID	Diameter [mm]	Number of cutting plates/teeth [z]	Length of cutting edge [mm]	Cutting speed Vc [o/min]	Feed per tooth a_z [mm]
1	Milling head	Garant	213300 125/8 213340	Ø125	8	-	200	0.45
2	Spindle-shaped milling cutter	Garant	203024 20	Ø20	4	102	70	0.17
3	15° conical milling cutter	HAAS	01-0132 02-0487	Ø30.6	3	9.5	150	0.3
4	Radius milling cutter	Garant	207154 5	Ø5	2	9	33	0.02
5	Spindle-shaped milling cutter	Garant	202392 20	Ø20	3	40	190	0.19
6	Tap	Holex	111005 3.15	Ø3.15	2	16	25	-
7	Drill	Holex	122777 6.5	Ø6.5	2	53	95	-
8	Hole punch	Garant	132640 M8	M8	3	35	15	-
9	Drill	Holex	114360 16	Ø16	2	120	31	-
10	Drill	Holex	114360 9.6	Ø9.6	2	87	31	-
11	Hole punch	Holex	132645 M12	M12	3	24	7	-
12	Drill	Garant	114400 12,8	Ø12.8	2	80	25	-
13	Hole punch	Garant	132150 M16	M16	3	32	15	-
14	Spindle-shaped milling cutter	Holex	202760 3	Ø3	4	12	70	0.01
15	Spindle-shaped milling cutter	Garant	203372 20	Ø20	10	75	115	0.04
16	Spindle-shaped milling cutter	Garant	203024 12	Ø12	4	76	70	0.06

The tools used to produce the support of clamping washers are shown in Table 5, which lists the tools necessary for production the supports of clamping washers [5].

Table 5 *Tools for production the supports of clamping washers [5]*

 Milling head	 Spindle-shaped milling cutter	 Conical milling cutter
 Radius milling cutter	 Tap	 Milling cutter made of hard metal with TiAlN coating
 Hole punch	 Spindle-shaped milling cutter with TiAlN coating	 Drill with TiN coating

3 DESCRIPTION AND PRODUCTION TIME COMPARISON

The analysis of the processing operations available in the HSMWorks software package shows that there are two possible options for processing pockets: 2D Pocket and 2D Adaptive Clearing. The machining-times of these two software package options will be compared.

- Producing a pocket with diameter of Ø250 mm and height of 30 mm using the 2D Adaptive Clearing option.

The tool path for this option is shown in Figure 2.

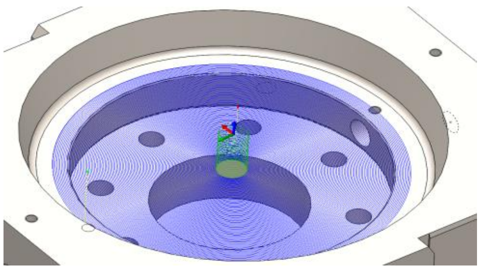


Figure 2 *Tool path for the 2D Adaptive Clearing option*

In this operation, the tool steps down to the predefined height and radially removes material with the entire length of cutting edge, with a material load of 1 mm. The volume of material removed in this operation is V = 1471.8 cm³. The time needed to process this pocket is 25 minutes and 5 seconds.

- Producing a pocket with diameter of Ø250 mm and height of 30 mm using the 2D Pocket option.

The tool path for this option is shown in Figure 3.

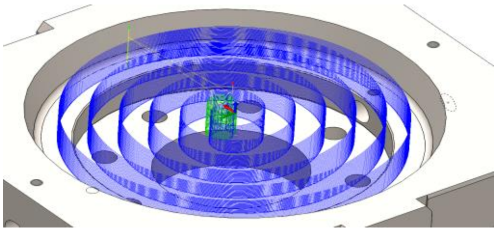


Figure 3 *Tool path in 2D Pocket option*

When using this option, 80% of the tool diameter is engaged. Milling is performed frontally and radially up to the predefined diameter, with a cut depth of 1 mm. The passes are repeated until the tool reaches the predefined height. The volume of material removed in this operation is V = 1471.8 cm^3. The time needed to process this pocket is 48 minutes and 26 seconds.

- Producing a pocket with diameter of Ø200 mm and height of 30 mm using the 2D Adaptive Clearing option.

The tool path for this option is shown in Figure 4.

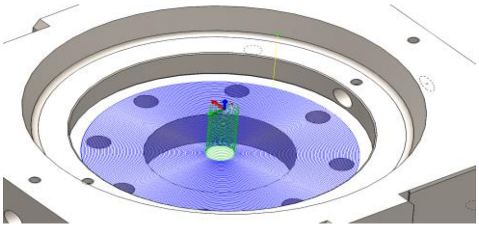


Figure 4 *Tool path in the 2D Adaptive Clearing option*

When using this option, the tool steps down to the predefined height, radially removing material with the entire length of cutting edge, with a material load of 1 mm. The volume of material removed in this operation is V = 942 cm^3. The time needed to process this pocket is 18 minutes and 16 seconds.

- Producing a pocket with diameter of Ø200 mm and height of 30 mm using the 2D Pocket option.

The tool path for this option is shown in Figure 5.

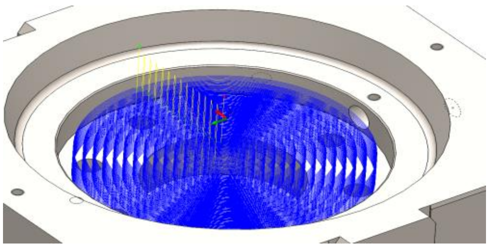


Figure 5 *Tool path in the 2D Pocket option*

When using this option, 80% of the tool diameter is engaged. Milling is performed frontally and radially up to the predefined diameter, with a cut depth of 1 mm. The passes are repeated until the tool reaches the predefined height. The volume of material removed in this operation is V = 942 cm^3. The time needed to process this pocket is 70 minutes and 55 seconds.

- Producing a pocket with diameter of Ø100 mm and height of 40 mm using the 2D Adaptive Clearing option.

The tool path for this option is shown in Figure 6.

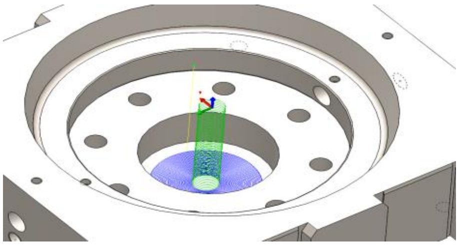


Figure 6 *Tool path with the 2D Adaptive Clearing option*

When using this option, the tool steps down to the predefined height, radially removing material with the entire length of cutting edge, with a material load of 1 mm. The volume of material removed in this operation is V = 314 cm^3. The time needed to process this pocket is 5 minutes and 25 seconds.

- Producing a pocket with diameter of Ø100 mm and height of 40 mm using the 2D Pocket option.

The tool path for this option is shown in Figure 7.

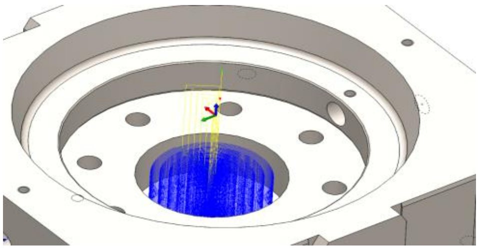


Figure 7 *Tool path in the 2D Pocket option*

When using this option, 80% of the tool diameter is engaged. Milling is performed frontally and radially up to the predefined diameter, with a cut depth of 1 mm. The passes are repeated until the tool reaches the predefined height. The volume of material removed in this operation is V = 314 cm^3. The time needed to process this pocket is 21 minutes and 55 seconds.

If the time needed to produce the analyzed pockets (Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm) using the aforementioned software package options is compared, it can be seen that the total time needed to produce the analyzed pockets using the 2D Adaptive Clearing option is 48 minutes and 46 seconds, i.e., 0.813 hours. When using the 2D Pocket option, the time needed for production is 141 minutes and 16 seconds, i.e., 2.35 hours.

The production cost using the 2D Adaptive Clearing option is EUR 48.78, while using the 2D Pocket option, the production cost is EUR 73.2. The considered hourly rate for the CNC machine is EUR 30.

Table 6 provides an overview of comparison between the production times of each aforementioned option in the HSMWorks software package.

Table 6 *Production time for Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm pockets using the 2D Adaptive Clearing and 2D Pocket options*

Analyzed pocket	2D Adaptive Clearing option	2D Pocket option
Ø250x30 mm	25 min 5 s	48 min 26 s
Ø200x30 mm	18 min 16 s	70 min 55 s
Ø100x40 mm	5 min 25 s	21 min 55 s
Total time [min and s]	48 min 46 s	141 min 16 s
Total time [h]	0.813 h	2.35 h

4 CONCLUSION

While analyzing the technical drawing of the workpiece to be processed, defining the number of clamping moves, and selecting the processing operations, the comparison between the production time during the first clamping move and time needed for processing the Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm pockets using the 2D Adaptive Clearing and 2D Pocket operations of the HSMWorks software package was performed due to the significant volume of material to be removed. The time needed to produce the analyzed pockets (Ø250x30 mm, Ø200x30 mm, and Ø100x40 mm) differs significantly. The time needed to produce the three analyzed pockets using the 2D Adaptive Clearing option is 48 minutes and 46 seconds, i.e., 0.813 hours, whereas their production time using the 2D Pocket option is 141 minutes and 16 seconds, i.e., 2.35 hours. The difference in production time when using the 2D Adaptive Clearing and 2D Pocket options is 1.537 hours, i.e., EUR 46.11.

Using an inadequate programming method for production the machine parts has increased the production cost. The analyzed machine part is produced in batches of 10 or 20 pieces due to the needs of production process and the production plant. Considering the defined batches, the differences in production time and cost for a batch of 10 pieces are 15.37 hours, i.e., EUR 461.1, whereas for a batch of 20 pieces, they are 30.74 hours, i.e., EUR 922.2.

Simultaneous time analysis in the process shows that the CAM programming of machine parts can proactively has the impact on production time and cost of machine parts, as well as the tool life.

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Branislav Rajković[*1], *Vladan Kamenović*[*2], *Zoran Ilić*[*3], *Ljubiša Obradović*[*4], *Goran Angelov*[*]

CONCEPTUAL DESIGN OF HYDROTECHNICAL INSTALLATION FOR SPRINKLING THE TAILING DUMP IN THE MINES AND FLOTATION PLANT KOPAONIK – LEPOSAVIĆ[**]

Orcid: 1) https://orcid.org/0000-0002-6646-0144 2) https://orcid.org/0000-0001-9476-5378
3) https://orcid.org/0000-0002-3174-9941 4) https://orcid.org/0000-0002-6715-4173
5) https://orcid.org/0000-0003-3841-8667

Abstract

This paper presents a description of operation and main elements of mechanical installation on an example of the conceptual design of the hydrotechnical installation for sprinkling the MFP Kopaonik tailing dump. Calculation for the pump selection is given at the level of conceptual design in the calculation part. Presentation of the PID of installation for sprinkling the tailing dump, as well as the technical characteristics of the main elements of installation, are also given.

Keywords*: sprinkling of tailing dump, hydrotechnical installation, technical characteristics*

1 INTRODUCTION

For expanding the flotation tailing dump MFP Kopaonik, the Mining and Metallurgy Institute Bor has made the Basic Design for Expansion the Flotation Tailing Dump in 2018. In addition to this project, at the request of the investor Trepča AD RMHK Holding, the Conceptual Design for Sprinkling the Flotation Tailing Dump in the MFP Kopaonik in Leposavić [1] was made. At the time of the project, recultivation of the tailings area had not yet been done, so there was a problem of dust emission from a part of tailings area into the surroundings, especially in the summer. The conceptual design of sprinkling provides a technical solution for overcoming this problem in the technological, construction, electrical and mechanical parts. In this paper, the attention will be paid to the selection of a pump and detailed technical characteristics of both the pump itself and main elements of mechanical equipment specific to such sprinkler systems, namely the big volume guns and control valves.

2 TECHNICAL DESCRIPTIONS

The purpose of the installation for sprinkling the Leposavić flotation tailing dump is to keep the surfaces of the tailing dump emitting the airborne dust in a wet state in order to prevent dust from the landfill being blown into the environment. The installation is planned for operation only in the

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia,*
E-mail: branislav.rajkovic@irmbor.co.rs

[**] *This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, contract number 451-03-66/2024-03/200052.*

summer period of the year, when the problem of dust emission is the greatest. The surfaces emitting the airborne dust practically represent the upper part of the slopes that extend from the bottom of the tailing dump to the top of the embankment along most of the perimeter of tailing dump (Figure 1).

Figure 1 *Slope of the Leposavić flotation tailing dump before recultivation*

The installation in question enables keeping these surfaces in a wet state by periodic watering with technical water. Technical water for watering the tailing dump will be provided from the Ibar river nearby (Figure 2), from which the water will come purified by filtering through a layer of soil to the well, which will house a deep well pump for technical water transport to the sprinklers-big volume guns.

Figure 2 *View from the top of the Leposavić flotation tailing dump on the Ibar river*

Sprinkling the tailing dump will be carried out by 18 big volume guns placed behind the crown of the embankment distributed at an appropriate distance from each other along the perimeter of tailing dump (Figure 3).

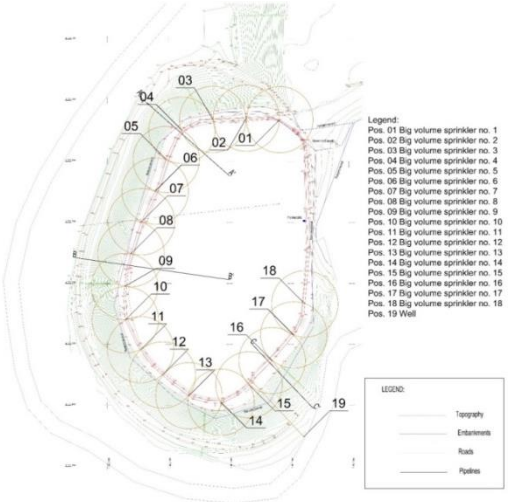


Figure 3 *Layout of the installation for sprinkling the Leposavić tailing dump*

Deep well pump will supply water to one big volume gun at one time, while the others will be turned off. Turning the big volume guns on and off will be controlled by the control unit, located next to the deep well pump via automatic valves mounted upstream of the big volume guns. The big volume guns have the ability to rotate around the vertical axis within adjustable limits so that one big volume gun sprinkles a certain area or zone. Sprinkling zones from individual big volume guns are shown in Figure 4, so that each big volume gun has its corresponding sprinkling zone.

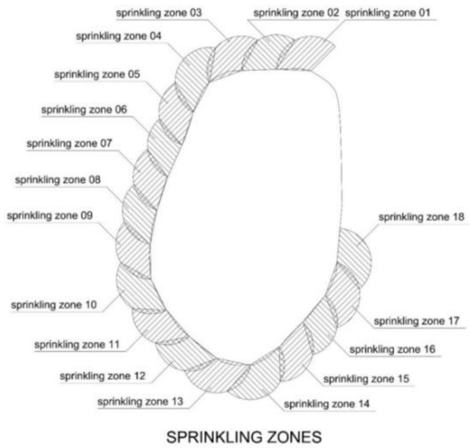
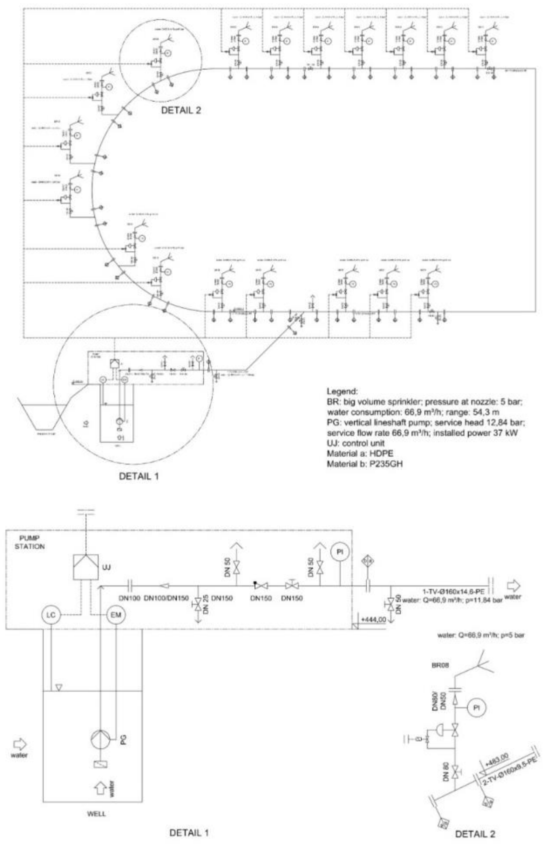


Figure 4 *Sprinkling zones of the Leposavić tailing dump*

The time of switching on and off the big volume guns will depend on condition of the surfaces to be wetted, climatic conditions and other technological requirements. An electric motor-driven deep well pump located in the pump station pumps water from the well. A suction strainer is provided on the suction port of the pump, and air relief and vacuum valve, check valve and manual gate valve are provided on the discharge port. Pump electric motor operation will be controlled via the control unit by turning the pump off when the level sensor registers the switch off water level limit in the well thus protecting the pump from running dry. A pressure gauge is provided for reading the pressure at the exit from the pump station. The main pipeline will be in the lower part with dimensions of Ø160x14.6 nominal pressure PN16 made of HDPE and it will transport technical water from the well to the top of the embankment in a length of 130 m with a height difference of 39 m. In the upper part, the main pipeline will be Ø160x9.5 with a nominal pressure of PN10 made of HDPE and will be laid along the entire perimeter of the embankment in a length of 1260 m. The pipelines will be laid on the ground freely. Depending on the terrain profile, the air release valves will be provided in the pipeline at the highest points, and drain valves at the lowest points. The big volume guns connections will be made of seamless steel pipes. Every connection is provided with a manual gate valve and automatic valve without auxiliary energy for turning sprinkler on and off, which is controlled via a solenoid valve that receives a control signal from the control unit in the pump station. A pressure gauge is provided for reading the pressure upstream from each big volume gun. The PID of the installation for sprinkling the tailing dump Leposavić is shown in Figure 5.



Sprinkler installation PID

Figure 5 *PID of the installation for sprinkling the Leposavić tailing dump*

3 CALCULATIONS

The hydraulic calculation of the system for sprinkling the Leposavić tailing dump was carried out in order to select a deep well pump for technical water transport from the well to the big volume guns. Since only one big volume gun is in operation at one time, the calculation was made for the most unfavorable section from the well to the big volume gun no. 01 for a flow rate value of 66.9 m^3/h.

Input data:

1. The total pressure loss in the pump station amounts Δp_1=1 bar.

2. The height difference from the exit from the pump station to the connection of the big volume gun no. 1 is H=39 m.

3. The total pressure loss at the connection of a big volume gun is Δp_2=1 bar.

4. Pressure at nozzle of a big volume gun is p_k=5 bar.

3. $\delta = 0.01[mm]$ –absolute roughness of HDPE pipe for diameters below 200 mm [2].

4. $\upsilon = 1.006 \cdot 10^{-6} \left[\frac{m^2}{s}\right]$ - kinematic viscosity of water for temperature of 20°C.

5. Local losses amount 10% of line losses.

The following calculation formulas were used in the calculation:

$$v = \frac{4 \cdot Q}{d^2 \cdot \pi}$$

$$Re = \frac{v \cdot d}{\nu}$$

$$\Delta p = \rho \cdot g \cdot H + 1.1 \cdot L \cdot \frac{\lambda}{d} \cdot \rho \cdot \frac{v^2}{2}$$

The individual symbols have the following meanings:

$L[m]$-length of the pipeline section

$\rho = 1000 \left[\frac{kg}{m^3}\right]$-water density

$g = 9.81 \left[\frac{m}{s^2}\right]$- gravitational constant

$Q \left[\frac{m^3}{s}\right]$- volumetric flow rate of water in the pipeline section

$H[m]$- height difference of the pipeline section

$d[m]$- internal diameter of the pipeline section

$v \left[\frac{m}{s}\right]$- actual water velocity in the pipeline section

$\nu \left[\frac{m^2}{s}\right]$- kinematic viscosity of water

Re–Reynolds number

$\delta[mm]$- absolute roughness of the pipe

$k = \delta \cdot 10^{-3}/d$- relative roughness of the pipe

$\lambda = \frac{1,325}{\left(\ln\left(\frac{k}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right)^2}$ – friction coefficient according to Russo and Smith

$\Delta p[Pa]$- pressure loss of the pipeline section

The pump head required amounts:

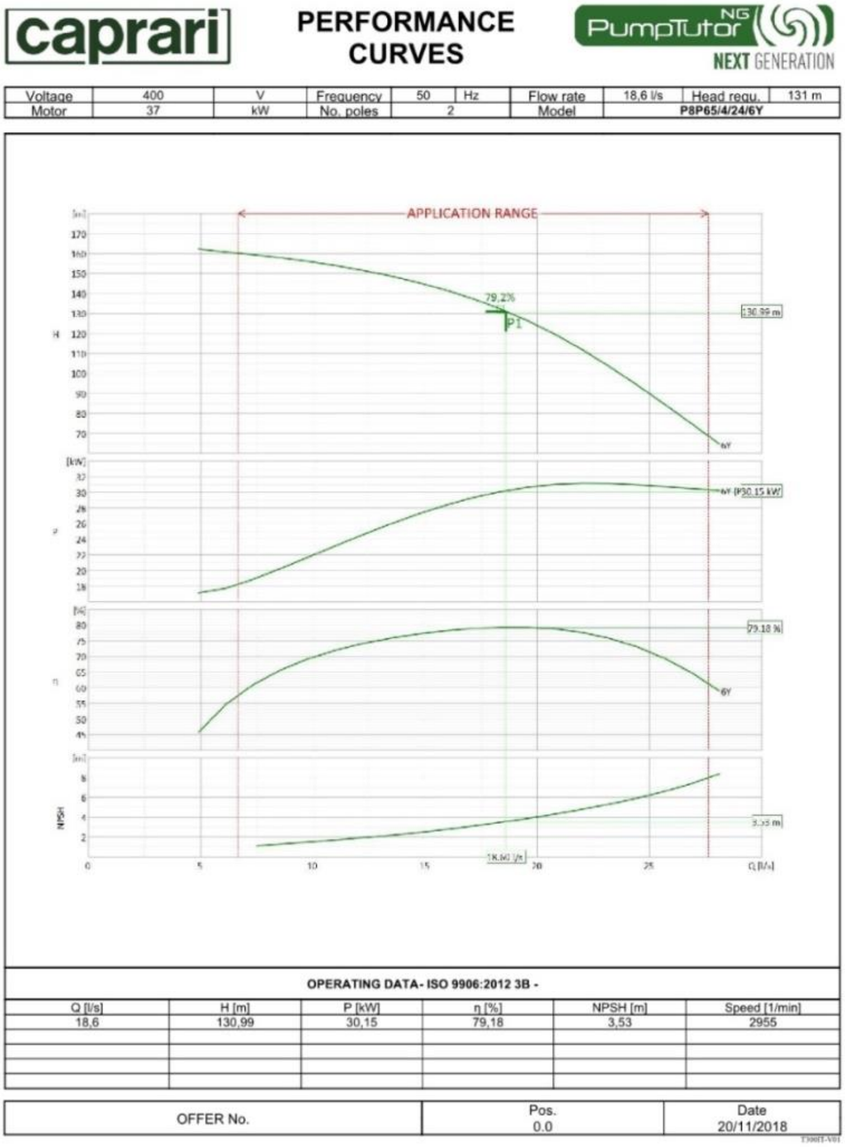
$$\Delta p_p = 1.1 \cdot (\Delta p_1 + \Delta p + \Delta p_2 + p_k) = 12.8\ [bar]$$

The calculation results of the pressure loss in the main pipeline of the HDPE pipes are shown in Table 1, and the pump performance curves in Figure 6.

The technical data of the selected pump are given in Table 2.

Table 1 *Calculation results of the pressure loss in sections 1 and 2*

Pressure loss in sections 1 and 2												
Section number	Volumetric flow rate through the section	Volumetric flow rate through the section	Section length	Height difference of the section	Internal diameter of the section	Velocity	Absolute roughness	Relative roughness	Reynolds number	Friction coefficient	Pressure loss in the section	Pressure loss in bar
-	Q*	Q	L	H	d	v	δ	k	Re	λ	Δp*	Δp
-	l/s	m^3/s	m	m	m	m/s	mm	-	-	-	Pa	bar
1	18.6	0.0186	130	39	0.1308	1.385	0.01	7.65E-05	180068	0.016	399868	4.0
2	18.6	0.0186	780	0	0.141	1.192	0.01	7.09E-05	167042	0.017	71951	0.7
Total			910	39							471819	4.7



Voltage	400	V	Frequency	50	Hz	Flow rate	18,6 l/s	Head requ.	131 m
Motor	37	kW	No. poles	2		Model	P8P65/4/24/6Y		

OPERATING DATA- ISO 9906:2012 3B -

Q [l/s]	H [m]	P [kW]	η [%]	NPSH [m]	Speed [1/min]
18,6	130,99	30,15	79,18	3,53	2955

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Figure 6 *Pump performance curves*

Table 2 *Technical data of the selected pump*

Designation	**Six stages deep well (vertical lineshaft) pump for clear or slightly muddy water**
Manufacturer	Caprari
Model	P8P65/4/24/6Y
Lineshaft column type	LA4/24
Number of lineshaft columns	1
Drive head type	E20/55/4/24
Electric motor size	200
Nominal electric motor power	37 kW
Rated voltage	400 V
Rated frequency	50 Hz
Speed	2955 min^{-1}
Flow rate at operating point	18.6 l/s
Head at operating point	130.99 m
Power at operating point	30.15 kW
Pump efficiency	79.18%
Overall efficiency	74.2%
NPSH at operating point	3.53 m
Maximum temperature of water	60 °C
Maximum solid content (silt)	80 gr/m^3
Discharge connection size	DN100
Immersion depth	4.3 m
Overall dimensions of package LxWxH	590x434x5648,5 mm
Mass of package	354.8 kg

The pump consists of the following main parts:

1. hydraulic part – 6 pump stages with semi-axial impellers, type P8P65/4/24/6Y
2. lineshaft column, type LA4/24
3. drive head, type E20/55/4/24
4. electric motor 50 Hz 37 kW V1 2P IE3 400V, type P303702T2V12001
5. suction strainer, type SUP8

In this paragraph, a brief description of the pump will be given according to [3]. In the hydraulic part of the pump in each stage, there are the semi-axial impellers statically and dynamically balanced to ensure the vibration free operation. The impellers are mounted on a common shaft. At the housing ends of each stage, the shaft is supported by the rubber bearings resistant to wear by the abrasive action of the solid particles in water. The shaft passing through the lineshaft column transmits the power from the drive head to the impellers, while water flows up through the column. The lineshaft column consists of one or more pipes joined by flanges and its length depends on the required immersion depth of the pump. The shaft is supported by rubber bearings in the riser, which are lubricated by the lifting liquid. The drive head supports the assembly weight and provides the connection of discharge pipe to the discharge port. An electric motor is mounted on the drive head. All drive units are fitted with a device to prevent the pump from rotating in reverse. The strainer prevents foreign bodies from entering the suction port.

Valves at the discharge side of the pump belong to the usual equipment for this type of installation. Layout of the pump station and well is shown in Figure 7.

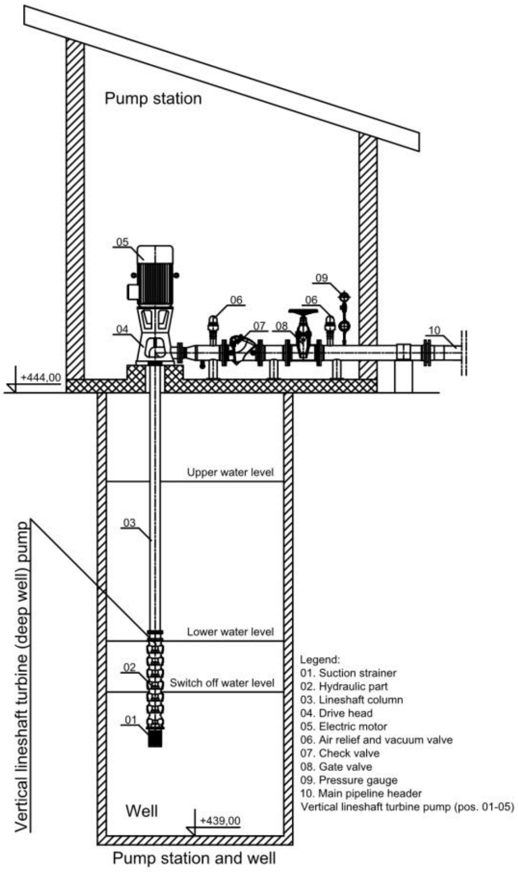

Figure 7 *Pump station and well of the sprinkling installation for sprinkling the Leposavić tailing dump*

4 DISCUSSION

Selection of the pump in this case was done based on the calculation of the pressure loss in a simple pipeline, considering that only one big volume gun works at one time. A somewhat more complicated case of selecting a deep well pump can be found, for example, in [5].

In this paragraph, a brief description of a big volume gun will be given according to [6]. The big volume gun is connected to the pipeline via a flange. The big volume gun may be with adjustable part circle rotating angle as in our case, or full circle rotating angle. The Komet automatic brake allows the big volume gun to maintain a constant rotation speed in all operating conditions regardless the pressure or flow. Komet deflector allows water to distribute uniformly starting from the gun over its entire throw range. The selected big volume gun is with a fixed trajectory angle but there are advanced options with adjustable trajectory angle, as well as with a dynamic jet-breaker.

The technical data of the big volume gun are given in Table 3, according to [6].

Table 3 *Technical data of the big volume gun*

Designation	**Big volume gun with fixed trajectory angle and part circle rotating angle**
Manufacturer	Komet
Model	TWIN 101 ULTRA
Pressure at nozzle	5 bars
Flow	66,9 m^3/h
Nozzle diameter	28 mm
Range	54.3 m
Trajectory angle	24°
Connection dimensions	DN50
Mass	9.48 kg

The water control valve serves for on/off regulation, i.e. to turn the big volume gun on and off. The valve is without auxiliary energy and is activated via a solenoid valve that receives a signal from the control unit. The valve, in addition to on/off regulation, can also be delivered with various other control functions [7].

The technical data of the control valve are given in Table 4, according to [8].

Table 4 *Technical data of the control valve*

Designation	**Diaphragm control cast iron valve for water with on/off regulation, series 400**
Manufacturer	Bermad
Model	410-KX
Nominal size	DN80 PN16
Specifications	Basic valve + 3 ways solenoid 24V AC
Valve position	Basic valve normally closed
Working fluid	Water with temperature up to 60°C
Body and cover material	Cast iron, polyester or epoxy coated
Diaphragm material	Nylon fabric, reinforced natural rubber
Diaphragm retainer and spring material	Stainless steel
Connections	Flanges DN80 PN16
Dimensions LxH	250x210 mm
Mass	19 kg

Proposal for installation the big volume gun with associated fittings at the big volume gun connection is given in Figure 8. As it can be seen from figure, a gate valve, strainer, control valve and pressure gauge are provided at the connection of each big volume gun.

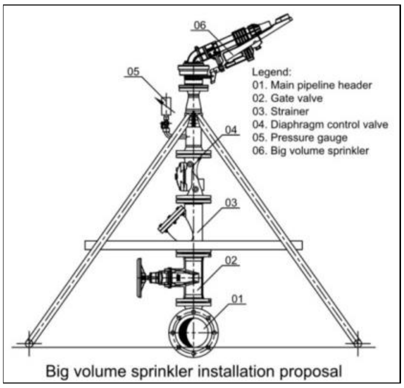

Figure 8 *Proposal for installation the big volume gun*

5 CONCLUSION

This work came out from the conceptual solution of sprinkling the Leposavić tailing dump as one variation. This conceptual solution was dictated by certain restrictions and requirements set by the investor. Before making a detail design of this type, it is necessary to prepare a detail technological design using a series of data obtained through measurements and tests, such as data related to the physical characteristics of surfaces to be wetted, then data on capacity the water supply sources, as well as data on physical and chemical characteristics of water which is used for sprinkling, etc. These data would allow determining the most favorable way of sprinkling the tailing dump as well as the most favorable way of water supply, including the preparation, transport and distribution of water. The equipment selection always depends on technological requirements, and in this paper, the attention is paid to the main hydrotechnical equipment specific to this particular installation. Adequate equipment will suit some other working conditions, which may deviate more or less from the one described in this paper [9]. Depending on the set requirements, more advanced solutions of such installations are also possible, for example for work in winter conditions or with a higher level of automation. The authors hope that this work will be useful to the designers and users of the tailing dump sprinkling installations.

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Original Scientific Paper
Civil Engineering

Nikola Jovanović[*1], *Jelena Stefanović*[*2], *Miloš Živanović*[*3], *Zlatko Pavlović*[*4], *Nikola Miljković*[*5]

DESIGN OF A PEDESTRIAN BRIDGE ON THE DISPLACED RIVERBED OF THE ĆEHOTINA RIVER IN PLJEVLJA, MONTENEGRO[**]

Orcid: 1) https://orcid.org/0009-0008-0982-2576 2) https://orcid.org/0000-0001-6418-1814
3) https://orcid.org/0009-0006-3331-4294 4) https://orcid.org/0000-0001-8102-1820
5) https://orcid.org/0009-0008-0982-2576

Abstract

This paper aims to review the design of a pedestrian bridge on the displaced riverbed of the Ćehotina River in city Pljevlja. The footbridge is intended for pedestrian and cyclist traffic. The design of the pedestrian bridge is part of the Main Design of Bridges on the Displaced Riverbed of the Ćehotina River. The paper describes in detail the bridge design, the choice of a static calculation software, as well as which standards were used for dimensioning the elements and adopting legally prescribed bridge dimensions.

Keywords: *bridge, pedestrian bridge, Ćehotina, riverbed, standards*

1 INTRODUCTION

A bridge is a construction object built to cross natural and artificial obstacles. The purpose of a bridge is to enable people and vehicles to cross them. Bridge design is a complex construction and technical undertaking, which must meet many requirements, not just the technical solution of its supporting structure [1]. Bridges are key to the development of infrastructure and often play a significant role in the economy, connecting regions and facilitating everyday life. In addition to functionality, bridges often become symbols, and some of them are also known for their aesthetic design, historical significance or engineering achievements.

Bridge construction requires precise planning, engineering, selection of materials and labor, so that the bridge is safe and long-lasting. Bridges, like all other construction projects, must meet the requirements of quality, durability, functionality, cost-effectiveness, aesthetics and ecology, that is, environmental impact. To successfully solve such requirements, one must have a wide range of knowledge, and in the case of larger and more complex projects, it is necessary to involve a larger number of experts in different specialties [2].

These requirements are often mutually contradictory and must be harmonized through compromise. Problems of designing and constructing civil engineering structures are an integral part of bridge construction. Therefore, knowledge of various disciplines

[*] *Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia,*
E-mail: nikola.jovanovic@irmbor.co.rs

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is necessary in order to achieve reliable, durable and economical structures. When designing bridges, it is necessary to decide on the type of bridge, the choice of materials, the method of construction and maintenance [3].

2 LOCATION OF THE PEDESTRIAN BRIDGE

The strategy for further development of coal exploitation in the Pljevlja Basin from the Potrlica - Kalušići open-pit mine envisages the relocation of the Ćehotina riverbed across the levels of the internal landfill. After the formation of the internal landfill at the "Potrlica" open-pit mine at an elevation of 760 meters above sea level, the Ćehotina river is planned to be returned through the exploitation field of the Mine. A watertight channel to direct the Ćehotina river is planned to be constructed through the disposal area with a total length of approximately 2.9 km, from the position of the "Durutovići" dam to the bridge at the waterfall of the exit portal of the Velika Pliješ tunnel (elevation 750 meters above sea level) near the sedimentation tank, at the exit from the exploitation field of the Mine.

As part of the relocation of the Ćehotina river, a pedestrian bridge crossing (hereinafter referred to as the footbridge) is planned in Pljevlja. The footbridge is intended for pedestrian and cyclist movement. The beginning of the bridge is at km 1+530, as shown in Figure 1.

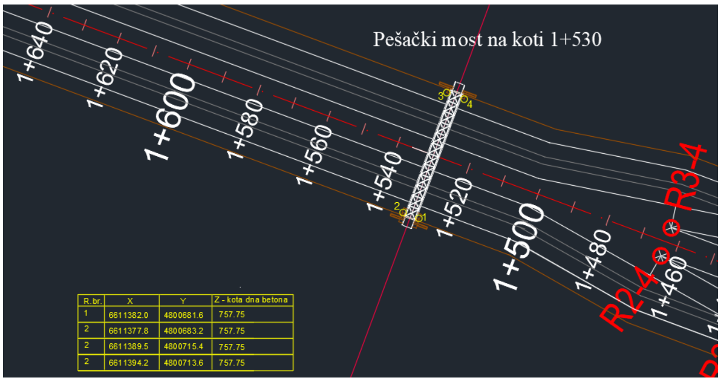

Figure 1 *Situation plan showing the bridge on the displaced riverbed of the Ćehotina River*

3 DESCRIPTION OF THE PEDESTRIAN BRIDGE

The width and height of the pedestrian bridge were determined based on the condition that two rows of cyclists can easily pass one another. The footbridge is intended for pedestrians and cyclists [4]. The width and height of the footbridge were determined based on the condition that two rows of cyclists can be found on it (Figure 2). For this reason, the width and height of the bridge were adopted as 3 m, while the length was conditioned by the width of the canal that it must bridge, without the support foundation encroaching on the canal profile. The dimensions of the transverse profile of the pedestrian bridge were adopted in accordance with the Manual for Road Design in the Republic of Serbia [4]. The exact location of the bridge was defined together with the Investor. In this way, the location was defined on the ground, the microlocation (situation) and the longitudinal profile of the bridge were recorded.

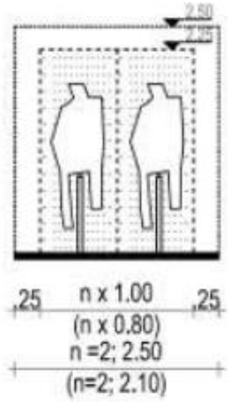

Figure 2 *Section of the bicycle path [1]*

The bridge structure is steel, prefabricated and rests on two foundations of a movable and immovable support (Figure 3). The steel spatial lattice above the Ćehotina river channel has a span of l = 36.0 m. The structural elements are standard rolled profiles in welded construction, and prefabricatedly connected on site, so that the dimensions of the segments do not exceed 12 m. The steel structure is constructed in the intended vertical lattice segments, 4 segments 6 m long and one, central, of 12 m, which are interconnected by prefabricated extensions. The assembly is planned with a truck crane. The first and last frames of the bridge are prefabricated, made in the workshop, welded and placed on the supports. The supports are dimensioned to absorb horizontal and vertical forces [5]. A layer of waterproofing is planned over the concrete slab, and then the production of cast concrete, which has a transverse slope of more than 1%.

Figure 3 *3D view of the pedestrian bridge on the displaced riverbed of the Ćehotina River*

Static and seismic calculations of the steel structure of the structural elements were performed in the program "TOWER 8" - a static analysis program. Static influences were calculated according to the first-order theory. Seismic influences were calculated according to EN - Equivalent static load for the VIII seismic zone with a realistic distribution of masses. The structural design shows a table of materials, sets of beams with dimensions, the position of all loads acting on the structure, M, T, N diagram for relevant combinations, stress and stability control of the main structural elements. Dynamic analysis was performed in accordance with EC recommendations [5].

Dimensioning of steel elements is performed for the most unfavorable influences - the relevant combination for bending, torsion and shear. Dimensioning is shown separately for each element of the main structural beam, for relevant load combinations according to the current standards for steel structures. For the corresponding rods, deformation control was performed, stability control for rods exposed to pressure and bending, tension and bending, stability control for lateral buckling, control of parallel stresses and permissible deflections. The calculation of connections for relevant influences was performed in the IdeaStatica program.

Foundation T1 on the left bank of the relocated Ćehotina River accepts reactions from the fixed bridge support at the level of +759.25 m, is founded in a landfill formed in the previous period and has dimensions B/L=500/400cm. The foundation elevation is at +757.75 m, and the excavation elevation is +756.50 m. The calculation model is designed so that the relevant horizontal forces (primarily the combined forces that occur due to the lateral effect of the wind) are transferred to the concrete foundation via dowels. Foundation T2 on the right bank of the displaced Ćehotina River accepts reactions from a frame that is hingedly supported on a reinforced concrete foundation at the level of +759.25 m. It is founded in a landfill formed in the previous period and has dimensions B/L=500/210 cm. The foundation elevation is at +757.75 m, and the excavation elevation is +756.50 m. The calculation model is designed so that the relevant horizontal forces are transferred to the foundation by friction between the bearing plate and the dowel and via the anchors.

Soil replacement to a depth of 1 m is planned under the foundation. At the excavation bottom elevation of +756.50 m, the subsoil is compacted to Ms=20 MPa and the existing soil is further replaced with crushed stone in layers of 20 cm with compaction, so that the compressibility modulus at the foundation elevation of +757.75 m is 50 MPa. After excavation and compaction, a geogrid is placed in the foundation pit to strengthen the soil and prevent uneven settlement, and a 15 cm protective layer of gravel is placed over it, followed by a 10 cm layer of lean concrete. It is mandatory to install markers on the bridge piers immediately after concreting in order to monitor soil settlement and deformation of the structure.

4 CONCLUSION

This paper presents the design of the pedestrian bridge on a displaced riverbed of the Ćehotina River. The design process itself was a complex construction and technical undertaking that required numerous requirements to be met. First of all, the dimensioning of the steel elements was carried out for the most adverse impacts in order to ensure their reliability.

The use of the static calculation software, the calculation of connections, as well as the drawing and modeling software significantly facilitated the design process. All standards were met during the design, both in terms of bridge dimensions and static requirements and anti-corrosion protection. On the other hand, the aesthetic aspect of the bridge was also met, which in the near future may become a symbol of the location.

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[1] Willis B. A., Mineral Procesing Technology, Oxford, Pergamon Press, 1979, pg. 35. (for the chapter in a book)

[2] Ernst H., Research Policy, 30 (2001) 143–157. (for the article in a journal)

[3] www: http://www.vanguard.edu/psychology/apa.pdf (for web document)

Specifying the unpublished works is not desirable and, if it is necessary, as much as possible data on the source should be listed.

Acknowledgement is given where appropriate, at the end of the work and should include the name of institution that funded the given results in the work, with the name and number of project, or if the work is derived from the master theses or doctoral dissertation, it should give the name of thesis / dissertation, place, year and faculty where it was defended. Font size is 10, italic.

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1 Alberta Ajnštajna, 19210 Bor
E-mail: nti@irmbor.co.rs; ana.kostov@irmbor.co.rs
Telephone: +381 (0) 30/435-164; +381 (0) 30/454-108

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