DEFINING THE REMEDIATION MEASURES OF THE INNER WASTE DUMP SLOPES AT THE OPEN PIT GACKO-CENTRAL FIELD**

Orcid: 1) https://orcid.org/0000-0003-3485-201X; 2) https://orcid.org/0000-0002-6620-8563; 3) https://orcid.org/0000-0002-1209-7423; 4) https://orcid.org/0000-0003-0905-477X

Abstract

The open pit mining takes place in a heterogeneous working environment with known parameters with greater or lesser reliability. This is the main reason why the unexpected processes can occur at the open pits that endanger the safety of exploitation, people and machinery. Due to this reason, the interventions at the surface facilities in cases of occurrence of such processes are carried out with the basic function of ensuring the stability, safety of workers and mining equipment. These works require the highest priority, and they are carried out with equipment that is already present at the open pit or can be provided in a short term and based on the available information, because there is rarely enough time for the additional specific research and tests. The processes that lead to endangering the safety of exploitation are most often related to two types of phenomena, the appearance of slope instability and appearance of unforeseen amounts of water in the open pit contour, although they can also be related to the other situations (e.g., self-ignition of coal).

First of all, the activities that must be carried out in these cases have to take into account two factors, the safety of works and limited time of implementation. This paper describes the phenomenon of instability of the inner waste dump at the open pit Gacko-Central Field, analysis of the phenomenon and procedure for defining the remediation measures.

Keywords: surface exploitation, exploitation safety, slope stability, remediation works

1 INTRODUCTION

The coal deposit Gacko, although it represents a unique complex layered deposit of lignite, is generally divided into four exploration and exploitation fields, the West (open pit Gračanica), Central, East and South Field (roof coal series). In the Western Field, the exploitation works have been completed, and currently the exploitation of lignite for the needs of the Thermal Power Plant Gacko is carried out within the limits of the Central and Southern Fields [1].

Works within the boundaries of the Central Field began in 2010, according to the Supplementary Mining Design for the expansion of the open pit Gračanica. In the beginning, the works were carried out in parallel on the exploitation of remaining reserves in the West Field, i.e., the excavation Field B of the open pit Gračanica, and since 2013, the works have been carried out exclusively within the boundaries of the Central Field. Solutions for this project covered the period until the end of 2015 [2].
In 2016, the works were carried out according to the Simplified Mining Design, so that in 2017, the Main Mining Design of the open pit Gacko - Central Field for a capacity of $2.3 \times 10^6$ t/year of the run-off mine coal would be completed. This design has predicted the exploitation within the borders of the Central and South Field. Coal mining within the South Field or roof coal series is characterized above all by a favorable overburden coefficient, but also by lower coal quality, high stratification, i.e., the presence of numerous seams and inter-seams of waste within the coal series and overburden and waste with the unfavorable physical and mechanical characteristics [3].

Currently, the works are being carried out according to the Supplementary Mining Design for exploitation the part C of the open pit Gračanica - Gacko surface. The basic design solution involves the coal mining at the roof coal series working site and central working site in a way and with equipment that is adapted to the conditions of exploitation. By carrying the out works at two sites, the possibility of coal homogenization for the needs of the Thermal Power Plant is ensured until the planned coal refining plant is put into operation [4].
Due to the mentioned reason, it is necessary to provide all necessary conditions for safe and economical production at both mining sites.

As coal mining at the open pit Gacko-Central field is historically burdened with numerous problems, which are primarily reflected in insufficient capacities of the basic and especially auxiliary mining equipment, some of the technological solutions were forced in the previous period even though they were not originally designed [5]. As a consequence of the lack of transport capacity for waste, an inner waste dump was formed within the excavated area of the central working area, which, at the beginning, had a temporary character, but as time went on and in the conditions of deeper exploitation with an ever-increasing current coefficient of overburden, the problem of missing transport capacity was not solved, the disposed masses in the excavated area of the central working site remained permanently.

The inner waste dump was formed as a truck and bulldozer dump, and the formed floors had the parameters adopted for external waste dumps as the boundary structural parameters. Due to a lack of auxiliary equipment, the upper surfaces of the floors are only partially or not planned, and often the floors themselves deviate from their geometry. Due to the inadequate structural parameters and changed conditions of the working environment, there were phenomena indicating the occurrence of instability of the inner waste dump.

In order to systematically approach the remediation of the inner waste dump, the following phases of defining the solution, shown in Figure 4, were adopted.

**Figure 4** Phases of defining the inner waste dump remediation measures
2 PROCEDURES FOR DEFINING
THE REMEDIATION MEASURE OF
THE INNER WASTE DUMP SLOPES

2.1 Terrain reconnaissance

After the earthquake of April 21, 2022 in the region of Herzegovina at the Open Pit Gacko-Central Field and the external and internal waste dumps, the phenomena of instability the slopes of the formed waste dumps and transport roads and belt conveyor routes were observed. These phenomena of instability were particularly pronounced in the belt conveyor routes and transport roads, where the systems of cracks and fissures and mass sliding were clearly observed, which led to the violation of embankment integrity of the belt conveyor routes or transport roads.

Cracks, fissures and cracking zones were clearly visible (Figures 5 and 6).

Apart from the local ones, no major stability violations of the structures and slopes of the open pit and waste dump were found.

Two months later, based on field observations, it was established that the engineering-geological processes leading to the instability have intensified (Figure 7).
The reason for increase the intensity of processes leading to the slope instability are primarily:

- Earthquake of April 21, 2022, magnitude 5.7 on the Mercalli scale with an epicenter 16 km east of Stolac (B&H).
- Dumped mass of waste at the inner waste dump formed the slopes that in some cases exceed the designed slopes in height at the analogous external waste dumps.
- Surface of floors of the inner waste dump does not allow drainage of water that falls directly on them and is retained for a long period of time leading to this water remaining in the waste dump body and significantly affecting the change in physical and mechanical properties of deposited masses.
- Formation of floors of the inner waste dump was developed from the top to the bottom by shaking of trucks from the upper surface, which often exceeded the designed height of floors, instead of the less technologically favorable, but from the aspect of stability, safer formation from the lower level, starting from the floor of excavated coal, with a gradual increase in the height of floors.

It should be noted that apart from the earthquake, the other reasons are the result of permanent lack of the basic, and above all, auxiliary equipment at the open pit, as the result of which the waste dump was not formed and planned satisfactorily.

The intervention measures to reduce the negative effects, caused by movement of the inner waste dump, were the reconstruction of embankments and routes of belt conveyors and transport roads, their filling, planning and compaction, and then the load increase in the slope foot of the inner waste dump in the places where the sliding was the most intense (Figure 8) and establishing the monitoring of the inner waste dump stability (Figure 9).

Works on the conveyor belts and transport roads are still ongoing and the completion of planned activities is a prerequisite for the safe and reliable operation of the system. In addition to already completed or works that are in the final stage on belt conveyors of the I BTO system KLO 750 and KLM 93, it is necessary to urgently carry out the appropriate works on stabilization in the area of belt conveyor for coal transport TU 2 and drive station of belt conveyor TU 3.

Activities to stabilize the moving masses of the inner waste dump are based on load increasing in the slope foot of this waste dump.

Figure 7 Cracks and cracking systems at the inner waste dump in the area of the VSCI water collection pipeline route, on the waste dump slopes and transport roads (June 15, 2022)
2.2 Inner waste dump monitoring

Systematic monitoring and mapping of the instability phenomena of the inner waste dump, applied to the situational plan of the waste dump, was also introduced. The directions of cracks and cracking zones, and the main directions of mass movement, were registered and marked (Figure 9).

![Remediation zones on the plateaus and slopes of the inner waste dump (June 15, 2022)](image)

**Figure 8** Remediation zones on the plateaus and slopes of the inner waste dump (June 15, 2022)

The benchmark system was established on May 31, 2022, and Table 1 gives the coordinates of reference points and displacements in a direction of all three axes for the period until June 14, 2022.

![Network of benchmarks (red markers) for monitoring the inner waste dump with directions of movement proportional to the intensity of movement (June 15, 2022)](image)

**Figure 9** Network of benchmarks (red markers) for monitoring the inner waste dump with directions of movement proportional to the intensity of movement (June 15, 2022)
As there is a major infrastructure facility in the hinterland of deposited masses of the inner waste dump of the open pit, a displaced river bed of the river Graćanica, the monitoring also included the characteristic points of the river bed and, in the monitoring process, no changes in the position of reference points along the river bed were noted.

The monitoring results (Figure 10) also indicate that in the hinterland of the inner waste dump, the waste dump level has decreased, and there has been a rise on the slopes and in the foot zone. The total area affected by the movement is about 280,000 m² (28 ha). It is estimated that the movement included at least 1,500,000 m³ of deposited masses.

The condition of the mined bottom coal, in a part between the front of works or water reservoir in the deepest part of the open pit and waste dump, indicates that under the pressure of moved masses the cracks they were formed in the unmined parts of the bottom coal. Considering the structure of coal series and coal seams, that marls, banded coal marls and marly clays with weaker strength parameters than coal and bottom coal seams and inter-seam waste, it can be assumed that the discontinuities arose precisely in these working environments, and what, in some places, was also observed on the ground.

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Table 1 Results of the inner waste dump monitoring
2.3 Data collection

During the monitoring process itself, a significant volume of data was collected in terms of determining the dynamics of movement the unstable masses of the inner waste dump. At the same time, the collection of other important data was carried out, which are contained in the geological studies or other studies and the results of specific research and tests relating to the considered area and environment. Considering the results of specific tests, there are, first of all, the results of physical-mechanical and hydrogeological characteristics of the environment. The mentioned data, together with data on geological structure of the working environment and conditions of works that preceded the observed phenomena, represent the basis to define the necessary remediation measures.

2.4 Data analysis and adoption the relevant values of the working environment parameters

The observed and mapped cracks and cracking systems indicate that the masses move in the form of hectometer-sized blocks in a direction of the work front, that is, along the gradient of the excavated coal bottom (Figures 9 and 10). In order to more accurately describe the existing slope of the inner waste dump for characteristic sections, that is, for slopes at places of maximum height and slope, a slope stability check was carried out. Figure 11 shows two characteristic cross-sections on which calculations of the slope safety factor of the inner waste dump were done.

The most important input data for the calculation the slope stability at characteristic sections refer to the physical and mechanical parameters of deposited masses, their structure, degree of cracking and presence of water in deposited material.

Currently available data, specifically related to the deposited waste, are insufficient, unreliable and often very old, and do not reflect the real state of changes in the working environment during the century of exploitation and with the progress of works. In order to solve this problem, it is necessary to take a critical look at the available data necessary for the required stability analysis and check them using one of the fast test methods, or apply the reverse analysis method, compare the available values of physical-mechanical parameters with the values for similar materials at the other open pits, or literary va-lues.[6] Only after a
comparative analysis, a closer idea can be obtained on the input data quality necessary for the calculations as well as an assessment of the result reliability of the slope stability check [7].

Figure 11 Isolines of changes of the benchmark level (in a direction of the z axis)

2.5 Defining the technical remediation measures

Considering the importance of the observed engineering-geological phenomena on:
- development of the production process and necessary provision the appropriate amount of higher quality coal for the needs of the Thermal Power Plant,
- safety of people at the open pit,
- safety of equipment and facilities, primarily the water reservoirs, transport roads and main belt conveyors for transport the overburden and coal,
- size of the affected area,
- volume of the moved deposited masses, the activities on stabilization the inner waste dump are defined.

In this particular case, the following is recommended:
1. To continue works on increasing the load on slope foots of the inner waste dump by planning with a bulldozer. Masses for loading the slope foot should be provided by planning the upper surfaces of floors of the waste dump and softening the slope system to an angle of 12 to a maximum of 14°, as much as the available space allows.
2. By planning the waste dump surface and construction of channels, to ensure the drainage of water that falls directly on the waste dump surface.
3. During planning, if possible, to fill cracks and cracking zones, and by multiple passes of the equipment, to increase the compaction of material in those zones in order to prevent the infiltration of surface water during precipitation into the waste dump body.
4. Deposit the waste in the zone between the existing southern slope and inner waste dump up to the level of belt conveyor of the combined waste system. Disposal should be carried out in the extreme western part with formation the upper edge up to the geological profile 76-76'.

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5. To bring the pumping station on a reservoir to the designed state and thus ensure a low level of water in the reservoir. If possible, clean the water reservoir and deepen it in order to ensure better drainage of the working environment in the vicinity of water reservoir.

6. Continuous monitoring the inner waste dump, with time shortening between two readings.

7. The mentioned activities should be accompanied by preparation the appropriate technical documentation that will elaborate in detail the development of works in the area of inner waste dump in the function of its stabilization.

8. It is necessary to urgently prepare an Elaborate on the stability of the open pit and waste dump slopes as a part of regular monitoring the condition of mining works and facilities at the open pit and development a project for additional engineering-geological and hydrogeological explorations.

3 CONCLUSION

Implementation of emergency measures at the open pits, in cases of unexpected disruptions to the stability and safety of production, must be implemented in accordance with all prescribed safety measures and in the shortest possible time. The problem is when the stability of surface exploitation facilities has already been disturbed, and they must be brought to a stable state by remedial measures. In such cases, a systematic approach to the planning, designing and implementing the remediation activities is necessary including the phases in Figure 4.

The applied procedures, techniques and technologies, type, characteristics and method of application the equipment, must be previously checked on the basis of all available, and if this proves to be insufficient, the additional data and information must be provided so that the planned works can be carried out in a safe manner.

Another important factor, time, is directly related to the costs of implementation of these works, and the most common rule is that the partial solutions give partial results and reduction of the costs of remediation works later results in delay the basic mining works, while a comprehensive and initially more expensive solution enables faster and safer works on reaching the full production capacity.

REFERENCES


