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Ljubiša Obradović, Sandra Milutinović*, Srđana Magdalinović*, Sanja Petrović**

AUSCULTATION OF THE RTH FLOTATION TAILING DUMP IN BOR WITH REFERENCE TO THE STABILITY OF DAMS AND DYKES AT THE TAILING DUMP**

Abstract

The RTH flotation tailing dump, located in the old open pit RTH in Bor about 500 m southeast of the Flotation Plant, has been in continuous operational work since 1985. The flotations tailing dumps are important mining facilities that are constantly changed during their exploitation period. Due to the changes occurring in the tailing dump during its exploitation, it is necessary to perform a continuous technical and technological surveillance - auscultation in order to collect parameters in real time to predict the phenomena, which will enable the normal exploitation of tailing dump. This paper presents the current state of the flotation tailing dump RTH, based on the auscultation monitoring program, carried out in the period August 2020 to February 2021. As for the normal exploitation of the flotation tailings dump in safe and stable conditions, a special attention is paid in this paper to the stability analysis of the dams I and II, as well as the sand dyke between them.

Keywords: *auscultation, monitoring, tailing dump, dam stability*

1 INTRODUCTION

The flotation tailing dump in the area of the old open pit RTH (the tailings dump is named after the mine) has been in operation since 1985, and according to the project: MAIN MINING PROJECT OF THE NEW FLOTATION TAILING DUMP IN THE EXCAVATED SPACE "RTH", CI, June 1984. The above-mentioned project envisaged a filling height of the tailing dump of K+350 m above sea level, with the possibility of further upgrading the tailing dump.

The tailing dump has the shape of an ellipse with the approximate direction of central axis east-west, Annex 1. The Dam I is built of hydrocyclone sand; it closes the tailing dump from the northwest side, towards the old dump and slag dump. The Dam I rests on a high planer with its left side (viewed downstream through the valley of the former Bor river), and with its right side on the smelter slag disposal site, from where it passes into the peripheral embankment with which it forms a functional unit. To the southeast of the tailing dump, there is a waste disposal site from the old open pit of the ore body "H", which separates the tailing dump from the Oštrelj road and Bor - Zaječar railway. In addition to the mine overburden that was deposited there (which has an inhomogeneous granulo-

* *Mining and Metallurgy Institute Bor, e-mail: ljubisa.obradovic@irmbor.co.rs*
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metric composition), this space was also used to dispose of ash, garbage, and other waste material.

The Dam II was built on this part of the hydrocyclone sand. Viewed down the valley of the former Bor River, the Dam II extends on its left side towards the high planer, passing into the peripheral embankment, so at the point of connection with the planer, it reached the designed height of K+378 m above the sea level. From the north, north-east and east sides, the tailing dump is closed with a high planer with an elevation of over K+400 m above the sea level, On the south, south-west and west sides are the main railway line and road that comes in a form of circle of the RTB facilities, which are protected from the RTH tailing dump by a perimeter embankment, built of the hydrocyclone sand.

Figure 1 *Flotation tailing dump RTH, GoogleEarth source, taken on April 9, 2021*

2 OBSERVATION METHODOLOGY OF DAMS AND EMBANKMENTS

Inspection of dams and embankments is carried out in accordance with the Serbian Standard SRPS U.C5.020, the application of which is a mandatory for all dams and embankments with height higher than 15 m, starting from 1980. Observation of high dams in the natural environment requires a multidisciplinary approach, and is achieved through the following aspects:

- visual observation of the visible surfaces of dams and immediate surroundings where the dam is founded,
- and registration of all changes on those surfaces;
- geodetic observation of benchmarks at the characteristic points of embankment and foundation of the dam;
- measurement of the underground water level and piezometric pressures with the free-level piezometers or manometers;
- measurement of the quantity and quality of leachate at collection points - measuring profiles and in drainage systems;

- measurements with special devices for registration the earthquake ground movements;
- measurements with special instruments installed under the surface of the dam body and foundations (measurements of expansions, displacements, total and pore pressures, and temperature);
- registration of hydrometeorological parameters (temperature, precipitation, runoff, winds, relative humidity, etc.).

The aforementioned observations have the common goal of providing the necessary insight into behavior of an object, environment in which the object is located, and the immediate surroundings, from the moment of design, during the object construction, its exploitation and, if necessary, after the end of exploitation and closure of the object.

Based on the observation data, the following is done:

- checking whether the conditions foreseen by the project are fulfilled or not;
- acquiring knowledge about behavior of the object within the conditions foreseen by the project;
- taking the additional monitoring, remediation, or insurance measures (for the endangered area) if some measured values are less favorable than the values provided by the project, and if it is determined that this endangers the object or object surroundings.

2.1 Visual observations

Visual observation is aimed at a direct observation of occurrences and phenomena related to the exploitation conditions, infiltration regime, and tailing dump stability [3]. The obligation of visual observation is daily and is not limited to a part of the day, shift, etc. All workers employed at the tailing dump are subjected to the obligation of vi-sual observation, including the leading supervisory and technical staff of the Copper Flotation Plant in Bor. This observation monitors the dynamics of construction the embankments, condition and functionality of piezometers, operation of drainage system, operation of hydrocyclone batteries, size of the sedimentation lake, evenness of filling the tailing dump, etc. According to the results in the field and conducted measurements, the MMI Bor prepares the periodic reports. During auscultation work, a special attention should be paid to the following phenomena:

- deformations of the basic terrain or external and internal slopes in certain parts of the tailing dump as well as the dam itself and perimeter embankment;
- appearance of springs, ponds, or wet zones;
- occurrence of suffosion phenomenon;
- occurrence of erosion;
- size of the sedimentation lake, its height, and position;
- uniformity of filling and reached the height of tailings accumulation

2.1.1 Occurrence of the phenomenon of suffosion

Suffosion is a phenomenon by which the infiltration currents move the smallest particles of material without moving the basic skeleton of coarse-grained material. By washing out small particles, the volume of interstitial space increases, and thus the permeability and rate of infiltration. Intensification of the suffusion phenomenon can lead to the creation of larger voids in the mass, followed by uneven settlement of embankments and dams on the tailing dump. This can have unforeseeable consequences if not detected in time. Detection of this phenomenon is possible by visual observation and control of suspended particles in the underground and leachate water. If the occurrence of suffusion is determined, the urgent measures must be taken to rehabilitate the flotation tailing dump. During the tour of the RTH tailings in the period February 2020 - August 2021, no occurrence of suffusion was observed on the dams and embankments, except in a part where the reservoir abuts a high planar, and it has been occurring occasionally for years. Periodically, when the amount of water in the storage lake increases and it rests directly on the slope of the high plan (due to unevenly deposited mining debris, there are a large number of cracks and caverns), there is a sinking of water and partly mud, which through the cracks and cracks on the old TIR collector to this collector, they go into the watercourse of the Bor River, and it is additionally polluting. As soon as the loss of water in the storage lake was noticed by throwing several jumbo bags in the area of the leakage, it was temporarily stopped. A permanent solution to this problem will be given through the project of shielding the old TIR collector with a waterproof concrete plug so that losses of this nature will be under control in the future.

2.1.2 Occurrence of erosion

Erosion at the RTH flotation tailing dump is a daily phenomenon and can be internal or external, and occurs as a daily phenomenon due to the effect of air currents or atmospheric precipitation on the dam crown, as well as on the internal and external slopes of dams and embankments [1]. Internal erosion is more dangerous because it is not visible until it appears on the external slope, and then the condition is already critical. It is characterized by appearance of springs and ponds and removal of material from the flotation tailing dump. External erosion can be under the influence of wind and heavy rains, as well as a consequence of sudden snow melting. Internal erosion occurs as a result of wind and precipitation effects, as well as water from the storage lake, which in the PPS zone directly rests on the internal dam slope.

Wind erosion, as in the previous period, has the most harmful effect on the geometry of dams and embankments. Figure 2 shows the embankment on untreated part of the tailing dump between PPS and Dam 2, where a damage caused by the wind daily to the RTH tailing dump is best seen, taken in 2021. The material is removed from the dam crown and stored outside the tailing dump area. This significantly disrupts the designed geometry of the dam and embankment. During the material removal from the dam crown, large depressions up to 3 meters deep are created, what significantly threatens the dam stability. The embankment has changed its designed height and cross-section, and the embankment crown is not of designed width leading to a reduction in the safety coefficient of that section, because the designed ratio of embankment height and water in the embankment body have changed.

Figure 2 *Detail of the endangered part of the embankment between PPS and Dam II, flotation tailing dump RTH, 2021*

Figure 3 shows a part of Dam II where, due to erosion, the first overflow of water and sludge occurred over Dam II into the surrounding area on 01/29/2021, which could have caused very serious problems at the flotation tailing dump. The quick re sponse of employees at the tailings dump stopped the overflow of sludge, which was quickly localized and stopped. This part of embankment is highly threatened by the wind erosion, and here urgent interventions are necessary in terms of correcting the geometry of embankment in accordance with the current technological project, in order to prevent the harmful consequences that further erosion of the embankment can cause for the stability of this part of embankment, as well as the entire flotation tailing dump RTH as a unique mining facility. In order to rehabilitate the dam crowns and embankments at the flotation tailing dump and bring their geometry to the designed geometry, the Investor concluded a contract with MMI Bor for the development of the DMD of the overhang the flotation tailing dump RTH, within which Volume II.1: Technical Design of Dam Rehabilitation will be prepared, and bring it to the designed state according to the valid technological project.

Figure 3 *Completely eroded crown of the Dam 2 where the first serious overflows where the observed water and silt over the crown and downstream slope were recorded on January 29, 2021*

2.1.3 Uniformity of filling the accumulation space of the flotation tailing dump

The evenness of the filling of the storage area in the case of the RTH tailings pond is directly affected by the position of storage lake and location of the floating pumping station, which was not placed at the designed location, provided in the current Technology Project from March 2008 [2]. The position of the floating pum-ping station in the current conditions of exploitation at the RTH flotation tailing dump is shown in Figure no. 4 as location 1 or PPS1, while the designed location is shown as location 2 or PPS2. The images were taken during regular auscultation during the annual auscultation period. The current position of the PPS has a great effect on the inner slope stability of the embankment. Due to the proximity of the PPS embankment, the area around the PPS is exposed to the erosive action of water on the embankment. Sand particles are washed away, thus the body of the embankment and internal slope, which leads to flaking of embankment and separation of individual parts. Increasing the water level in the lake, flaking i.e., separation the parts of embankment is more and more pronounced. This reduces the weight of embankment, which directly affects the slope stability and increase the groundwater level in the body of embankment. After rehabilitation the embankment crown and armoring the old inactive TIR collector, it will be possible to move the PPS to the designed location next to Visoki Planir [4].

Figure 4 *Existing and designed location of the floating pumping station, tailing dump RTH*

2.2 Stability verification on characteristic profiles at the RTH tailing dump

Calculation the stability of the RTH flotation tailing dump was performed on profiles 2/1, 4/2, 8*/1, and 9/1, considering that water was registered only in them according to the measurements submitted by the Boric flotation technical service. The geodetic condition of the dams was recorded on February 1, 2021 by the geodetic service ZIJIN Bor. The position of the profile was chosen on the basis of position of the exploratory drill holes through the dams and installed piezometers. The position of analyzed profiles is shown in Figure 5 and Table 1. Table 2 presents the physical and mechanical parameters of flotation tailings, and Table 3 presents the physical and mechanical parameters for disposed mine waste [5].

Table 1 *Position of analyzed profiles*

Profile	X1	Y1	X2	Y2
2/1	7 589 877	4 881 499	7 590 157	4 881 394
4/2	7 589 937	4 880 906	7 590 004	4 880 986
8*/1	7 590 589	4 880 608	7 590 414	4 881 080
9/1	7 590 446	4 881 111	7 590 777	4 880 659

Table 2 *Physical and mechanical parameters of the flotation tailing dump*

Profile	Volumetric weight, kN/m^3	Cohesion, kN/m^2, (zone 1/zone 2)	Angle of internal friction, ^{o}, (zone 1/zone 2)
2/1	22,28	0/15	25/20
4/2	20,45	0/15	25/20
8*/1	14,37	0/15	25/20
9/1	17,88	0/15	25/20

Table 3 *Physical and mechanical parameters for deposited material at the mine disposal site*

Work environment	Cohesion, kN/m^2	Angle of internal friction,°	Volumetric weight, kN/m^3
Deposited waste	10.00	30.00	20.00

Table 4 *Physical and mechanical parameters of the substrate*

Work environment	Cohesion, kN/m^2	Angle of internal friction,°	Volumetric weight, kN/m^3
Degraded andesite	50	27	20

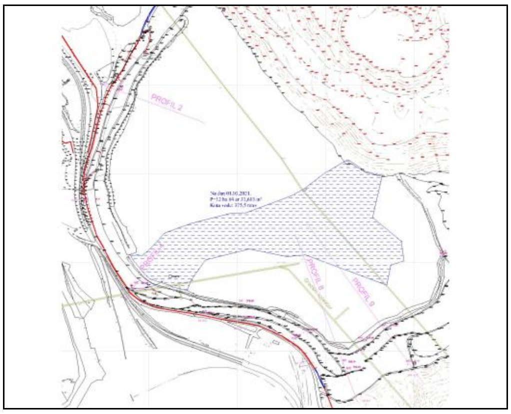

Figure 5 *Position of the analyzed profiles*

To define the underground water level, the data on water level in the installed piezometers for analyzed profiles submitted from the flotation plant in Bor, the measurements from 02/09/2021 were used. The stability calculation was done with the SLIDE v6.0 program from ROCSCIENCE [6]. The stability calculation is carried out under the limited equilibrium conditions, according to the Yanbu method. The effect of groundwater on stability was modeled on the basis of measured water levels in the piezometers and the level of water mirror in the tailing dump. Calculation of stability according to the analyzed profiles for constant static loads and dynamic loads for seismicity coefficient KS = 0.13 is shown in Figures 6 and 7 for profile 4/2, while the calculation results are shown in Table 5.

Table 5 *Summary of the stability coefficient of general slopes according to the Yanbu method*

Profile	F_s static	F_s dynamic
2/1	1.846	1.231
4/2	**1.036**	**0.783**
8*/1	2.955	1.926
9/1	**1.112**	**0.868**

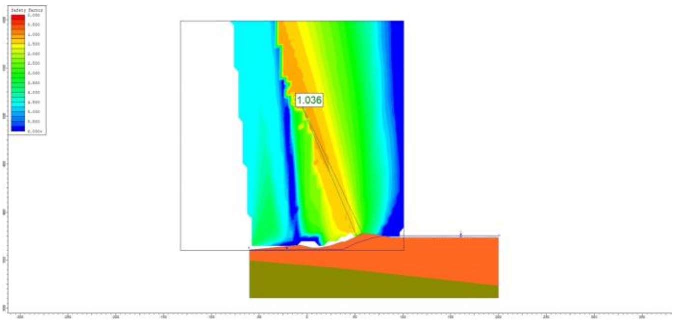

Figure 6 *Stability coefficient by profile 4/2 for static loads, Yanbu method*

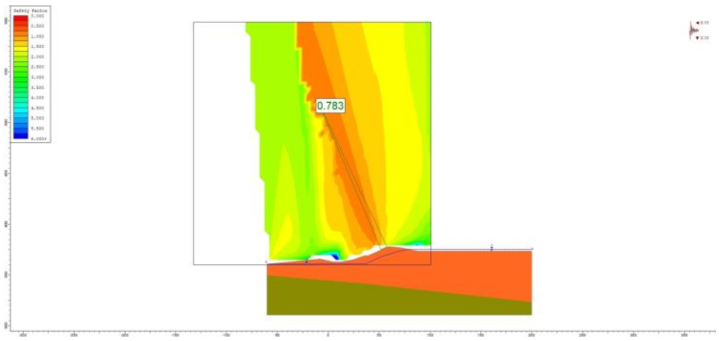

Figure 7 *Stability coefficient by profile 4/2 for dynamic loads, Yanbu method*

By comparison the obtained safety coefficients of the flotation tailing dam with the minimum permitted coefficients, according to the current standard for dams (SRPS U.C5.020), which for embanked dams over 15 m in height is a minimum of F_s = 1.50 in the case of permanent static loading, i.e. F_s = 1.00 in the case of an occasional dynamic load for occurrence the earthquake, it can be concluded that for profiles 4/2 and 9/1, the values for both coefficients (for static and dynamic loads) are significantly below the prescribed minimums.

3 CONCLUSION

Based on the above, the conclusion is that it is necessary to take the remedial measures in the profile zone 4/2 and 9/1 (in the area of pumping station, i.e. the water mirror), primarily by lowering the groundwater level and removing the water mirror from the inner slope of the flotation tailing dump embankment, as well as bringing the geometric elements of the dam, i.e. the mine disposal site in the zone of profile 9/1 into the designed parameters. Also, related to the stability of the RTH tailings dams, it is necessary to constantly monitor all changes on the dams: the occurrence of cracks, landslides, and subsidence, occurrence of percolating water, as well as the geodetic recording of the dams in the event of aforementioned occurrences, to timely observe all important changes on the endangered analyzed profiles.

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