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POSSIBILITY OF REHABILITATION AND OVERHANG THE DAM 6 AT THE "VALJA FUNDATA" TAILING DUMP IN MAJDANPEK[**]

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Abstract

In order to enable further overhang of the flotation tailing dump and its exploitation in the safe and stable conditions up to the designed elevation of K+545 m altitude, since the stability coefficients in a part of the tailing dump next to PS Kaludjerica are below the minimum due to a wide seepage front through the outer slope of the embankment, its rapid rehabilitation is necessary. In this paper, the problems affecting the rehabilitation and further overhang of the tailing dump are present.

Keywords: *tailing dump, slope stability, rehabilitation, overhang*

1 INTRODUCTION

The tailing dump "Valja Fundata" dates back to 1961 and is the main tailing dump, named after the stream of the same name, Valja Fundata. This tailing dump was formed in the valley of the "Valja Fundata" stream, which begins immediately in front of the Copper Flotation in Majdanpek and extends in a direction of the south for about 1300 m, where two new branches flow into it. At a distance of about 1800 m, this valley changes its direction towards the west, where it joins another larger branch. Then, at about 2400 m from the Copper Flotation, this valley widens considerably and joins a new branch, which eventually ends with a rocky limestone barrier.

Most of the Valja Fundata valley (85%) is built of impermeable rocks such as andesites, pyroclasts, conglomerates and crystalline schists. The above-mentioned valley is closed by a natural barrier - a limestone massif, which rests on crystalline schists in the north, while in the south it rests on quartz conglomerates.

Along the main NNE-SSW fault direction, an underground stream of the Valja Fundata stream was formed in a length of about 750 m, which then flows into the Veliki Pek river. A stream flowed through this valley with a water volume of about 5 l/s of water. The mentioned stream, as well as all storm water from the entire catchment area of Valja Fundata, flowed through the main cave into the Veliki Pek river.

In order to enable the use of the Valja Fundata valley for deposit the flotation tailings and formation of an accumulation lake for return of technological water back to the

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flotation process, it was necessary to properly close all the karst channels, in order to prevent the outflow of tailings and water, while it was allowed to leachate flows unhindered into the Veliki Pek river.

The area of tailing dump covers an area of about 390 hectares. Around the perimeter, the tailing dump rests partly on the surrounding mountain heights above 545 m altitude, and partly on the sand embankments. The total length of this part of the circumference where the artificial sand embankments are being built is 5.5 km. On the rest of perimeter, the natural terrain is above 545 m altitude in a length of 7 km.

At the "Valja Fundata" flotation tailing dump, the main infrastructure facilities include the following:

- Sand dam "Vančev potok"
- Sand dam "Kaludjerica"
- Sand dam "Prevoj Šaška"
- Sand dam "Pustinjac 1"
- Concrete and sand dam "Pustinjac"
- Pumping station for tailings PS2, pumping station "Kaludjerica", concrete channel between these two pumping stations, floating pumping station for return water.

Figure 1 *Satellite view of the "Valja Fundata" tailing dump with associated facilities, (Source: Google Earth, August 2023)*

2 OBSERVED PROBLEMS AT THE DAM 6 OF THE "VALJA FUNDATA" FLOTATION TAILING DUMP

The investigated field on which the subject flotation tailing dump is located, was the subject of geotechnical and hydrogeological research, when the research goal was to provide the new geotechnical and hydrogeological foundations for the entire area covered by the tailing dump with the surrounding area. The engineering geological mapping was carried out in order to get a better understanding of the actual situation on the subject terrain. A special attention was paid to the state of the external slope of the embankment (Figure 2), terrain zones with the existing deformations, modern exogenous processes, hydrogeological phenomena and terrain stability. On the observed rock outcrops, the thickness of deluvial cover was estimated. Then, the petrological type and rock mass strength were macroscopically defined as well as the presence of fissure discontinuities. The dominant cracks were measured and their orientation, gap size, presence and type of filling, shape and roughness were defined. The results are presented on the basis of observations from the field semi-instrumental mapping and correspondingly obtained geodetic situations [1].

Figure 2 *State of the external slope of the embankment*

Erosion at the "Valja Fundata" flotation tailing dump is an everyday occurrence and can be internal or external. 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 the appearance of springs and ponds and removal of material from the flotation tailings dump. External erosion can be caused by the wind and heavy rains, as well as sudden melting of snow. Internal erosion occurs due to the effect of wind and precipitation, as well as the contact of water from the lake and inner leg of the dam. Wind erosion is present on the tailing dump throughout the year with a lower or higher intensity. Due to the harmful effect of wind on the tailing dump, the geometry of all dams on the flotation tailing dump is threatened daily where the crowns of dams suffering the most and less parts of the beaches, because they are partially covered by the dams [3].

Figure 3 shows a part of the dam 6 viewed from direction of the dam 1, where the damage caused by the water and wind erosion on a daily basis at the "Valja Fundata" tailing dump can be seen. Erosion also affects the outer slope of the embankment in the Sector 6 from direction of the PS "Kaluđerica", shown in Figure 5. Erosion caused by the action of both atmospheric water and leachate from the accumulation area of the tailing dump causes the shelling of the outer slope and its collapse. As a result of the leachate action, the sand particles are carried out, as a result of which depressions are formed, and after that, when the stability coefficient falls below the critical level, the parts of the outer slope collapse. Later, as a result of heavier rainfall, larger or smaller ravines are formed along the entire length of the outer slope, which can both locally and generally affect the stability coefficient reduction of endangered dams and embankments [2].

Figure 3 *Effect of water erosion on the outer slope of the Dam 6, August 2023*

Figure 4 *Effect of water erosion on the outer slope of the Dam 6, August 2023*

The stability calculation was done with the Slide v6.0 program from Rocscience. With the Slide program, the stability calculation is performed under conditions of the limit equilibrium. The calculation was made according to the Bishop simplified method for the circular sliding surfaces. The program enables the automatic search of the critical sliding plane with a minimum safety factor. The calculation results show the sliding planes that correspond to the minimum safety factor on each profile. All other sliding planes on each profile have a higher safety factor than shown one (Figures 5 and 6).

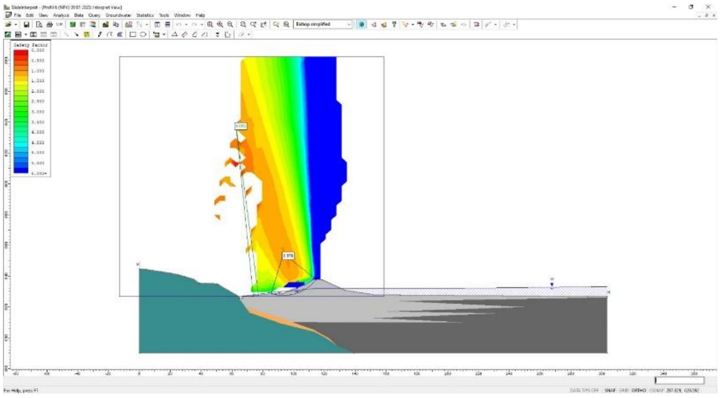

Figure 5 *Static coefficient of safety for profile 6 - 6'*

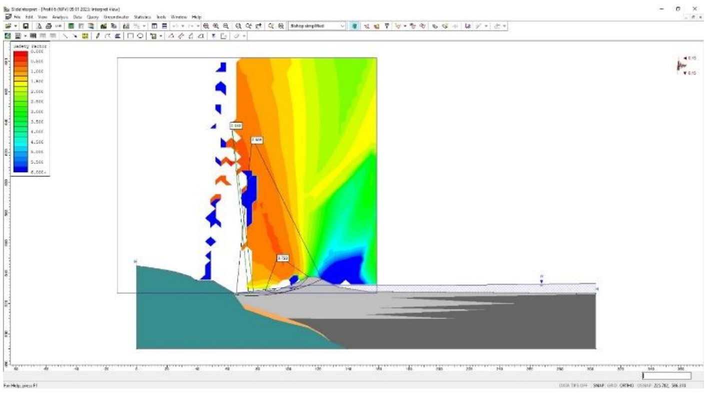

Figure 6 *Dynamic coefficient of safety for profile 6 – 6'*

By comparison the obtained values of the safety coefficients of the flotation tailing dam with the permitted minimum values, prescribed by the technical conditions for the design of embanked dams and hydrotechnical embankments - SRPS U.C5.020, which for the embanked dams over 15 m in height is a minimum of Fs = 1.50 in the case of permanent static loading, i.e., Fs = 1.00 in case of occasional dynamic load for the earthquake occurrence, it can be concluded:

- According to the analysis profile 6 - 6', the value of safety coefficients for static and dynamic loads is below the minimum prescribed value.

Also, the results of performed geotechnical and hydrogeological investigations showed that the future expansion of the flotation tailing dump in the Sector 6 will engage a field with the complex structures and unfavorable geotechnical and hydrogeological properties.

If, during the realization of works on expansion the tailing dump and eventual rehabilitation of the field, the need for additional research and tests should arise and they can be carried out subsequently.

Due to the harmful effect of wind, it is necessary to correct the geometry of the crown of dams several times a year in all places where it is threatened, as well as corrections the external and internal slopes [4].

3 CONCLUSION

On the basis of problems presented in this paper, and in order to enable the expansion and rehabilitation of the tailing dump in the Sector 6, it is necessary to carry out the appropriate preparatory works in the field in order to prevent the water and material seepage through the karst cracks into the surrounding area. This is very important for the reason that it can lead to the pollution of surrounding underground and surface watercourses, as it was the case on two occasions in the past, when the river Veliki Pek and its coastal area were polluted by water and flotation tailings from the "Valja Fundata" tailing dump to its confluence into the Danube River.

In order to prepare the ground surface for further rehabilitation in the Sector 6, it is possible to implement the following actions in order to bring the Dam 6 to a stable state:

- Clearing the entire field in the Sector 6 of vegetation (cutting down trees, removing stumps, bushes and other plant cover) and taking it outside the sector boundary.
- Closing all observed karst cracks and possible sinkholes with the reinforced concrete slabs.
- In order to form a watertight layer and prevent water and material seepage from the extended part of the tailing dump, it is necessary to cover the surface of the Sector with a layer of selected mine overburden, which should be installed by rolling in a layer with a thickness of approximately 2 m.

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Original Scientific Paper
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INTEGRATED DISPOSAL OF MINING WASTE, AN EXAMPLE OF REHABILITATION THE DAMAGED EMBANKMENT AT THE RTH TAILING DUMP BY THE MINE OVERBURDEN[**]

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Abstract

The RTH flotation tailing dump was created by deposition the flotation tailings in the old open pit of the ore body "H", after which it got its name. The tailings dump is located about 500 m southeast of the Bor flotation facility and has been in continuous operation since 1985. At the beginning of exploitation, the RTH tailing dump, the tailings were only pumped into the open pit without cyclones, after that, when the open pit was filled, two sand dams were built to form the storage area, the dam 1 on the north-western side and the dam 2 on the south-eastern side, which are mutually connected by a peripheral embankment. During 2020 and 2021, due to the reduced production in the Bor pit, the smelter slag was processed more in the flotation plant. Although it has good geotechnical properties, smelting slag is not suitable for the construction of dams and embankments because it does not contain the clay particles that represent a binding agent, so when the wind blows on the built crowns of embankments and dams, the great erosion occurs, which threatens the stability of dams on the complete RTH tailing dump. This paper presents the rehabilitation of a damaged embankment with mining overburden, which represents a good example of integrated disposal of mining waste, where another mine waste (mine overburden) is used for the facility rehabilitation containing tailings of the Bor flotation plant, which reduces the need for the new exploitation and excavation the natural materials, earth and stone.

Keywords: *rehabilitation of dams and embankments, stability, flotation tailing dump, mine overburden, integrated disposal*

1 INTRODUCTION

The flotation tailing dump in the area of the old open pit RTH (the tailing dump got its name after the open pit) has been in operation since 1985. According to the project: Main Mining Desing of the New Flotation Tailing Dump in the Excavated Space "RTH", IBB, June 1984, the tailing dump has the shape of an ellipse with along the approximate direction of the main east-west axis, Figure 1. The Dam 1 is built of hydrocyclone sand and closes the tailing dump from the north-west side, towards the old open pit and the slag dump.

The Dam 1 rests on the high landfill with its left side (viewed downstream through the former Bor river valley), and

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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.

The waste dump is situated to the south-east of the tailing dump 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 open pit overburden that was deposited there (which has an inhomogeneous grain size distribution), this space was also used for disposal of ash, garbage and other waste material.

The Dam 2 was built on this part of the hydrocyclone sand. Looking down the valley of the former Bor river, the Dam 2 extends on its left side towards the high landfill, passing into the peripheral embankment, so that at the point of connection with the landfill, it reached the designed height of K+378 m altitude. From the north, north-east and east sides, the tailing dump is closed with a high landfill with an elevation of over K+400 m altitude. On the south, south-west and west sides there are the main railway line and road that comes in the circle of the RTB facilities, which are protectted from the RTH tailing dump by a perimeter embankment, built of hydrocyclone sand.

Figure 1 *Flotation tailing dump RTH (Google Earth source, April 2021)*

2 OBSERVATION METHODOLOGY OF DAMS AND EMBANKMENTS

Observation of dams and embankments is carried out in accordance with the Serbian standard SRPS U.C5.020, the application of which is mandatory for all dams and embankments with height greater 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 the visible surfaces of the 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 underground water level and piezometric pressures with piezometers with a free level or manometers;
- measuring the quantity and quality of seepage water at collection points - measuring profiles and in drainage systems;
- measurements with special devices for registering 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, 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 the object, environment in which the object is located and 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 the behavior of the object within the conditions foreseen by the project;
- taking the additional monitoring, rehabilitation or insurance measures (for the threatened 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's surroundings.

2.1 Visual observations

Visual observation is aimed to a directly observations of occurrences and phenomena related to the exploitation conditions, infiltration regime and tailing dump stability [4]. The obligation of visual observation is daily and is not limited to part of the day, shift, etc. All workers employed at the tailing dump are subject to the obligation of visual observation, including the leading supervisory and technical staff of the copper flotation in Bor. This observation monitors the dynamics of construction the embankments, condition and functionality of piezometers, operation of the drainage system, operation of the 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 the auscultation works, 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;
- occurrence of springs, ponds or wet zones;
- occurrence of sufosis phenomenon;
- occurrence of erosion;
- size of the sedimentation lake, its height and position;
- uniformity of filling and reached height of the tailing dump accumulation.

2.1.1 Occurrence of erosion

Erosion at the RTH flotation tailing dump is an everyday phenomenon and can be internal or external. It occurs as a daily phenomenon due to the effect of air currents or atmospheric precipitation on the crown of the dam, as well as on the internal and external slopes of dams and embankments. 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 the appearance of springs and ponds and removal of material from the flotation tailing dump. External erosion can be under the effects of wind and heavy rains, as well as a consequence of sudden melting of snow [2]. Internal erosion occurs as a result of the effects of wind and precipitation, as well as water from the storage lake, which in the PPS zone directly rests on the internal slope of the dam.

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 the PPS and Dam 2, where the damage caused by the wind on a daily basis at the RTH tailing dump is best seen, recorded in 2021. The material is removed from the crown of the dam and stored outside the tailing dump area. This significantly disrupts the designed geometry of the dam and embankment. During the removal of material from the crown of the dam, large depressions up to 3 meters deep are created, what significantly threatens the stability of the dam. The embankment has changed its designed height and cross-section, the crown of the embankment is not of the designed width leading to a decrease in the safety coefficient of that section, because the designed ratio of the embankment height and water in the body of embankment has changed [3].

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

Figure 3 shows the part of Dam 2 where, due to erosion, the first overflow of water and sludge occurred over dam 2 into the surrounding area on 01/29/2021. year, which could have caused very serious problems at the flotation tailing dump. The quick response of employees at the tailing 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 the 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 RTH flotation tailing dump as a unique mining object [5].

In order to rehabilitate the crowns of the dams and embankments at the flotation tailing dump and bring their geometry to the designed geometry, the Investor concluded a contract with MMI Bor for development the SMD for overhanging the flotation tailing dump RTH, within which the Volume II.1 will be prepared under the title: Technical Design of Rehabilitation the Dams and Embankments and Bringing Them to the Designed State According to the Valid Technological Design.

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

2.2. Conceptual solution for the integrated rehabilitation of endangered dams and embankments by the overburden excavation at the RTH tailing dump

The existing RTH tailing dump in Bor has changed its basic geometry, especially in the crown, due to the weather influences (primarily wind but also the atmospheric precipitation). Considering that this tailing dump is intended to be used in the future, there was a need to bring the existing crown of the tailing dump to the required position and geometry, i.e., it is necessary to rehabilitate it. The planned embankment will be made of earth. The convenience of this solution is that for its construction the deposited mine overburden is used, which is available in large quantities at the location in the immediate vicinity of the RTH tailing dump, the quality of which was checked in the Laboratory for Geomechanics in the MMI Bor, where it was determined that the geomechanical characteristics are of suitable quality for installation into embankment.

In short, the proposed conceptual solution for the rehabilitation of dams and embankments and their restoration to the designed state, according to the current technological design, consists of the following:

- Before the construction of embankment at the RTH flotation tailing dump in Bor, it is necessary to carry out the preparatory works at the tailing dump and borrowing of material - mine overburden, and these preliminary works include the following units:
  - Cleaning and leveling the crown of the existing sand perimeter embankment and leveling the adjacent surfaces on which the mine waste will be incorporated to form a new embankment.
  - Clearing and preparation of borrowed materials for exploitation.
  - Loading, transport and installation of mine overburden in embankments and dams by compaction in layers of a maximum width of up to 50 cm, with checking the compaction of each installed layer, where the compaction of the installed material on the ground should be at least 30 MPa.
- To bring the existing state to the designed state at an elevation of K+378 m altitude, it is necessary to install a total of about **12,550 m^3** of material into embankments and dams in a compacted state with the following geometric characteristics:
  - Embankment length at the base: **Ln=2,191.13 m**
  - Slope of the external and internal slope: **1:2**
  - Width of the embankment crown: **$B_{embankment}$ = 8.0 m**
  - Transverse crown slope: **1.5%**
  - Elevation of the embankment crown: **$K_{embankment}$ = 378.00 m altitude**
- To form the initial volume in the accumulation area of the tailing dump, considering that while the rehabilitation of the crown of the dams and embankments is being carried out at the tailing dump embankment, it is not possible to cyclone and build the embankment from hydrocyclone sand, at the request of the Investor, the crown of the embankments and dams at the RTH tailing dump embankment will be further elevated to a minimum elevations of K+380 m altitude, with the following geometric characteristics:
  - Embankment length at the base: **Ln=2,191.13 m.**
  - Slope of the external and internal slope: **1:2**
  - Width of the embankment crown: **$B_{embankment}$ = 8.0 m**
  - Transverse crown slope: **1.5%**
  - Minimum Elevation of the embankment crown: **$K_{embankment}$ = 380.00 m altitude**
  - Required volume of material for installation in a compacted state: **V=72.300 m^3**

During the summer and autumn of 2021, the rehabilitation works were carried out on the field, after the works on the crown of the dam and geometry of the embankment at the tailing dump, a stable condition was brought in accordance with the valid Technological design. The crowns and embankments after the rehabilitation works are present in Figures 5 and 6.

Figure 5 *Embankment between the Dam 2 and high landfill, October 5, 2021*

2.3. Checking the stability of characteristic profiles at the RTH tailing dump before and after rehabilitation works

The stability calculation of the flotation tailing dump RTH was performed on 4 profiles, but the profile 4 was taken for comparison, where the stability coefficients before the rehabilitation of the embankment were the lowest. Position of the analysis profiles is shown in Figure 6 and Table 1. Table 2 shows the physical and mechanical parameters of flotation tailings and Table 3 the physical and mechanical parameters for disposed mine waste [6].

Table 1 *Position of the analysis profile*

Profile	X1	Y1	X2	Y2
4	7 589 937	4 880 906	7 590 004	4 880 986

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

Profile	Bulk density, kN/m^3	Cohesion, kN/m^2, (Zone 1/Zone 2)	Internal friction angle, ^{O} (Zone 1/Zone 2)
4	20.45	0/15	25/20

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

Working environment	Cohesion, kN/m^2	Internal friction angle, °	Bulk density, kN/m^3
Disposed waste	10.00	30.00	20.00

Table 4 *Physical and mechanical parameters of the substrate*

Working environment	Cohesion, kN/m^2	Internal friction angle, °	Bulk density, kN/m^3
Degraded andesite	50	27	20

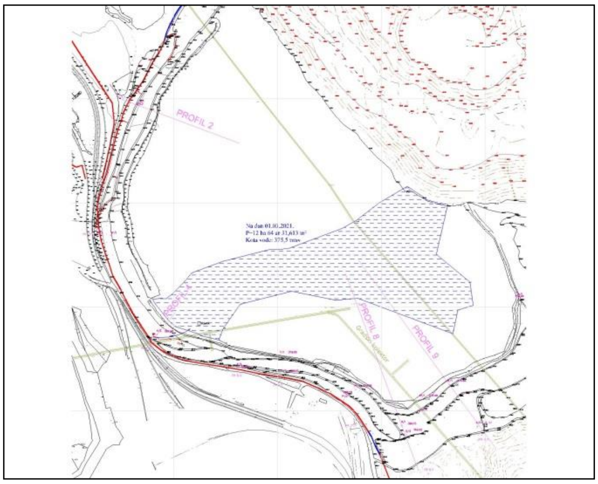

Figure 6 *Position of analysis profiles*

The stability calculation was done with the SLIDE v6.0 program of the company ROCSCIENCE [7]. The stability calculation is carried out under conditions of limit equilibrium, according to the Yanbu method. The impact of groundwater on stability was modeled on the basis of measured water levels in piezometers and level of the water mirror in tailing dump.

The stability calculation, according to the analysis profile for the constant static loads and dynamic loads for the seismicity coefficient KS = 0.13, is shown in Figures 7 and 8 for the profile 4 before rehabilitation [1]. The stability calculation after rehabilitation of the embankment is shown in Figures 9 and 10, 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**
Before rehabilitation		
4	1.036	0.783
After rehabilitation		
4	2.115	1.696

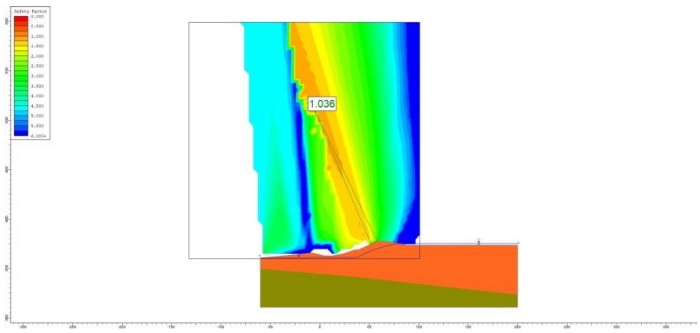

Figure 7 *Stability coefficient according to the profile 4 for static loads, Yanbu method*

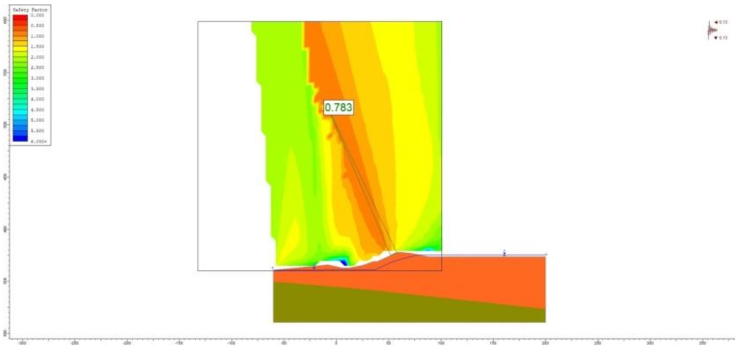

Figure 8 *Stability coefficient according to the profile 4 for dynamic loads, Yanbu method*

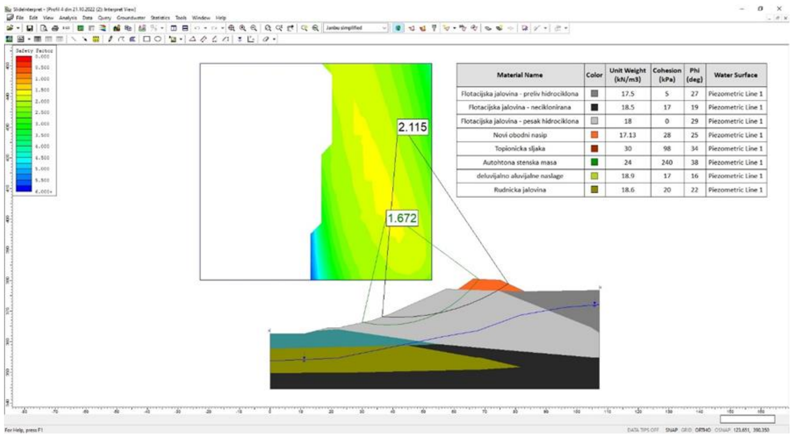

Figure 9 *Stability coefficient according to the profile 4 for dynamic loads, Yanbu method*

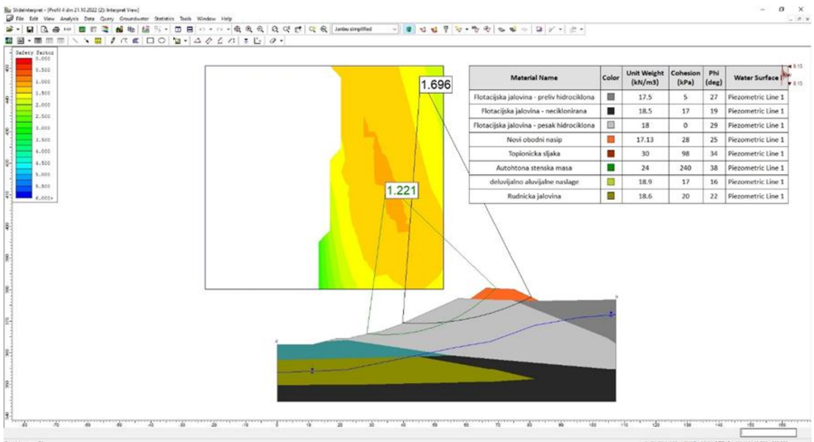

Figure 10 *Stability coefficient according to the profile 4 for dynamic loads after embankment rehabilitation, the Yanbu method*

By comparison the safety coefficients of the flotation tailing dam with permitted minimum coefficients, according to the valid standard for dams (SRPS U.C5.020), which for the embanked dams over 15 m in height is a minimum of Fs = 1.50 in case of permanent static load, i.e., Fs = 1.00 in the case of an occasional dynamic load for the occurrence of an earthquake, it can be concluded that for the profile 4 after rehabilitation, the values for both coefficients (for the static and dynamic loads) are more than doubled, i.e., significantly above the prescribed minimums.

3 CONCLUSION

Based on the above mentioned, the conclusion is that the integrated rehabilitation works on the embankments and dams of the RTH tailing dump showed the excellent results on the ground, so that the tailing dump can be further be elevated and exploited in safe and stable conditions, up to the designed height of K+390 m altitude. What is particularly important, both from an economic and ecological point of view, is that during the integrated remediation, only the existing mine waste was used, i.e., already disposed the mine overburden, without the need to form a new land loan and natural materials to be excavated and transported from another location what prevented the harmful effects of the new mining works on the environment for the needs of embankment rehabilitation.

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