Computer-aided design at the tailings dump – Livezeni colliery

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Abstract. Livezeni is one of the few active remaining collieries from Jiu Valley, in the Meridional Carpathian Mountains. Mining waste facilities classification is introduced according to Romanian technical prescription PT-C 39. Preliminary geotechnical studies on the basement rocks and the waste material are necessary to define the maximum height and the slope angle for ensuring the stability of the waste dump. The first step supposes modeling the morphology of the area based on various information sources. The decision on the shape and geometry of the dump could be taken according to various geotechnical, technological, legal and economic aspects involved, based on analysis done on the digital terrain model. A computerized design process allows the possibility to analyze several variants in less time and ensure results that are more accurate and useful in the later stage of building and remediation of the area. This process is illustrated on the waste dump Livezeni.

1 Introduction

Livezeni is one of the few active remaining collieries from Jiu Valley, a hard coal mining basin located in the southwest of Romania, in the Meridional Carpathians Mountains.

The waste dump is located on the outskirts of town Petroşani, in the vicinity of the former Livezeni coal washing plant and Livezeni underground mine, on the right side of the East Jiu River (Figure 1) and ensures the discarding of waste rock resulting from underground hard coal mine Livezeni. The sterile from the underground mine is transported over the Jiu River by means of a conveyor belt system (Figure 2).

Till the year 2019, the volume of sterile deposited from the washing plant and underground mine exceeded 563000 m^3. A lake was formed on the west side of the tailings dump due to rainwater accumulation; on the south side there are some illegal constructions (Figure 3).

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Fig. 1. Location of tailings dump Livezeni in the town of Petroşani.

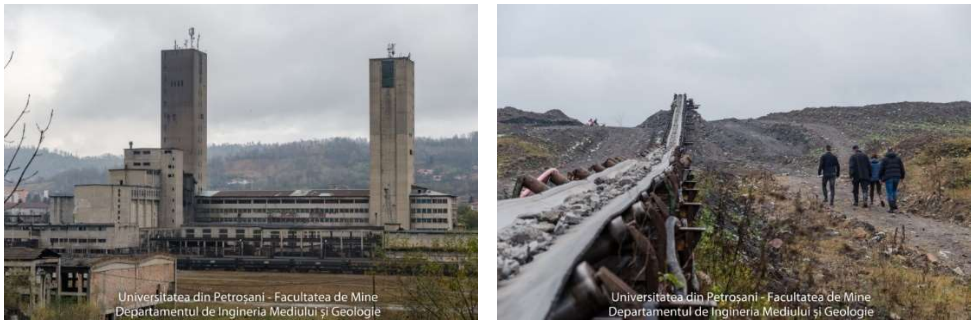

Fig. 2. Main building of Livezeni colliery and detail of conveyor belt system (l= 800 mm, L = 909 m).

Fig. 3. The lake formed on the southwestern side and illegal constructions from the south side of the dump.

2 Characteristics of Livezeni tailings dump

The mining waste facilities in Romania are designed, built and checked according to technical prescription PT-C 39 [1]. This technical prescription contains several criteria for mining waste facilities classification [2, 3].

After the waste facilities classification criteria according to technical prescription PT-C 39, the Livezeni tailings dump is:

- 1.1.1 – a waste facility,
- 1.2.1 – a soft rock waste facility,
- 1.3.1 – a nonflammable waste facility,
- 2.1.1 – a single bench waste facility,

- 2.2.2 – a high waste facility (> 30 m),
- 2.3.2 – a waste facility on inclined surfaces (< 20°),
- 3.1.2 – a waste facility with dust generation possibilities,
- 3.2.7 – a waste facility with water exfiltration downstream during the building process
- 4.2.3 – a waste dump built by conveyor belts transport

According to the nature of the objectives from the influence area and the stability degree of the deposit, the waste dump Livezeni is a 3.3 category: a waste facility with displacements that could be limited by technical measures located in an area with low traffic and low personal circulation.

2.1 Dump description

The construction of the dump was planned to be carried out in one bench, extending from north to south, on a trapezoidal surface with the large base on the southern side.

The base land related to the dump is shaped like an elongated trough in the north-south direction (the direction in which the dump advances), generally ensuring a good deposits stability. It is relatively flat, with elevations between 585 and 600 m, being located between two areas with altitudes of approx. 600 ÷ 610 m.

Currently, the landfill is extended over a length of the lower berm of 360 m and a maximum width of 120 m, having an area of approx. 37500 m^2 (3.75 ha), and the height varies between 7.3 ÷ 30.6 m. The dump's upper berm is uneven, with elevation points between 609 ÷ 621 m.

For the transport of tailings from the Livezeni colliery, a conveyor belt of 800 mm width is used, mounted on a trestle that crosses the East Jiu River, and two conveyor belts are placed in a cascade, on the dump. The conveyor belts are mounted on metal supports fixed to the ground by railway tracks and concrete sleepers, their length is approx. 909 m. The last conveyor belt has at the discharge point a cantilever part for discharging the material in the form of a deposition cone, from where it is pushed, leveled and compacted with a bulldozer (Figures 2 and 4).

Fig. 4. Detail of the end of the conveyor belt and the dumping of the material in the form of deposition cone followed by the pushing of the piled material with the bulldozer.

According to the estimates provided by the beneficiary, it is expected that in the period 2019-2024 a total amount of 28500 m^3 of tailings is necessary to be dumped, the estimated annual amount being approx. 5000 m^3. EM Livezeni holds an exploitation license until 2024. Following field observations and the geotechnical research carried out, it appears that the general condition of the dump is not good, being affected by visible instability phenomena in the southern extremity.

Phenomena of the type of erosion caused by the rainwaters are visible, especially on the slopes of the dump, and are usually of small scale; sometimes, however, these erosive

phenomena have led to small local landslides that appear in the form of cones of dejection, and the presence of detachment niches and transverse fractures raise certain question marks regarding compliance with the piling process according to the designed monograph. The surface of the dump is relatively level, it does not present strongly uneven areas where the waters from the precipitation can collect and infiltrate through the dump. Regarding the slopes of the dump, they have heights between 7.3 m in the northern extremity, 31 m in the southern extremity, respectively 16.3 m in the eastern part and 19.4 m in the western part. In terms of landfill technology, the construction of the landfill is done in a single bench by pushing the material with a bulldozer. This technology led to a bench height of 31 m in the southern area of the dump, an area where instability phenomena appeared (Figure 5).

Fig. 5. Ruts, detachment niches, transverse fractures and slips of the southern slope and detail of the eastern slope.

2.2 Considerations on the geotechnical characteristics of the rocks

The tailings extracted from the mine and resulting from coal sorting are represented by a heterogeneous mixture both from a petrographic and granulometric point of view. It comes mostly from the sterile rocks of the productive and basal horizons of the Petroșani basin. From a petrographic point of view, the mixture consists of clays, gritty clays, marls, sandstones, coal shales and coal fragments. From a granulometric point of view, the rock mixture is composed of material with a wide range of grain sizes: similar to boulders and gravels contained in a matrix of fine granular fragments (psephitic-psammitic) and dust in which the coarse granulometric fraction predominates, which led to the conclusion that these rocks will be affected by settlements that can reach 4 - 7% of the height of the dump, their consolidation being forecast to occur after approx. 6-12 months.

The basement terrain is relatively flat with a slight slope (9.3°) to the south. The dump has heights between 7.3 and 30.6 m in the longitudinal axis, respectively, between 16.35 and 19.4 m near the cross-section 3, and it is estimated that the possible instability phenomena may occur only in the slope area and will be small scale. Hypothetically, these can also be produced through the direct foundation.

Consequently, for performing stability calculations, the geotechnical characteristics of the piled material as well as of the material from the base land are of interest, for this purpose, the 4 samples were taken and analyzed in the Rock Mechanics laboratory of the University of Petroșani, the values taken into consideration for carrying out the stability calculations based on the results of these analyzes being presented in Table 1 [4]. Considering the current technical condition of the dump (assessed following field visits by members of the research team as generally good) which places it in the 3.3 category, according to the degree of danger (i.e. mining waste facility with displacements that could be limited by technical measures - building small dams, drainage channels - located in an area with restricted traffic and/or restricted movement of people), the research team opted for average values of geotechnical

indices. To perform the stability analyses, two sets of values were considered, respectively, for the moisture of the rocks in the natural state and for the moisture of the rocks at the saturation limit. The values of the main geotechnical parameters involved in the stability calculations, for the sections and slopes with the most unfavorable geometric elements, are shown in Table 1.

Table 1. Physical-mechanical characteristics used in stability analysis.

Sample	Volumetric weight, [kN/m^3]		Cohesion, c [kPa]		Internal friction angle, φ [°]	
	Natural humidity, $\gamma_{a\text{-}nat}$	Saturated moisture, $\gamma_{a\text{-}sat}$	Natural humidity, c_{nat}	Saturated moisture, c_{sat}	Natural humidity, φ_{nat}	Saturated moisture, φ_{sat}
Tailings	17.95	18.35	36.46	16.83	25.83	21.26
Tailings	18.90	19.40	35.42	15.33	25.28	20.30
Base rock	18.90	19.30	36.80	19.66	30.25	23.02

2.3 Stability analysis of the dump

The results of the stability analysis are shown in Table 2. and based on them it can be stated that for normal conditions of natural humidity, in general, the stability reserve of the slopes is large enough, so that no instability phenomena are possible. Previous stability studies [5] concluded that stability problems can occur when the rocks are saturated or when the natural slope angle of the rocks $\alpha_o = 37^o$ is exceeded or when the height h = 20 m is exceeded.

Table 2. Values of the stability factor for cylindrical - circular sliding surfaces.

Section/Slope	Geometric elements		Fellenius		Bishop		Janbu	
	H (m)	α (°)	w_{nat} (%)	w_{sat} (%)	w_{nat} (%)	w_{sat} (%)	w_{nat} (%)	w_{sat} (%)
S 1-1 South	30.60	28.55	1.21	0.80	1.38	0.96	1.56	1.06
S 2-2 South	21.20	31.14	1.81	1.17	1.92	1.27	2.10	1.37
S 3-3 West	19.40	33.55	1.78	1.10	1.90	1.19	2.03	1.29
S 3-3 East	16.35	34.90	1.44	0.88	1.70	1.03	1.64	1.01

The literature recommends a stability factor greater than 1.3 (Fs ≥ 1.3) [6, 7]. In order to achieve this goal, a model of the initial situation and several redesigned shapes of the tailings dump Livezeni were done.

3 Waste dump design

As in other cases [3, 8], the first challenge was to create a digital terrain model of the basement terrain [9]. In order to complete this task, it was necessary to scan old maps with elevation curves of the area and then digitize these curves (Figure 6).

Based on current survey data provided by E.M. Livezeni [10] the 3D model of the heap was built (Figure 7) and three alignments were defined for creating profiles (Figure 8).

The geometrical parameters of the tailings dump are:

- length at the top 300 m and at the lower part 360 m,
- width at the top 66 - 83 m and at the lower part 110 – 125 m,
- maximum height 30.6 m on the southern side (section 1) and 21.2 m (section 2), 19.4 m on the western side (section 3) and 16.35 m on the eastern side (section 3),
- slope angle 43.5° on the northern side, 28.55° on the southern side (section 1), 31.14° on the western side (section 3) and 34.9° on the eastern side (section 3),

- surface 3.75 ha, volume 563619 m^3.

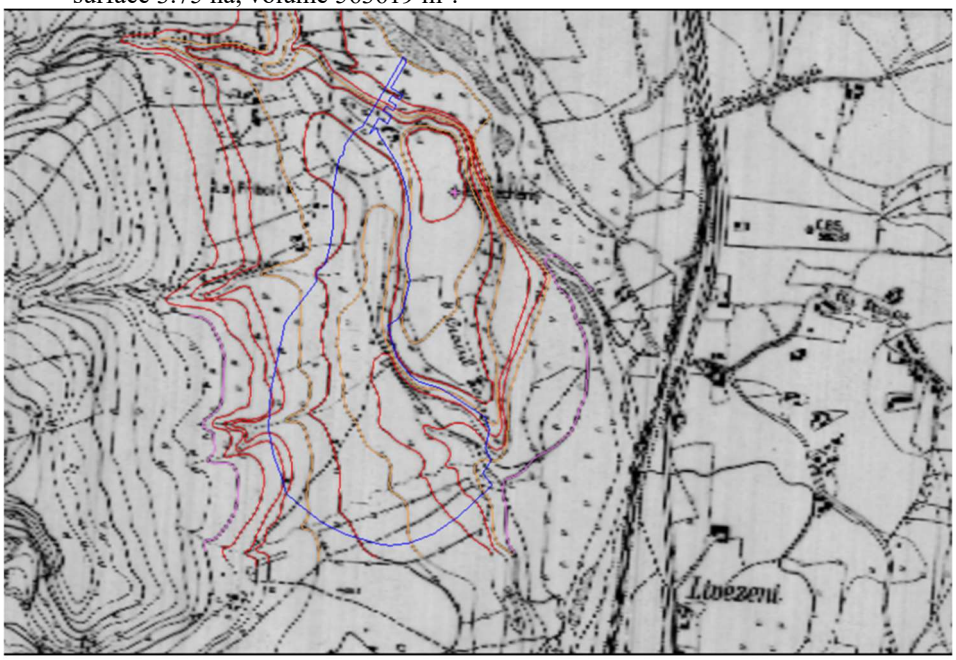

Fig. 6. Digitized elevation curves beneath the Livezeni tailings dump and the contour dumping perimeter.

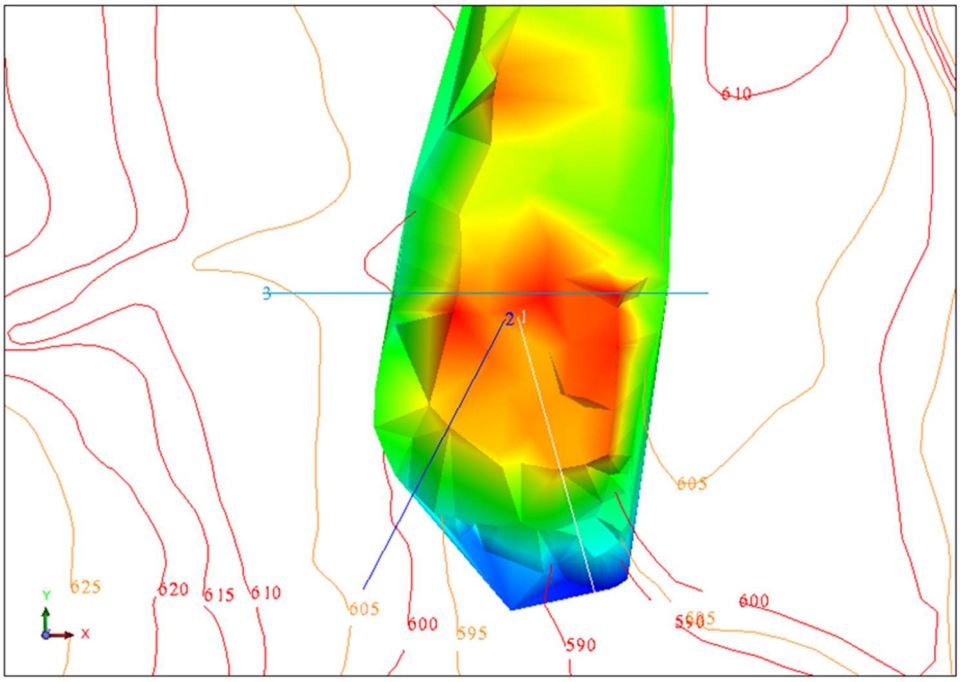

Fig. 7. The 3D model of initial situation of the Livezeni tailings dump with the highlighting of the three alignments on which sections were executed.

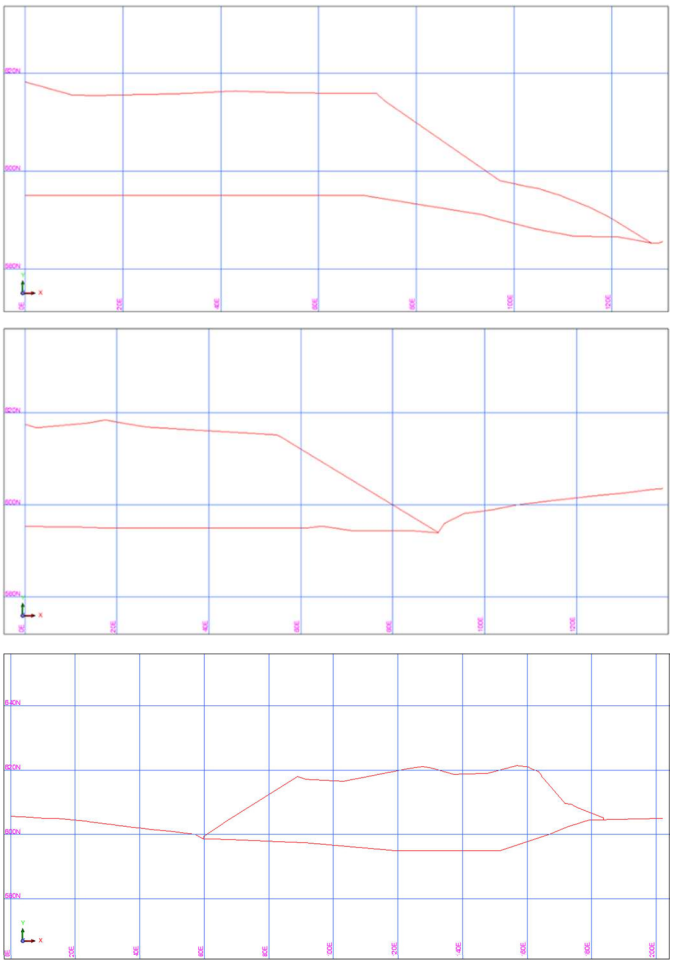

Fig. 8. Livezeni tailings dump – section 1 (top), section 2 (middle) and section 3 (bottom) highlighting the profile of the landfill and the basement terrain.

3.1 Redesigned shapes of the tailings dump Livezeni

In order to ensure the stability of the waste dump, several scenarios were taken into account [4].

For the area with the highest bench height (h = 30.6 m), where the current slope angle is α=28.55°, the lowest value of the stability factor was determined (Fs = 1.21 at natural humidity and Fs = 0.8 under rock saturation conditions). In order to increase the stability coefficient in the conditions of this bench height, a general slope angle of α = 23.51° was determined, under the conditions of saturated rocks. To achieve this general slope angle, two options for dividing the current bench were analyzed.

In the first variant, the division of the current bench height into two benches of equal height (h=15.5 m) was analyzed, with individual slope angles of 33÷34°, separated by a berm with a width of 18÷19 m (Figure 9).

In the second variant, the division of the current bench height into two benches of different heights was analyzed, the lower bench with a height of h = 21 m and a slope angle α = 28.5° and the upper bench with a height of h=10 m and a slope angle of maximum 35° separated by a 17 m berm width (Figure 10).

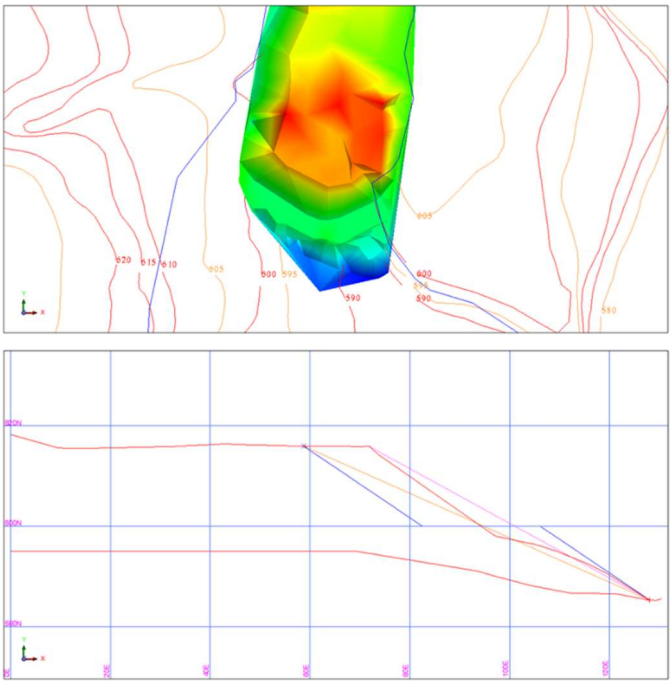

Fig. 9. Livezeni tailings dump – redesigned with two benches of 15.5 m high and an intermediate berm of 18 m. 3D model (top) and section 1 (bottom) highlighting the profile of the landfill and the basement terrain.

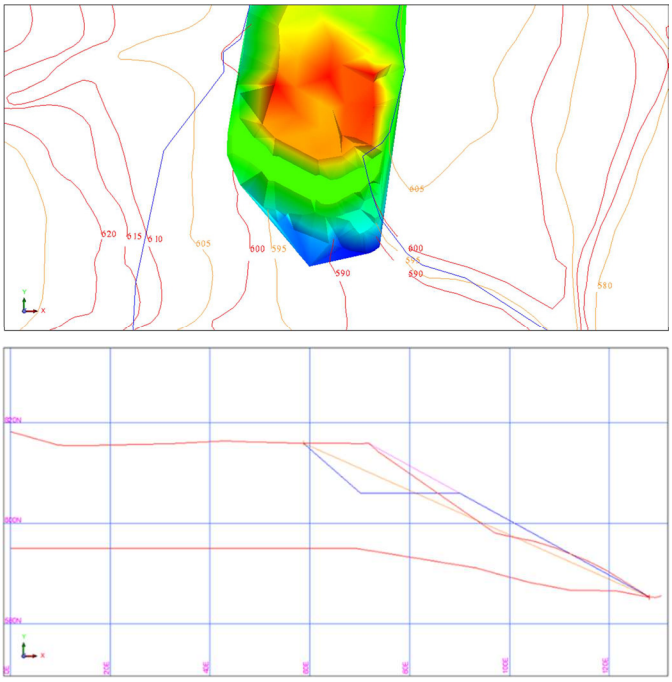

Fig. 10. Livezeni tailings dump – redesigned with two benches (lower bench of 21 m high and upper bench of 10 m) and an intermediate berm of 17 m. 3D model (top) and section 1 (bottom) highlighting the profile of the landfill and the basement terrain.

Implementing both the first and the second options involves pushing the tailings dumped in the upper area towards the southwestern part of the dumping perimeter. The volume of material to be moved is approximately 24000 m^3 in the case of the first variant, respectively, 14500 m^3 in the case of the second variant. For this reason, the second variant was the recommended one.

In order to accommodate another volume of tailings, estimated by E.M. Livezeni at 28500 m^3 and to protect the constructions from the southern side of the tailings dump, the extension of the heap in the south-western direction and the potential storage capacity was analyzed (Figure 11). In this way, a potential storage capacity of approximately 30000 m^3 was estimated, more than enough compared to the requested capacity.

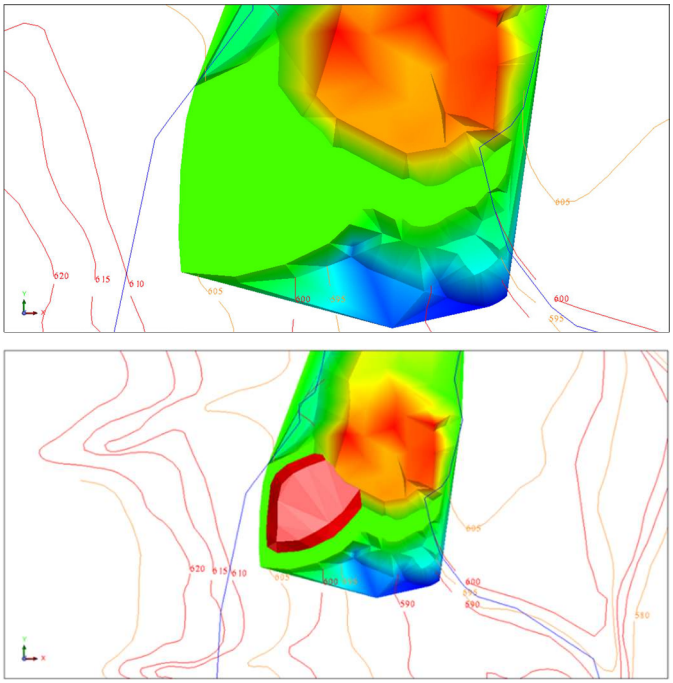

Fig. 11. Livezeni tailings dump –3D model designed with the extension of the first bench in the southwestern area at an elevation of 606 m (top) and the extension of the second bench between elevations 606 - 616 m (bottom).

4 Conclusions

Following field observations and the geotechnical research carried out, it appears that the general condition of the dump was not good, being affected by visible instability phenomena in the southern extremity.

The landfill technology, in one bench, by pushing the material with the bulldozer, led to a bench height of 31 m with a slope angle of 28.55° on the southern side of the dump, an area where instability phenomena appeared.

Previous stability studies concluded that stability problems can occur at rock saturation, a slope angle greater than the natural slope angle of the rocks (α_o = 37°) or the bench height exceeding 20 m.

In order to achieve a stability factor greater than 1.3 in the condition of rock saturation, several scenarios were analyzed.

Due to the comparative advantages, the recommended solution was the reconfiguration of the tailings dump with two benches of deposition, the lower one with a height of h = 21 m and a slope angle α = 28.5° and the upper one with a height of h=10 m and a slope angle of maximum 35° separated by a 17 m berm width and the extension of the heap in the south-western direction.

An additional storage capacity of approximately 30000 m^3 and a safety factor of 1.3 is ensured for the tailing dump Livezeni.

The forecast for the additional storage capacity was 28500 m^3 at the level of the year 2019. The data for 2023 show that around 20.000 m^3 were dumped and the current shape of the dump can be seen in Figure 12.

Fig. 12. Livezeni tailings dump shape in June 2023 (eastern and southern view).

As a final conclusion, a computerized design process gives the possibility to analyze several variants in a much shorter time and to ensure that the results are more accurate. The generated model is very useful in the subsequent stage of building and remediation of the dumping area.

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