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INTERDEPENDENCY OF SAFETY FACTORS AND GEOMETRIC ELEMENTS OF THE WASTE DUMPS IN THE BERBEȘTI MINING BASIN

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Abstract: *As a result of mining operations, large amounts of sterile rocks result, which involve the occupation of some land surfaces and which can generate risk situations such as geotechnical phenomena (especially landslides). The risks the population is exposed to in the event of landslides and their increasing incidence in mining areas, make more and more researchers interested in investigating, inventorying and characterizing the conditions and landslides risk areas. The stability conditions for any engineering construction are evaluated right from the design phase. Since the physical and mechanical characteristics of the rocks that define the working slopes and the dumps in the mining perimeters cannot be significantly improved in order to increase stability reserves, the emphasis remains on their appropriate design. The paper aims to develop a fast method to provide indications of the safety factor for different geometric configurations of slopes. Based on the stability analyses, two nomograms were built that graphically represent the dependence between the geometric elements of the slopes and the values of the safety factors, the case study being carried out for the waste dumps in the Berbești Mining Basin, known for its lignite mining activity.*
Keywords: *Dumps, design, geometry, landslides, stability, safety factor*

1. Introduction

The mining industry, through its specific activities, generates long-term negative effects on the environment.

The large quantities of waste rocks, resulting from the exploitation and processing works, occupy large areas of land, potentially generating risk situations such as landslides [1, 2, 3, 4].

Landslides are increasingly frequent events and can be caused by natural or anthropogenic factors that lead to a change in the ratio of forces in rock massifs or rock constructions such as waste dumps. The effects of these landslides are represented by morphological changes of the land, material damage, and what is more serious, sometimes in loss of human lives [1, 4, 5].

Over the years, numerous landslides have occurred in the Berbesti mining basin, both in open-pits and waste dumps, but also outside the mining perimeters.

Most of the landslides occurred in the Ruget open-pit, but larger proportions landslides should also be mentioned, as was the case of those produced at the Berbești Vest external dump in 2017 or at the side working slope of the Olteț – Alunu open-pit in 2019 (Figure 1) [7, 8, 9, 10, 11, 12].

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vol. 30, selected papers from the 11th edition of
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a. b. c.

Fig. 1. Slope slides; a. Ruget open-pit; b. Berbești West external dump; c. Olteț – Alunu open-pit

These landslides are mainly related to the morphology of the land, litology of the area, the abundant rainfall, but also the lack of hydrotechnical works (water drainage systems).

Considering the number and extent of landslide phenomena produced in the Berbești mining basin, both in the perimeters with suspended activity and in those still in operation, it is necessary to constantly monitor the state of the slopes of the open-pits and dumps, to continue researching the causes and factors that influence their stability and to find solutions for the rapid assessment of stability reserve.

2. Site description

The Berbești mining basin is located at the confluence of Vâlcea and Gorj counties, bordered to the east by the Olt hydrographic basin and to the west by the Jiu hydrographic basin.

From a geomorphological point of view, the Berbești mining basin is located in the region of the Southern Subcarpathians and the Getic Plateau, the hills having moderate heights being crossed from north to south by a strong hydrological network, and from an orohydrographic point of view, the basin is located in the hilly area.

The main watercourses are Gilort and Amaradia, which flow into the Jiu river, and Olteț, Cerna, and Bistrița rivers which flow into the Olt river. Rivers have high flows in the spring due to melting snow or heavy rains, followed by a period of relatively stable flows until autumn [10].

The Berbești mining basin was divided into 4 mining perimeters respectively: Gilort - Amaradia, Amaradia - Tărâia, Tărâia - Cernișoara, and Cernișoara – Bistrița [9].

Inside each perimeter there are mines and open-pits, some with suspended activity and others still in operation.

At this point, Berbești mining basin is divided into two mining perimeters, namely:

- mining perimeter with suspended activity that includes the Bustuchin, Seciuri, and Ruget open-pits (Figure 2);
- mining perimeter in operation that includes the Olteț - Alunu, Berbești, and Panga open-pits (Figure 3).

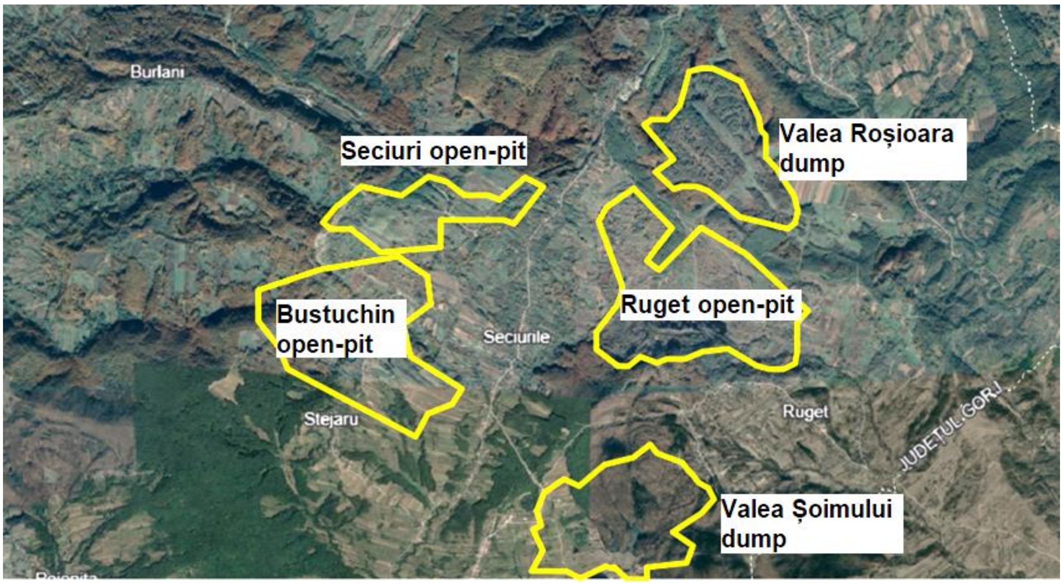

Fig. 2. Mining perimeters with suspended activity [13]

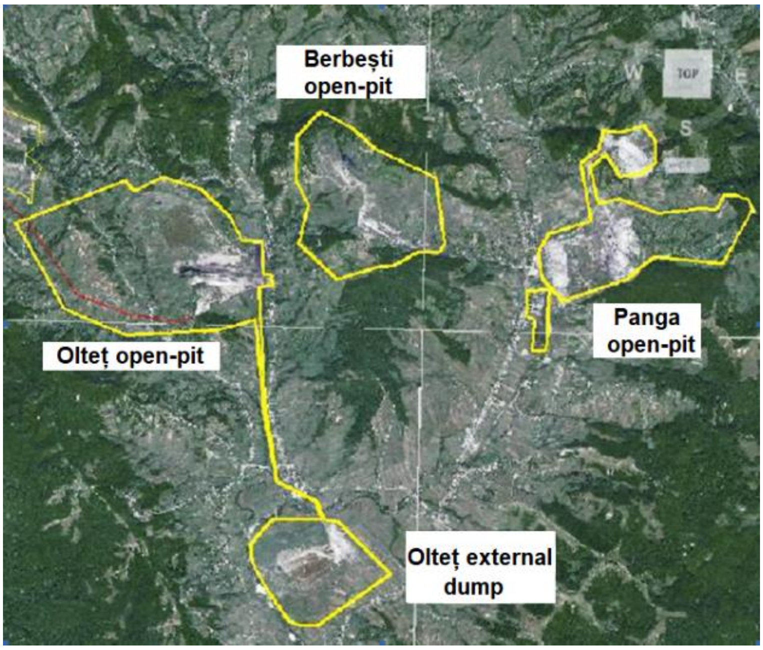

Fig. 3. Mining perimeters in operation [13]

The Seciuri, Bustuchin, and Ruget open-pits were closed one after the other, in 1996, 1997, and 2013 respectively, generally as a result of the opposition of the inhabitants to being displaced and financial losses and, the others continue to carry out their lignite exploitation activity [9].

3. The physical and mechanical characteristics of the waste rocks related to the Berbești mining basin

Based on the granulometric analyses, the plasticity index, the consistency index, the cohesion and the mineralogical composition, the rocks in the cover can be grouped into three large categories:

- cohesive rocks (clays, fat clays, marly clays) – 41.6%;
- weakly cohesive rocks (dusts, sands, dusty clays) – 30.4%;
- non-cohesive rocks (sand and gravel) – 28%.

Geological prospecting and exploration works combined with laboratory analyzes have shown that more than 60% of the sterile rocks from the Berbești open-pits are clays with a fine-dispersed or granular structure and an irregular or less oriented texture [9].

The Figure 4.a shows some rock samples subjected to direct shearing tests in order to determine the values of the mechanical characteristics, respectively of the cohesion and of the internal friction angle. Also the volumetric weight of the rocks was determined (Figure 4.b), these three properties of the rocks being the main ones required in the stability analyses.

a. b.

Fig. 4. Laboratory tests; a. Rock samples subjected to direct shearing tests; b. Sample subjected to an overload corresponding to the natural loading determined by the lithological column in order to determine the volumetric weight of the rocks

In order to design stable sterile dump slopes, several tests were carried out starting from various assumptions focused on sets of values of geometric elements, slope height/slope angle - h/α (5 m/20°, 5 m/25°, 5 m /30°, 105 m/20°, 10 m/25°, 10 m/30°, 15 m/20°, 15 m/25°, 15 m/30°, 20 m/20°, 20 m/25°, 20 m/30°) and considering the weighted average values for the physical and mechanical characteristics of the waste rocks in the Berbești mining perimeter.

The results of the statistical processing carried out based on the values of the geotechnical characteristics of the waste rocks, both of the rocks deposited in external and internal dumps, determined in the laboratories of the University of Petroșani and/or taken from geotechnical studies (more physical-mechanical characteristics of the dumped material were collected from a geotechnical study made available by CET Govora representatives [9]) are centralized in Table 1.

The values of the geotechnical characteristics of the rocks are directly influenced by their nature and conditions of humidity, compaction, degree of roundness of the grains, etc [14, 15].

In the case of dumps, we are talking about a mixture of different types of rocks. The values of the geotechnical characteristics of waste rocks are also influenced by the proportion in which they occur in the dump.

When sands, non-cohesive rocks predominate, the average cohesion decreases and the angle of internal friction increases. In general, the cohesion of sands tends to zero for sands containing dust or clays and is zero for pure sands. The clay and dust in the composition of the sand layers act as a binder. The situation changes in the case of waste rock mixtures that include larger fractions of clayey, marly, dusty rocks, as the value of the cohesion increases and the value of the internal friction angle decreases.

Table 1. The geotechnical parameters for the Berbești waste dumps resulting from the statistical processing

Types of rocks	**Percentage share, %**	**Volumetric weight, γ_v [kN/m^3]**	**Cohesion, c [kN/m^2]**	**Internal friction angle, φ [°]**
Weakly cohesive clays (dusts, sandy dusty clays)	30.40	19.30	13.00	14.50
Cohesive rocks (clays, fat clays, marly clays, silty clays)	41.60	19.00	21.50	9.75
Non-cohesive rocks (sands, silty sands, clayey sands, silty clayey sands)	28.00	18.40	1.70	16.70
	Total	Weighted average values		
	100%	18.92	13.37	13.14

The volumetric weight is variable in Berbești mining basin, generally low in the case of lignite and topsoil (between 12 and 15 kN/m^3) compared to clayey, marly, dusty, sandy rocks or rock mixtures of different types (17 - 21 kN/m^3) [5].

The higher the volumetric weight and the lower the cohesion and the angle of friction, the lower the stability reserve. In this case, the slope could reach the state of imbalance.

4. Stability assessment and solutions of proper designing of geometrical elements of slopes

Having as a preliminary basis the representative values of the geotechnical characteristics (which describes a situation favorable in the context of designing stable slopes) the research continues with the effective assessment of the stability conditions of the slopes.

4.1 Slope stability analyses

The values of the geotechnical characteristics of the rocks, shown in Table 1 were used to define the sterile materials that compose the dumps related to the Berbești mining basin, and based on them the actual stability analyzes were carried out, the results being shown in Table 2.

The assessment of the stability was carried out in accordance with the existing recommendations in the specialized literature where the optimal value of the safety factor (Fs) is between 1.25 ÷ 1.5 [5].

Table 2. The results of the stability analyzes

h (m) / α (°)	5			10			15			20		
	F	J	B	F	J	B	F	J	B	F	J	B
20	2.150	**2.084**	2.216	1.445	**1.410**	1.513	1.209	**1.182**	1.261	1.087	**1.070**	1.135
25	1.863	**1.808**	1.923	1.244	**1.213**	1.292	1.025	**1.004**	1.073	0.915	**0.898**	0.959
30	1.656	**1.615**	1.706	1.091	**1.066**	1.131	0.896	**0.876**	0.934	0.792	**0.778**	0.830

Methods of analysis: F – Fellenius, J – Janbu simplified, B – Bishop simplified [16, 17, 18, 19, 20]

Color legend: Fs lower than the minimum recommended value (Fs < 1.25), Fs approaches the balance limit (Fs = 1 ÷ 1.1), Fs indicating an unstable slope (Fs < 1).

The three stability analysis methods provided close values of the safety factors, only the minimum

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 17-24

values resulting from the application of Janbu's method were considered further.

In Figures 5 and 6 two of the results of the stability analyzes performed on the individual slopes of the dump are presented.

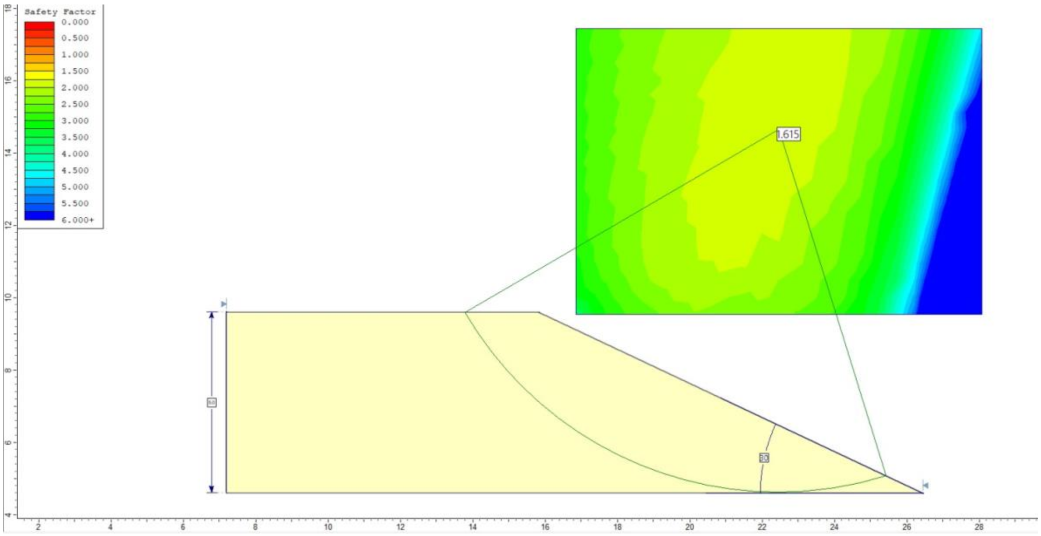

Fig. 5. Stability analysis for the dump step having h = 5 m and α = 30° (Fs = 1.615)

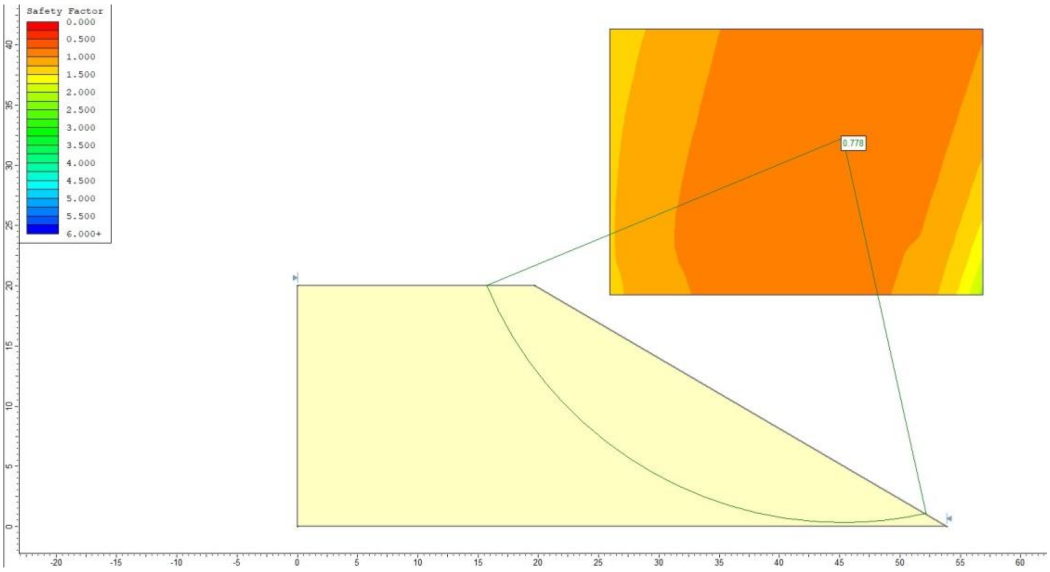

Fig. 6. Stability analysis for the dump step having h = 20 m and α = 30° (Fs = 0.778)

The safety factor depends on the slope height, slope angle, and the nature of the constituent rocks, the share of the clayey rocks in the structure of the slope having a significant influence on its technical condition.

4.2 Dependence between safety factors and geometric elements of the slopes

Considering the fact that mining activity is ongoing in some perimeters of the Berbești mining basin, it was aimed to develop a quick method that would provide indications regarding the safety factor.

As a result, based on the performed stability analyses, nomograms were built that graphically represent the dependence between the geometric elements of the slopes and the values of the safety factors (Figures 7 and 8).

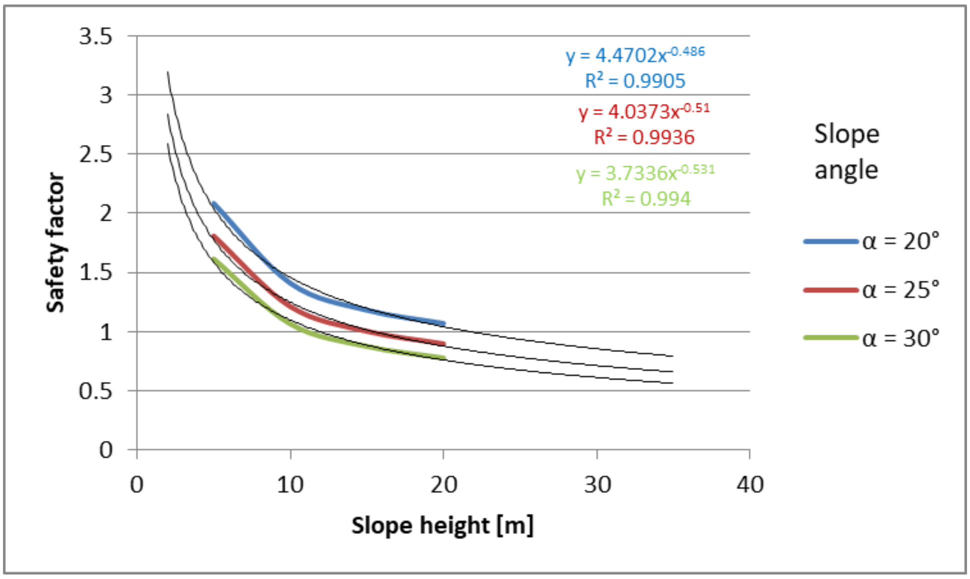

Fig. 7. Variation of the safety factor as a function of the slope height at different values of the slope angle (power function)

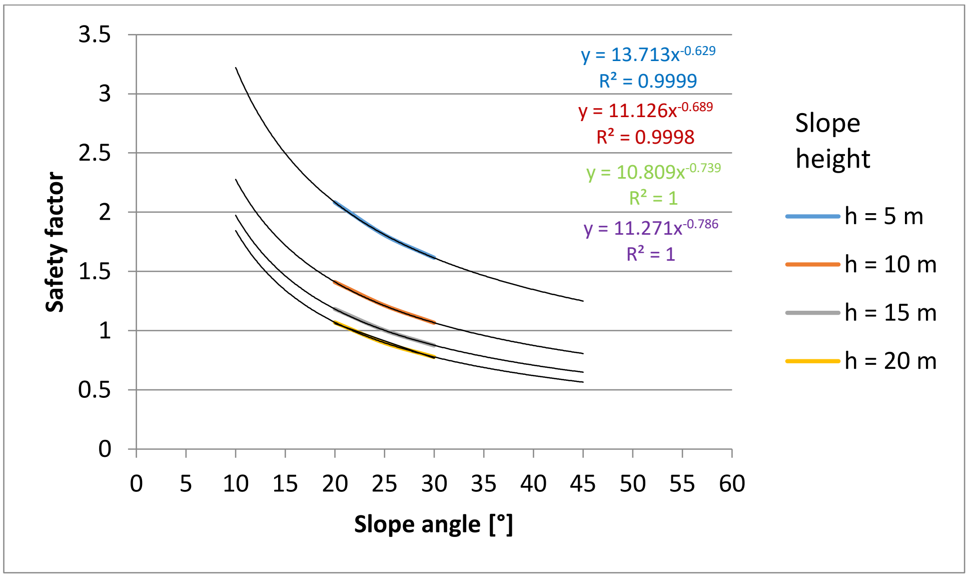

Fig. 8. Variation of the safety factor as a function of the slope angle at different values of the slope height (power function)

The variation of the safety factor is dictated by a power function. High correlation and determination coefficient values (R between 0.995 and 1, R2 between 0.99 and 1) indicate perfect correlation, a model that perfectly predicts the values in the target field. The higher the values of these coefficients (the maximum value being 1), the smaller the estimation error. A linear functional dependence between the variables is found, that is, each value of the height or slope angle corresponds to only one value of the safety factor. So, it is confirmed once again that the stability factor decreases with the increase in the value of the slope height or slope angle, and based on the graphs it is possible to design the appropriate geometric elements (which ensure an acceptable stability reserve) for the waste dumps in the Berbești mining basin.

Regarding the case of the Berbești basin dumps consisting of cohesive and weakly cohesive clayey rocks, respectively non-cohesive sandy rocks (dusts, sandy dusty clays, clays, fat clays, marly clays, dusty clays, sands, dusty sands, clayey sands and clayey dusty sands), stability analyzes revealed a stable condition for slopes with maximum heights of 5 m and maximum slope angles of 300, or maximum heights of 10 m and maximum slope angles of 20°.

A slope with a height of 10 m and an inclination of 25°, respectively a slope with a height of 15 m and an inclination of 20°, shows an acceptable reserve of stability, but it is found below the imposed limit value.

A slope for which the design geometry is based on one of the following sets of values: 10 m/30°, 15 m/25°, or 20 m/20° shows a reduced stability reserve tending toward the equilibrium limit state.

A slope with a height of 15 m and an inclination of 30°, respectively a slope with a height of 20 m and an inclination of 25°-30°, is in a state of imbalance (unstable slope).

In the case of this waste rock mixture, whose physical and mechanical characteristics are shown in Table 1, it results that there are not many possibilities for designing the geometry, which requires the search for solutions to improve the strength characteristics, such as:

- electrochemical consolidation;
- thermal treatment;
- consolidation with lime piles;
- injection of rocks.

It should be noted that these methods are expensive and have a limited application.

5. Conclusions

The Berbești mining basin is located in a hilly area strongly affected by negative geomechanical phenomena. The mining activity is one of the factors that influence the stability of massifs or engineering constructions, through excavations and interventions on the natural geometry of the massifs, by exposing the rocks to external factors and worsening their quality, but also by constructing waste dumps without respecting the designed geometrical elements. In addition, natural factors, such as geological, lithological, hydrometeorological factors, or others, influence the stability of slopes through their distinct or cumulative effects.

Since the methods of improving the resistance properties of rocks are rarely applied due to the costs they involve or the limitations they face, the emphasis remains on the designing of favorable geometries, which ensure an acceptable stability reserve for the security of mining works, workers, and other objectives.

Therefore, the authors have proposed 2 nomograms that can be easily interpreted by both engineers and mining workers, so as to avoid dangerous situations that can occur when the designed geometry cannot be exactly respected in the in-situ as a result of the limitations imposed by existing conditions in the field (impossibility of correlating the activity of the machinery in the open-pit, variations in the thickness of the rock layers, reduced surfaces for depositing the waste rocks, etc.).

References

[1] **Lazăr, M., Dumitrescu, I.,** 2009
The impact of the mining industry on the environment and the ecological reconstruction of the affected areas (in Romanian). Mining Revue, 10.

[2] **Nguyen, P.M.V., Wrana., A., Rajwa, S., Rózanski, Z., Fraczek, R.**, 2022
Slope Stability Numerical Analysis and Landslide Prevention of Coal Mine Waste Dump under the Impact of Rainfall - A Case Study of Janina Mine, Poland, Energies, 15 (21), no. 8311

[3] **Fodor, D.,** 2008
Mining of mineral substances and useful rocks in open-pits (in Romanian), Corvin Publishing House, Deva, Romania

[4] **Fodor, D., Trotea, T.,** 2010
Construction, stability and management of waste dumps from lignite open cast (in Romanian), Mining Revue, 6

[5] **Rotunjanu, I.**, 2005
Stability of Natural and Artificial Slopes (in Romanian), Infomin Publishing House, Deva, Romania

[6] **Apostu, I.M., Rada, C., Lazăr, M., Faur. F., Sîli, N.,** 2022
Investigation of the Causes and Factors Generating Land Instability in the Berbeşti Mining Basin, Mining Revue, 28, pp. 24-36

[7] **Fodor, D., Lazăr, M.,** 2023
Considerations regarding the stability of dumps in Oltenia (in Romanian), AGIR Bulletin, 1

[8] **Lazăr, M., Faur, F., Apostu I-M., Rada, C.,** 2021
Long-term stability of the final slopes of the mining waste dumps from Oltenia, MATEC Web of Conferences, 342, no. 03005

[9] *******, 2023
CET Govora Documentation, Mining Division (in Romanian)

[10] *******, 2017-2019
I.C.S.I.T.P.M.L. Documentation (in Romanian), Craiova, Romania

[11] **Rotunjanu, I., Antonie, D., Rența, L.,** 2010
Considerations on the geotechnical characteristics of the cover rocks of the open-pits in Oltenia according to their depth and their influence on the geometric elements of the slopes (in Romanian). Mining Revue, 11

[12] **Faur, F., Lazăr M., Apostu I-M., Rada, C., Moisuc-Hojda, M.,** 2022
Assessment of the Stability State and the Risk of Landslides within Berbești Mining Basin (Romania) *Post Closure*, Inżynieria Mineralna – J. Polish Min. Eng. Soc., 2 (50), pp. 59–70

[13] *******, 2023
Google Earth Pro, 2023. https://earth.google.com/ (accessed on 08 April 2024)

[14] **Arad, V.**, 2010
Mechanics of rocks and soils (in Romanian), Focus Publishing House, Petroșani, Romania

[15] **Stănciucu**, M., 2018
Stability of Natural and Artificial Slopes (in Romanian), Technical Publishing House, Bucharest, Romania

[16] **Wyllie, D.C., Mah, C.W.,** 2004
Rock Slope Engineering. Civil and Mining, 4th ed., Spon Press — Taylor & Francis Group, New York, NY, USA

[17] **Duncan, J.M., Wright, S.G., Brandon, T.L.**, 2014
Soil Strenght and Soil Stability, 2nd ed., John Wiley&Sons, Inc., Hoboken, NJ, USA

[18] **Dongping, D., Li, L., Zhao, L.,** 2017
Limit equilibrium method (LEM) of slope stability and calculation of comprehensive factor of safety with double strength-reduction technique, J. Mount. Sci., 14, pp. 1–14

[19] **Huang, Y.H.,** 2014
Slope Stability Analysis by the Limit Equilibrum Methods: Fundamentals and Methods, ASCE Press, New York, USA

[20] **Salgado, R.,** 2022
The Engineering of Foundation, Slopes and Retaining Structures, *2nd ed*., CRC Press, Boca Raton, FL, USA