Slopes stability analysis from Rosia Poieni open pit mine, Romania

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Abstract. In the case of Roşia Poieni open pit mine the level of +805 m was established as a daily operating limit; the division into benches was based on this level by dividing into horizontal slices with a thickness of 15 m, equal to the height of the bench. Thus, there were 27 benches in the Curmătura area and 23 benches in the Ruginiş area. The general slope angle was set at 35°, the angle for which the tailings volumes and implicitly the opening-up coefficient were calculated. The stability analysis was performed for individual bench, 2 benches system and the general slope of the quarry (consisting of 24 benches), using two methods (Fellenius and Janbu). A polygonal slip surface was also modelled; such potential landslide surfaces can appear in the slopes of the Roşia Poieni quarry due to the natural cracking systems of the massif but also due to the secondary cracking generated by the used drilling-blasting works (exploitation technology). The stability check was done by applying Hoek's graphical-analytical method; the determined values for the safety factor satisfy the condition of being greater than 1.3. In these circumstances, no further measures are required to increase the stability reserve.

1 Introduction

The stability of slopes, and exploitation benches within an open pit mine is an important factor both in terms of safety of personnel and equipment operating on site, but also in terms of ensuring productivity and profitability of mining exploitation. It is important that the local and general stability of the emplacement is ensured on long term [1-4]. A slopes slide endanger the natural and human goals in their area of influence, and not infrequently consequences are found in material loss, but also in human life. Given the serious consequences that the phenomena of instability can have, it is necessary to carry out extensive studies on the technical condition of the slopes and the factors that can release slide. The large number of factors involved in such phenomena makes it difficult to accurately determine the stability reserve or to predict the time when the risk of slide occurs [2, 4, 5]. For this reason, the proposed methods by the literature for performing stability analyses are complex and require a good knowledge of the nature and rocks properties, but also of the

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mechanisms that lead to the appearance of slip surfaces and the entry into movement of material masses. Often, the results of the stability analyses are informative, and such analyses must be performed periodically, whenever changes in the rock massif stress state are found [1-3, 6, 7]. Stability computations involve determining the slip surface and determining the value of the safety factor according to which we can assess whether the slope is stable or not. For the concept of safety factor, in the literature there are several ways of defining, whether we are talking about a plane, circular or polygonal potential surface of breakage. Engineers have to choose between them; as a rule, this choice is included in the choice of computation method and will depend to a certain degree on the designer's request, but also on the computation possibilities [3, 5, 6]. Over time and depending on the development of computational techniques and numerical methods of analysis, different computation methods have been proposed, more or less complicated and more or less efficient [7, 8].

2 Geomechanical characterisation of Roșia Poieni open pit mine perimeter

In order to establish the physical-mechanical characteristics of the geological formations that appear in the Roșia Poieni mining perimeter, in situ observations, measurements, analyses and laboratory tests were performed. The field activity consisted in: establishing the sampling points; geological-technical mapping of exploration workings and especially executed works for geotechnical studies; micro-tectonically measurements to determine the degree of cracking and observation of major cracks; research and geological-technical mapping of areas with different alteration zones. The study of the physical-mechanical properties of the rocks was performed on rock samples taken from underground mine workings, from geological exploration drillings and geotechnical drillings [5, 9].

In parallel with the study of the cores taken from the exploration and geotechnical research drilling, a sampling and analysis was performed from the point of view of the strength characteristics of the underground mining works located on the horizons +750; +950 and +1050. The situation of the geotechnical samples taken from the underground mining works is presented in Table 1.

Table 1. Sampling location from underground works.

Horizon	Mining work	Sampling interval	Formation
+770	Gallery +770	0 – 750	Clayey-arenaceous complex Poieni andesites
+950	Gallery II	100 – 500	Fundoaia andesites Poieni andesites
+950	Gallery III	120 – 500	Fundoaia andesites Poieni andesites
+950	Gallery IV	100 – 800	Fundoaia andesites Poieni andesites
+950	Transversal gallery 70	8 – 200	Fundoaia andesites
+1050	Gallery IX	180 – 380	Fundoaia andesites Poieni andesites
+1050	Gallery XII	130 – 330	Fundoaia andesites Poieni andesites
+1050	Gallery XIII	140 – 240	Poieni andesites

The rocks that appear in the quarry field, have been affected by alteration processes related to the hydrothermal manifestations of magmatic eruptions and develop over large areas comprising both eruptive and sedimentary rocks. Hypogenic transformation products have a zonal development around the Fundoaia type andesitic body and are characterized by certain mineral associations of neoformation [5, 9]. The processes of chemical alteration with varying degrees of intensities and with different associations of minerals, give to the andesites in the area an anisotropy of mechanical properties which will determine very different behaviours of the rocks in quarry. Within the two large groups of igneous and sedimentary rocks, different varieties are separated, depending on the degree and intensity of hydrothermal alteration phenomena and within the two large groups of igneous and sedimentary rocks, different varieties are separated, depending on the degree and intensity of hydrothermal alteration phenomena and strength characteristics, as follows: low-strength rocks, with characteristics, as follows: low-strength rocks, with $\sigma_{rc} < 80$ daN/cm^2 (the rocks from the clayey-arenaceous complex and Poieni and Fundoaia andesites intensely altered) with a weight in the slopes of the quarry of approx.20 %; rocks of medium strength, semi-rocky with $\sigma_{rc} = 80$ - 800 daN/cm^2 (Poieni and Fundoaia andesites poorly altered, sandstones and microconglomerates), with the largest weight in the slopes of quarry, of approx. 6o %; hard rocks, rocky with $\sigma_{rc} > 800$ daN/cm^2 (Poieni and Vârşi silicified andesites) and conglomerates, which will enter into the constitution of the slopes in a proportion of approx.15 %.

3 Geometry of Roșia Poieni open pit mine

3.1 Opening, preparation and exploitation in Roșia Poieni open pit mine

The opening, preparation and exploitation of the copper andesite deposit from Roşia Poieni took into account the exploitation of the deposit in a large quarry with the final bottom at the level of +550 m, with a production capacity of 15 million t/year. The opening of the Roșia Poieni deposit was made through a technological road and an external half-trench, oriented N-S, from which the connecting ways were made until the current level of the quarry bottom +850 m (Figure 1). So far, the quarry has developed on 25 exploitation benches, between levels +1,210 m and +750 m.

Fig. 1. Overview of Rosia Poieni open pit exploitation.

Both in sterile and in ore, every year preparatory works are required which consist in: arranging the connection platforms for each bench; connecting the access roads from the outside with each new bench; construction of inclined planes with a maximum ramp of 7% inside of quarry, in order to achieve access on the berms of the benches, or opening of new benches; levelling berms and backfilling of pits; construction of roads on each berm and their connection to the existing ones; electrical cables laying, restoring the lighting system; scaling of working faces; liquidation of over dimension fragments; digging jumps for water collection; other excavation workings. All these workings start with the beginning of the excavations in each bench that begins.

The Roşia Poieni deposit has a large dip, with an extension also of great depth, therefore, it was necessary to transport the sterile to external dumps. The general slope angle of the bench system is 25° – 35°, the minimum difference between the working faces located on the same bench is 60 m, and the difference between the working faces located on different benches must be at least 100 m. The shape of the exploitation bench line is a circular arc. The method of exploitation with the transport of sterile to outer dumps is more complicated and less economical compared to the method by which the transport of sterile is made in inner dumps which, due to the morphology of the land where the deposit is located, is the only applicable exploitation method. Also, in the case of the Roşia Poieni quarry, the volume of sterile rocks is very high, and the transport system used (discontinuous - dump trucks) has special implications on the organization of the transport flux.

3.2 Geometrical elements of exploitation in Rosia Poieni open pit mine

From the analysis of the geological and geotechnical documentation and taking into account the types and characteristics of the equipment used for exploitation, the following geometrical elements of exploitation were adopted (Table 2), which also determines the characteristics of the reference model [4, 8]:

- bench height of 15 m, corresponds to the two-stage drilling dimensions of the drills; at the same time at this height of the blast rock of about 13 m, which can be taken over by the EKG-4 and EKG-8 excavators and eliminates the danger of collapse of the mining mass over the excavator;
- the width of the bench was establish at about 30 m; practically this width will be about 25 m, because the wall of the bench will never be absolutely vertical. This width of bench corresponds to the traffic needs, because the required width of the roads on benches is about 20 m, with three traffic ways, of which 2 ways for traffic and the other one for maintenance. The width of the benches will be reduced as the angle of the final general slope increases, such that the traffic will be made through a main serpentine road that will allow access to the bottom of open pit mine;
- the slope breakage for bench was considered to be about 70° at a height of 15 m from the bench; as it is, this slope will be about 80° - 90° after the blasting operation, but in time it will change, reaching 70° due to the breakage of the lip of bench and the flow of slope, the material accumulating at the base of the bench;
- the general working slope in open pit mine was adopted for the angle of 25°;
- the final slope of open pit mine was outlined in the first stage at an angle of 30°, as a result of geotechnical studies performed in the past [8].

Table 2. Geometrical elements of Roșia Poieni open pit mine.

Element		U.M	Value
Maximum bench height, h		m	15
Maximum slope angle of working bench		degree	70 - 75
The width of working berm, B_l	double sense	m	12
	one-way		8
The width of security berm, b		m	3
General slope angle of quarry		degree	60

The transformation of the transport berm into a safety berm will be done in the phase in which through exploitation the final contour of the open pit mine, has been reached. At the end of exploitation, remodelling works of the quarry slopes will be performed to bring them to a stable long-term configuration, the new geometry being shown in Table 3.

Table 3. Geometrical elements at the final configuration of Roșia Poieni open pit mine.

Element	M.U.	Value
Final bottom of open pit mine	m	+760
Maximum bench height, h	m	15
The width of berm on the final contour, B	m	5
General slope angle of quarry	degree	maximum 40

4 Slopes stability analysis from Roșia Poieni open pit mine

In order to perform the stability analysis, it is necessary to go through two stages, respectively to determine the position of the slip surface and to determine the value of the safety coefficient [10-13]. Currently, the slopes stability is estimated theoretically, using different computation methods and procedures developed by specialists in soil mechanics and engineering geology, for different types of rocks and computation hypotheses or practically, by measuring the strain surface [14-16]. As shown by A. Cassagrande (1950), the problem of slopes stability, as a whole, is an indeterminate, because the possibility of yield rocks that are part of them is determined by a number of factors that cannot be considered in their entirety in computations. To these factors the assumed risks are added, by using less appropriate computation methods or formulas or previous experiences, as well as other subjective risks such as: non-observance during the execution of the expected technical solutions, unfollow along the way the achievement of the designed conditions and parameters, etc. For this reason, the results of the stability computations have relative values and it is recommended to consider them as indicative [7,10,11,13,14].

The stability analysis of the individual benches of quarry was performed using the SLIDE 2D program, which offers the possibility to evaluate the safety factor for different yield surfaces [17].

For Roșia Poieni quarry situation, a stability analysis was performed for the individual benches, two-bench system and general slope of quarry. Because the geometry of the quarry benches is identical, for the stability analyses a certain bench was considered. To determine the geometry of the two-bench system and the general slope, the sections shown in Figures 3 and 4 were used, considering the height of bench of 15 m, the berm of 10 m (except for the first berm which is 15 m), and the slope angle of 70º. As shown in Figures 2 and 3, the two-bench system has a height of 30 m and a slope angle of 55º; the general slope (24 benches) has a total height of 360 m and a slope angle of 25º.

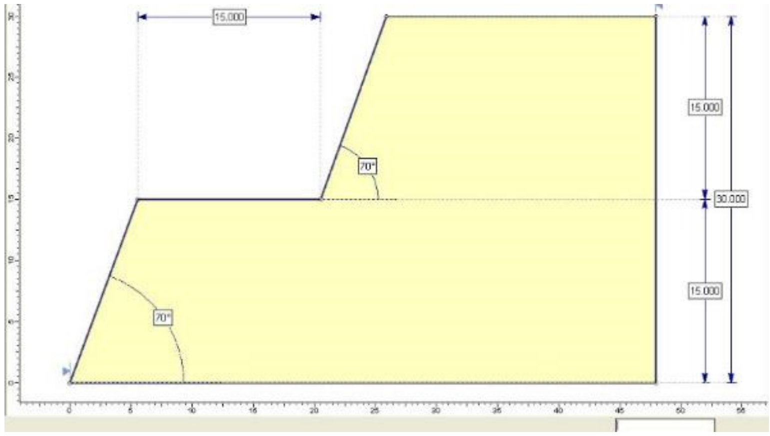

Fig. 2. Two-bench system geometry.

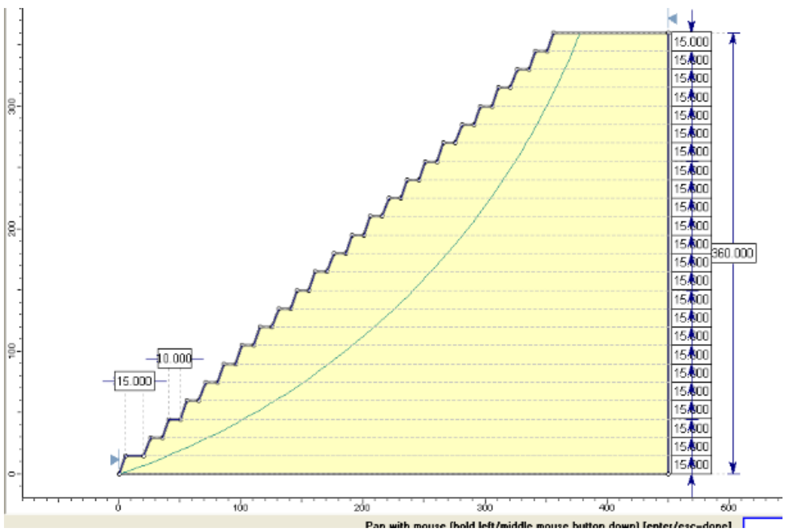

Fig. 3. General slope geometry of open pit mine (Curmătura area).

The results of the stability computations performed by means of SLIDE 2D, using two methods: Fellenius and Janbu, are presented in Table 4 and Figures 4 - 11.

Table 4. The results of the stability computations for considered situation.

Slope	**Height, h (m)**	**Slope angle, α (degree)**	**Stability analysis method**	
			Fellenius	**Janbu**
Cylindrical slip surfaces				
Individual bench	15	70	1.452	1.474 (1.483)
Two-bench system	30	55	1.608	1.639
General slope	360	25	3.567	3.754
Polygonal slip surfaces				
Individual bench	15	70	1.571	1.630

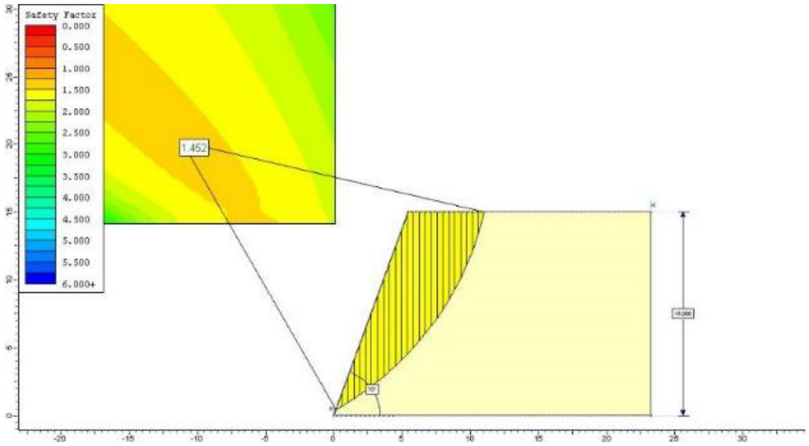

Fig. 4. Safety factor for individual slope (quarry bench) by Fellenius' method.

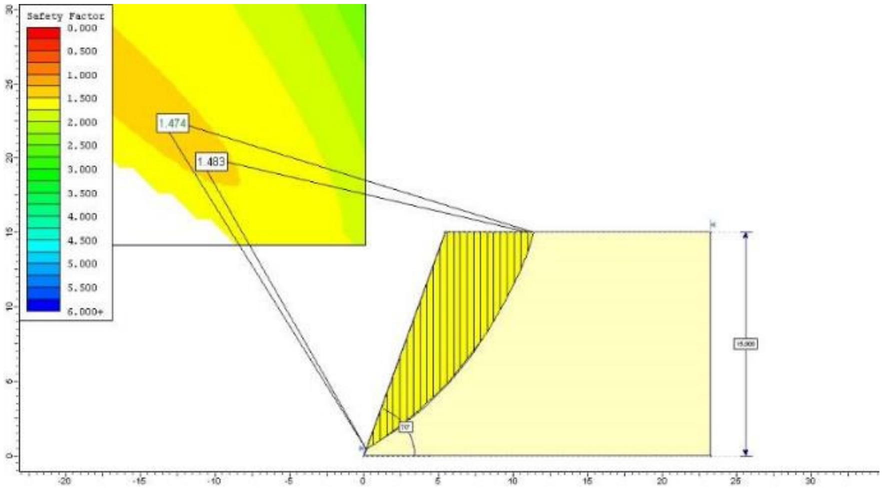

Fig. 5. Safety factor for individual slope (quarry bench) by Janbu' method.

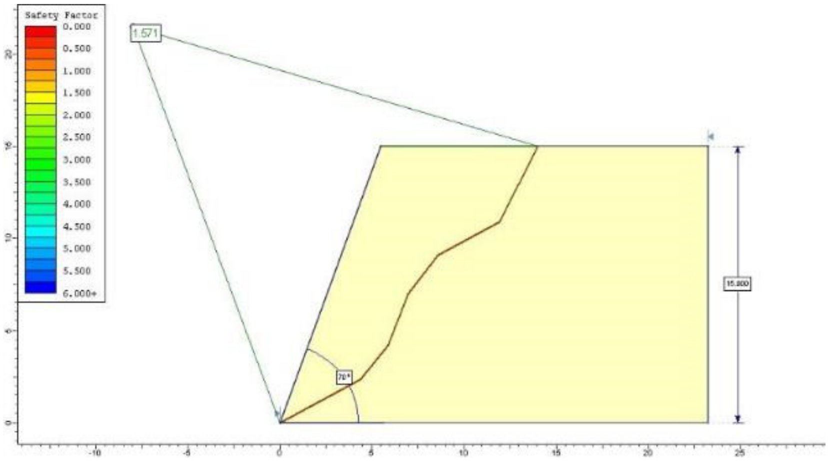

Fig. 6. Safety factor for individual slope (quarry bench), in the hypothesis of sliding along polygonal surfaces by Fellenius' method.

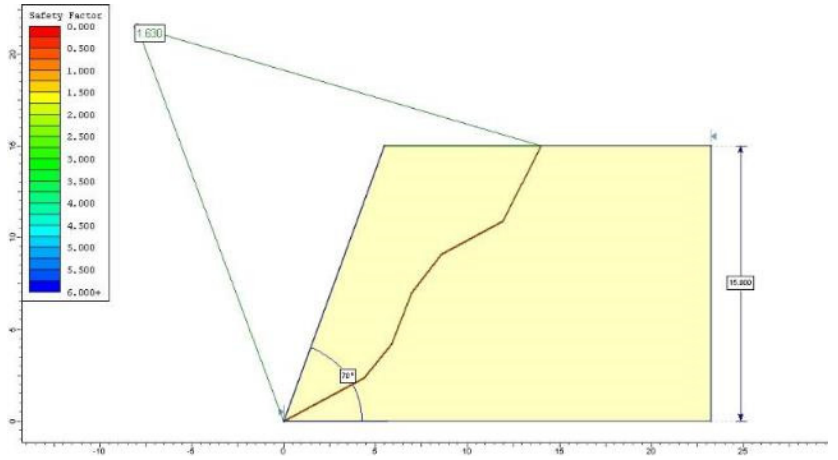

Fig. 7. Safety factor for individual slope (quarry bench), in the hypothesis of sliding along polygonal surfaces by Janbu' method.

Fig. 8. Safety factor for two-bench system by Fellenius' method.

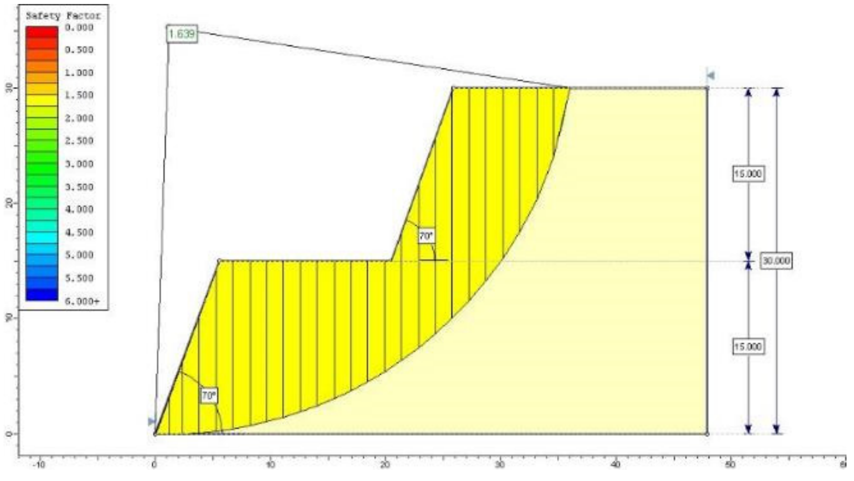

Fig. 9. Safety factor for two-bench system by Janbu' method.

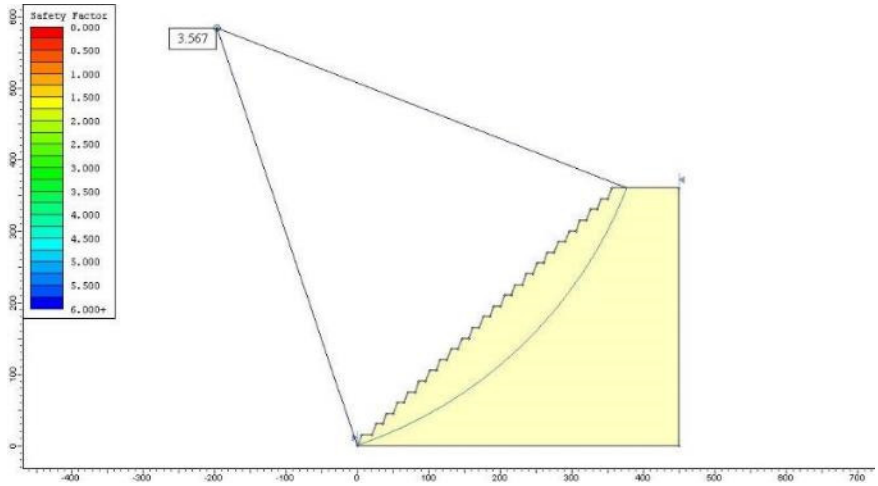

Fig. 10. Safety factor for the system with 24 benches by Fellenius' method.

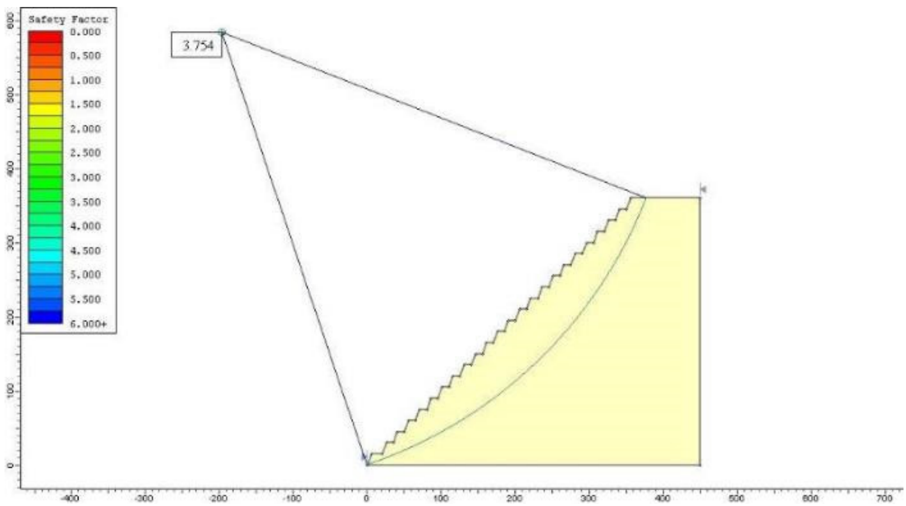

Fig. 11. Safety factor for the system with 24 benches by Janbu' method.

The computations show that the obtained values for the safety factor are greater than 1, which theoretically means that the stability conditions are ensured. The lowest values of the safety factor were obtained by Fellenius' method, for both situations considered. The values obtained are above 1.3 for individual slopes and the 2-step system, respectively over 3 for the general slope, and correspond to the imposed values by standards (for final slopes a value of the safety factor between 1.2 and 1.5 is allowed depending on the importance of the objectives neighbourhood of the slope and period of time for which it was designed). In default of real data, a presumed polygonal sliding surface was modelled. In the slopes of the Roșia Poieni open pit mine such potential slip surfaces can occur due to the natural cracking systems of massif but also due to the secondary cracking generated by drilling-blasting operations. Stability test was performed by Hoek's graphical-analytical method (see Table 5 and Figure 12) [18]. As can be seen from Table 4 and the graph in Figure 12, all obtained safety factor values satisfy the condition $F_S \geq 1.3$. Under these conditions, no additional measures are required to increase the stability reserve (through re-profiling works of slopes, anchoring, etc.).

Table 5. Slopes stability test from Roșia Poieni open pit mine.

Section	Function $X = \alpha - 1.2\varphi$	Function $Y = \frac{\gamma_v h}{c}$	Fs
Individual slope	28.00	7.05	1.40
Two-bench system	13.00	14.01	1.30
General slope	-17.00	169.20	2.00

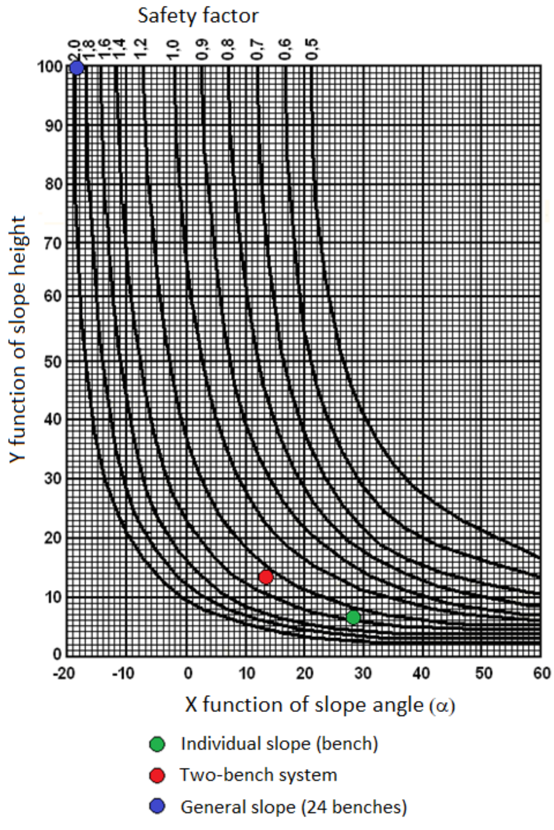

Fig. 12. Hoek graph for curved slip surfaces (according to [18]).

5 Conclusions

The results of the geotechnical laboratory and in situ studies correlated with geological-engineering conditions of deposit, lead to the conclusion that from the point of view of strength characteristics the rock complex that appears in the perimeter of quarry are included in three large groups: rocks of low strength (rocks from the clayey-arenaceous complex and Poieni and Fundoaia andesites intensely altered) with a weight of about 20 %; rocks of medium strength (Poieni and Fundoaia slightly altered andesites, sandstones and microconglomerates) with a weight of about 60 %; hard rocks (Vârși andesites, silicified

Poieni andesites and conglomerates) with a weight of about 15 %. The studies carried out till now on the action and effects in time of geological-technical factors include Roşia Poieni deposit in the category of deposits with difficult geological-technical conditions. From the point of view of the degree of cracking, the andesitic formations fall in a range from strongly fissured to medium fissured (IInd and IIIrd category), and the dimensions of the structural blocks vary between 0.10 - 1.00 m. Conglomerate arenaceous sedimentary rocks are included in the category of less fissured rocks, with structural block dimensions of 1 - 1.5 m. The micro-arenaceous clayey sedimentary complex consists of an intimate and successive stratified alternation of clayey and sandy series with thicknesses ranging between 0.10 - 0.50 m. The primary alteration processes produced hydrothermal transformations, with zonal development around the mineralized body, which affected the strength characteristics.

The value of safety factor depends on the massif stress state, compared to the maximum stresses that the rocks can bear. Since the massif stress state changes under the influence of various natural or artificial factors, it is necessary to choose the safety factor not only by assessing the stress state, but according to unknown, uncertain or subjective elements that affect the slopes stability. In the field of mining engineering, theoretical computation will continue to be a tool through which the degree of influence of the parameters on mining works stability can be established. However, it should be noted that in situ observations and measurements will be the means by which engineers can best identify the parameters to be considered when instability phenomena are studied.

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