

# Assessment of the technical conditions of Jieț waste dump in the context of its reintegration into the surrounding landscape

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**Abstract.** Coal mining activity in Jiu Valley is approaching, faster than expected a few years ago, to its end and one of the main directions for transforming the area (while ensuring its sustainability) is the development of tourism. Under these conditions, a problem that has remained partially unresolved is related to the integration of the former mining perimeters, especially the waste dumps, into the surrounding landscape. Such an approach must always start from a thorough check of the technical condition of these artificial earth constructions. For this reason the stability of the dumps in the Jiu Valley is considered to be an important issue, considering that possible failures endanger both the natural and the anthropic environment. In the case of the waste dump considered as a case study, because several years have passed since the last sterile rocks were deposited and since stability studies were performed, a new such study was considered necessary (given that the deposited rocks underwent certain changes: compaction, mechanical disintegration, chemical alteration, etc.). This paper presents the results of the stability analyzes carried out during 2022 and a series of conclusions regarding the limits within which the geometric elements must be framed so as to ensure a good stability reserve and thus allow the ecological restoration works to begin.

## 1 Introduction

At the level of the mining region (hard coal mining) known generically as the Jiu Valley, as a result of over 150 years of industrial exploitation of coal reserves, there have been appreciable quantities of waste rocks that have been deposited in waste dumps [1]. Thus, in the middle of the 90s, when the restructuring process of this sector of activity was started (in fact of mines closure) in the Jiu Valley (Petroșani) Mining Basin there were approx. 60 such deposits, of different shapes, which stored varied volumes of sterile rocks, occupied areas from a few hundred square meters to a few tens of ha and were located on land with varied topography (from flat lands to steep slopes) [2].

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Gradually, out of 16 existing mining units in 1990, only 4 are now operational, and with the closure of the mines the waste dumps have been put into conservation and normally all should have been, in one way or another, ecologically restored.

In reality, only a part of them were reclaimed and returned to the productive or natural cycles (by this understanding a systemic approach of reclamation works), another part (which benefited from favorable conditions) are spontaneously vegetated, but there are a few more (the active ones and some of the ones in conservation) that require active interventions to be reintegrated into the surrounding landscape.

Such an example is represented by Jieț waste dump, which, because of its location did not allow the spontaneous installation of sustainable vegetation, the only species present being represented by perennial grasses without ecological value and annual grasses, whose development is variable, from year to year, depending especially on climatic conditions.

Therefore, once the need for intervention for the ecological restoration (reclamation) of this dump has been established, a first stage is represented by studies related to its technical condition, in particular the assessment of the stability reserve, the identification of specific conditions (in terms of geometry) for which this reserve is satisfactory and the establishment, if necessary, of measures to increase it.

## 2 Presentation of Jieț waste dump

Jieț waste dump belongs to Lonea Mining Exploitation and was built in order to store the tailings from the technological processes of digging the directional tunnel from the bed of coal seam no. 3, the transversals tunnels and other mining works executed at this level.

The dump is located near the auxiliary shaft for materials Jieț, on the former coal-shipping platform from the Jieț - Defor open pit and is oriented on the SE - NW direction. It is located on the territory of Petrila Town, on Jieț street, about 300 m from the East Jiul river and 240 m from the Lonea - Jieț road (figure 1) [3].



**Fig. 1.** Jieț waste dump in 2022 [4].

The base terrain on which Jieț dump is located has a rugged relief, with elevations between 715 - 735 m, slopes with inclinations of 4 - 8° along the longitudinal section and 2 - 9° along the cross section and occupies an area of 1.04 ha [3].

The location area is not affected by the presence of watercourses, but there are 2 lakes, one upstream and one downstream of the dump, on a SW - NE direction.

The material from the Jieț dump consists mostly of waste rocks from the productive and basal horizons of the Petroșani syncline.

From a hydrogeological point of view, for the structure of the formations in the foundation, the presence of groundwater (that may lead to the formation of static resources) was not reported.

In the case of Jieț dump, the presence of springs is not reported, the only waters that can have a certain influence on the stability of the dump are represented by infiltrations coming from precipitations.

The transport of the waste rocks and the deposition were made with the help of a conveyor belt mounted on a trestle with three supporting pillars, with a console for the construction of the deposition cone, from where the waste material was pushed and leveled with bulldozers.

The Jieț shaft ceased its coal extraction activity in the last decade, currently operating only to provide materials for the no. 5 sector of Lonea Mining Exploitation and underground ventilation.

In the adjacent areas to the perimeter of the dump there are several individual households, roads with limited traffic and restricted access of people.

The dumping activities in the Jieț perimeter is stopped for about 10 years, as well as the waste dump monitoring activities. Meanwhile, illegal accumulations of all types of waste materials have appeared on and around the mining waste dump (especially waste resulting from small demolitions) (figure 2).



**Fig. 2.** Illegal accumulations of different types of waste materials.

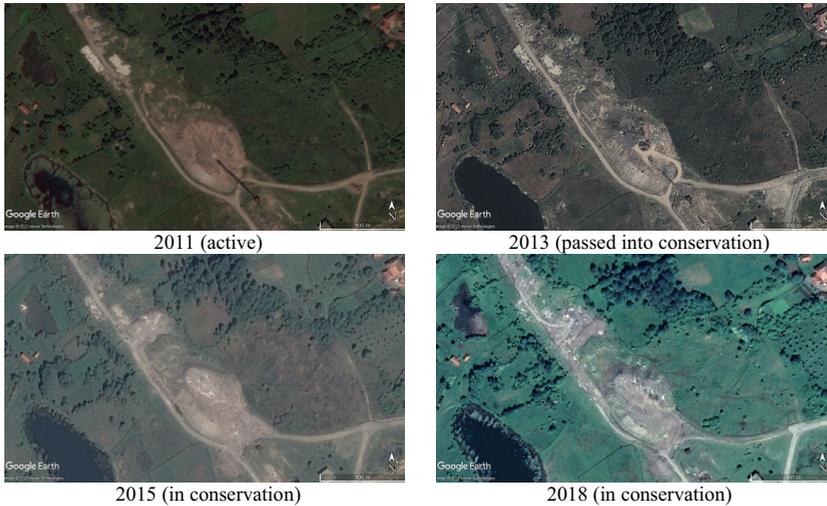
Considering the landscape and the characteristics of the area, it is necessary to analyze the current technical state of the waste dump and to establish the necessary measures for its reintegration into the surrounding landscape.

### **3 Geometrical characteristics of the waste dump**

Lonea Mining Exploitation is in operation (at least until the end of 2022), and the waste rocks are deposited only in the Lonea 1 dump located near the mine, while the Jieț dump is closed (in conservation) since 2013.

From a geometric point of view, the dump has undergone small changes compared to 2011 (figure 3). The geometric features refer to the configuration of the base terrain and the dump and include the slopes and the shape of their surfaces. The heights and slope angles

are the basic geometric elements and they depend on the types of rocks that form the studied area.



**Fig. 3.** The geometry of Jieț dump over time [4].

In the southwestern part, in order to prevent the slope of the dump from sliding, a support wall, with a height of 1.5 - 2 m, was built from prefabricated concrete beams.

The designed geometric parameters of the dump (table 1) were not dependent on the morphology of the land surface.

**Table 1.** Geometric parameters of Jieț dump.

Waste dump/year	Length (m)			Width (m)			Height [m]	Slope angle [°]
	Lower part	Average	Upper part	Lower part	Average	Upper part		
Jieț	2005*	-	160	-	35	-	2.3 – 12.6	11 - 36
	2022	210	175	140	50 - 80	40 - 65	30 - 50	1.5 - 18

\* according to documentations [3]

The dumping technology usually influences the stability of dumps in the conditions of their construction in several tiers, but in this case the location of the Jieț dump being on an almost horizontal terrain the problem of instability was and is only related to the geometry of the slopes.

Over time, the dumped material was compacted, at the top of the dump existing a settlement bed with a depth between 1.5 and 2 m. Also, there are active processes of disintegration of weakly cemented rocks (sandstones and marls). These processes result in fine materials (fine sands, dust and clay) that are entrained by rainwater and transported either to the inside of the dump or on slopes, to the base of the dump (on exterior).

The visual observations did not highlight major negative geotechnical phenomena. However, on the western slope, the presence of rain erosion gullies was noticed and, also, at the lower part of this slope, a superficial landslide was observed, produced as a result of the removal, for unknown reasons, of the support wall made of prefabricated concrete beams (figure 4).



Fig. 4. Gullies and shallow landslides on the western slope.

#### 4 The physical and mechanical characteristics of the waste rocks

The main physical and mechanical characteristics required in the stability analyses are the volumetric (apparent) weight, the cohesion and the internal friction angle [5-7].

In May 2022, in situ sampling was performed from four points relevant to the geometry of the dump (figure 5) and tests were performed in the laboratories of Geotechnics and Earth Mechanics within the Mining Faculty (University of Petroșani) in order to define the physical-mechanical parameters that characterize the current state of the dumps. The results are shown in tables 2 - 4.

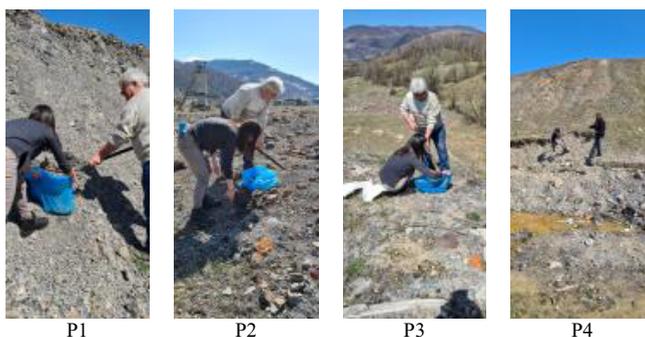


Fig. 5. Sampling campaign.

Table 2. Granulometry and the non-uniformity coefficient of the analyzed rocks.

Sample no.	Granulometry %					Non-uniformity coefficient	
	Clay	Dust	Sand	Gravel	Boulders	u	Description
P1	14	15	18	29.2	23.8	>> 15	very uneven
P2	6	9	19	40.1	25.9	>> 15	very uneven
P3	26	14	25.1	19.1	15.8	>> 15	very uneven
P4	22	18	25.7	21.5	12.8	>> 15	very uneven

Table 3. The mechanical characteristics of the waste rocks.

Sample no.	Deformation module, $E_c \cdot 10^2$ [kN/m <sup>2</sup> ]	Specific compaction, $e_p$ [cm/m]	Cohesion, $c$ [kN/m <sup>2</sup> ]	Internal friction angle, $\varphi$ [°]
P1	60.96	1.92	24	27.92
P2	54.15	1.86	18	30.54
P3	33.62	3.01	17	24.24
P4	31.49	3.42	23	27.47

**Table 4.** The physical characteristics of the waste rocks.

Sample no.	Natural state indicators						
	Determined in the lab			Computed			
	Volumetric weight, $\gamma_s$ [kN/m <sup>3</sup> ]	Specific weight, $\gamma_s$ [kN/m <sup>3</sup> ]	Natural moisture, $W_{nat}$ [%]	Porosity, $n$ [%]	Pore index, $e$	Saturation humidity, $W_{sat}$ [%]	Saturation coefficient, $S$
P1	18.46	24.51	11.58	32.50	0.48	19.64	0.59
P2	18.76	27.87	6.72	36.95	0.59	21.02	0.32
P3	16.62	24.34	16.43	41.38	0.71	28.99	0.57
P4	18.24	26.39	8.59	36.35	0.57	21.64	0.40

In order to perform a comparative analysis and observe the evolution or changes in physical and mechanical characteristics, the laboratory determinations made in 2005, 2014 [3] and 2022 were taken into account. The retrieved data were statistically processed, and for the stability analyzes the average values close to the median of the data series were taken into account (table 5). Based on field observations related to waste rocks permeability, it was considered that they have a high capacity to drain rainwater and therefore the possibility of rock saturation is very low, which is why, in the laboratory, the mechanical characteristics at saturation were not determined.

**Table 5.** Physical and mechanical characteristics for the stability analysis.

Material	Natural moisture			Saturation humidity
	Volumetric weight $\gamma_{nat}$ , [kN/m <sup>3</sup> ]	Cohesion, $c$ [kN/m <sup>2</sup> ]	Internal friction angle, $\phi$ [°]	Volumetric weight $\gamma_{sats}$ [kN/m <sup>3</sup> ]
Waste rocks	20.10	23	24	21.00
Natural terrain (soil)	18.15	15	22	19.20

Given that the waste rocks at the level of the Jiu Valley Mining Basin is generally a heterogeneous mixture of hard rocks incorporated into a mass of soft rocks and that its petrographic nature highlights the same type of rock, it was considered that the dumped material is similar, the differences that endanger the stability being the location area and the shape of the base terrain, the geometric shape of the dump, the presence of water, etc.

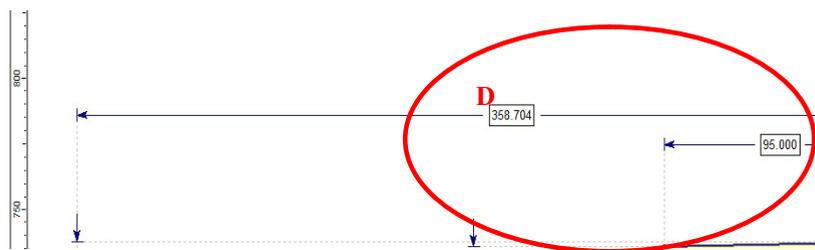
## 5 Stability of dump

Because the dumping activity has been stopped for a long time, and in the meantime there have been no concerns about monitoring and topographic survey of the dump, as well as restricted access to any recent technical documentation, for the stability analyzes old documentation was used [3], captures made with Google Earth Pro [4] and visual observations made during the sampling campaigns.

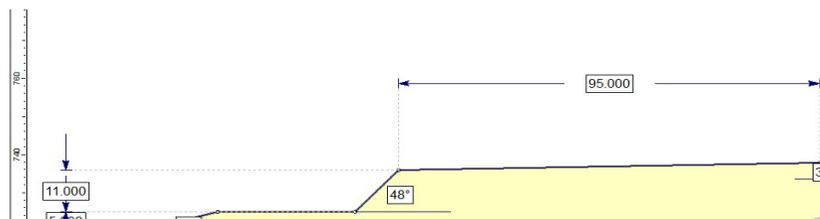
Based on the observations and measurements made in the field, 3 sections were drawn, respectively the longitudinal section A - A and the cross sections T1 - T1 and T2 - T2 (figures 6 - 10).



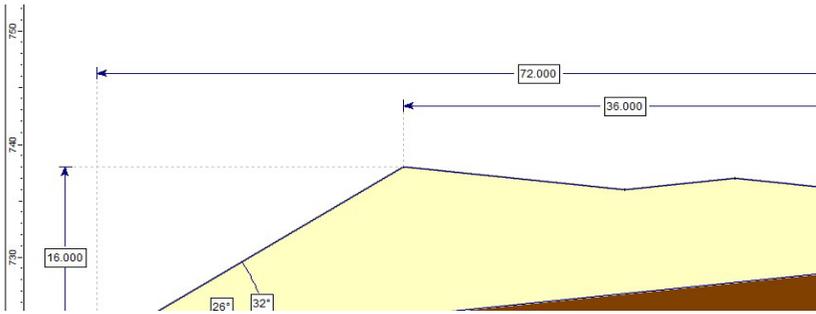
**Fig. 6.** Longitudinal and cross sections (modified after [4]).



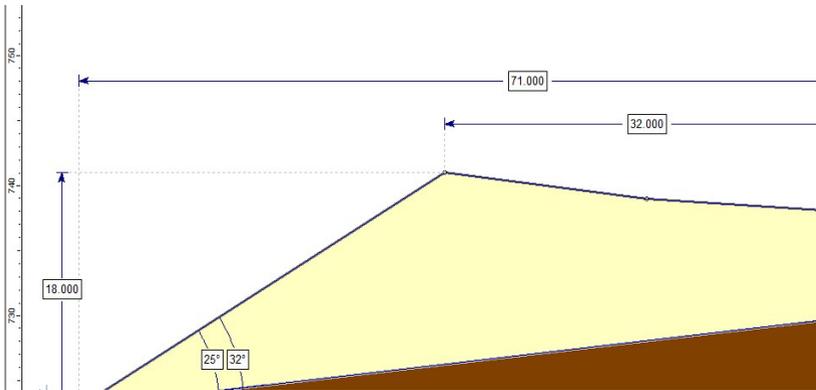
**Fig. 7.** Longitudinal section A-A.



**Fig. 8.** Longitudinal section A-A (detail D).



**Fig. 9.** Cross section T1-T1.



**Fig. 10.** Cross section T2-T2.

The stability analyzes were performed with the help of the software specialized in geotechnical problems, SLOPE, considering that a possible landslide can occur along a curved sliding surface.

This software performs stability analyzes based on limit equilibrium theory (LEM), the safety factor, or the stability coefficient being given by the ratio between the sum of the moments of the resistance forces and the sum of the moments of the forces generating the slide. For this purpose, based on the recommendations of the literature [5-8], the methods of Fellenius, Bishop, Simplified Janbu and Morgenstern-Price were used.

To confirm the results, the GFAS software was used, which is a program for earth mechanics using the finite element method (FEM), based on the Mohr-Coulomb failure criterion [9].

The finite element method is based on the following principles [10, 11]:

- Balance - between external forces and internal efforts;
- Kinematics - deformations and displacements;
- Constitutive relations - the behavior of the material.

During the stability analysis, the program gradually reduces the strength characteristics of the rocks to the values at which the slope slides. The program can provide information on deformations at different levels of work stress and can monitor progressive failure, including total failure by shearing.

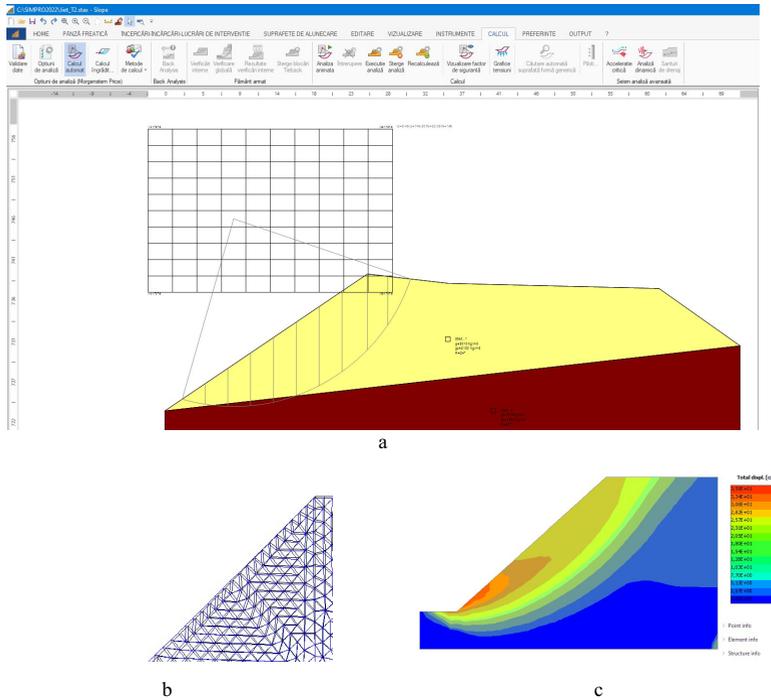
## 6 Results and discussions

All stability analyzes were performed for a slope with a height of 18 m and an inclination between 35° and 60°, these representing the maximum values of the geometric elements observed in the field.

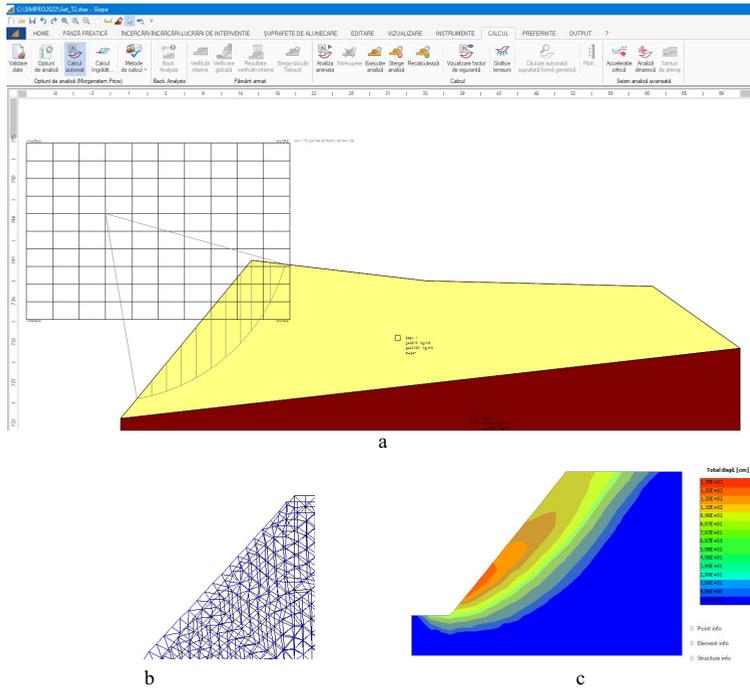
The results of the stability analyses performed for the geometric elements and the physical-mechanical characteristics presented in paragraphs 3 and 4 can be followed in table 6 and in figures 11 and 12.

**Table 6.** Results of the stability analyses.

Slope angle $\alpha$ [°]	Height [m]	Analyses methods				
		Morgenstern-Price	Fellenius	Bishop	Janbu	GFAS
35	18	1.46	1.31	1.47	1.24	1.5
40		1.34	1.21	1.34	1.15	1.3
50		1.09	1.05	1.10	1.02	1.2
60		0.60	0.91	0.93	0.92	1

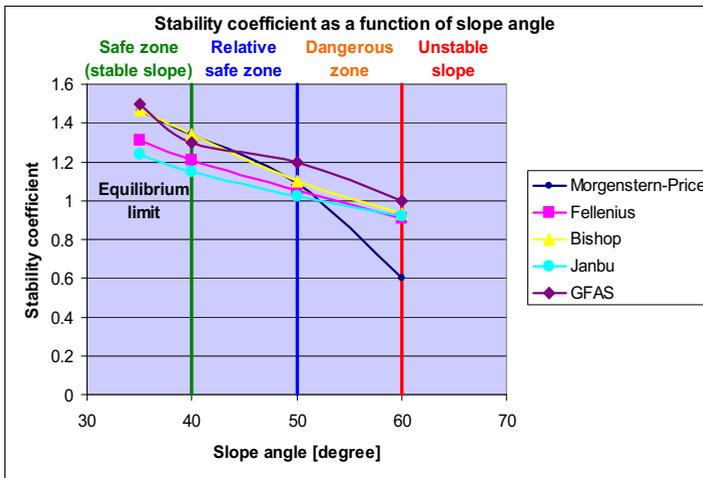


**Fig. 11.** Stability analyses for a 18 m high slope at a 35° angle. a. Critical sliding surface (LEM – Morgenstern-Price); b. Deformations (FEM); c. Total displacements (FEM).



**Fig. 12.** Stability analyses for a 18 m high slope at a 50° angle. a. Critical sliding surface (LEM – Morgenstern-Price); b. Deformations (FEM); c. Total displacements (FEM).

In order to facilitate the interpretation of the results of the stability analyses, with the help of the data from table 6, the graph from figure 13 was developed.



**Fig. 13.** Stability coefficient as a function of slope angle.

Following the stability analyses, in different working hypotheses, the following conclusions can be drawn:

- In the current configuration and in conditions of natural moisture, the slopes of Jieț dump are stable, but, as mentioned, in the conditions when the retaining wall made of prefabricated concrete beams (located on the western side of the dump) is removed, superficial landslides can occur, which, over time, by their interconnection can trigger a deep landslide involving the movement of a large volume of waste rocks;
- In areas where the dump reaches the maximum height (18 m) or heights close to this value, in order to have a satisfactory stability reserve (around 30%) the value of  $40^\circ$  of the slope inclination (maximum permissible value) must not be exceeded. However, given that the aim is to ensure the long-term stability of Jieț dump, a maximum value of the slope angle of  $35^\circ$  is recommended, which leads to an average increase by approx. 15% of the stability reserve;
- For slope angle values between  $40^\circ$  and  $50^\circ$ , also in conditions of a height close to the maximum, the calculated values of the stability coefficients indicate a decrease of the stability reserve below the limit of 30% recommended by the literature [5-7], dropping around 0%, ie a stability coefficient equal to 1 (equilibrium limit);
- For slope angle values greater than  $50^\circ$ , the value of the stability coefficient becomes less than 1 according to the analyses performed by most methods, which means that there is a real danger of landslides, even in conditions of natural moisture;
- The stability analysis methods used lead to relatively close results, including the finite element method, which gives a high degree of confidence;
- By vegetating the dump, both long-term stability conditions can be ensured (and even a slight increase of the stability reserve through the reinforcement effect given by the tree roots), as well as its reintegration into the surrounding landscape.

The waste rocks deposited in the dump that served the Jieț shaft is unsuitable for the installation of vegetation, so that, at present, the deposit makes a discordant note with the surrounding landscape, producing chromatic and aesthetic disturbances. At the same time, the gullies on the southwestern slope facilitate the penetration of water into the body of the dump thus creating the conditions for the occurrence of deep landslide. When establishing the final destination of the surfaces degraded by the mining activity, the natural factors that characterize the area of interest, the soil conditions, the principles of ecological restoration, as well as the technical possibilities to carry out the reclamation must be taken into account.

Although scientific methods can be used to investigate the pedological conditions and to choose the tree species that are best suited for the reintroduction of Jieț dump into the surrounding landscape [12, 13], taking into account the above, the ecological restoration option considered optimal for Jieț dump is the one of forestation, using for this purpose endemic species [14], unpretentious to the soil conditions. Before planting the seedlings, the surface of the dump (slopes and berms) must be properly arranged, by removing the metal elements, large rock fragments and, especially, the accumulated illegal waste.

## 7 Conclusions

Given that one of the future directions for the sustainable development of the Jiu Valley region is related to capitalizing on the tourist potential of the area, it is imperative to ecologically reconstruct the areas where mining has left negative marks.

From this point of view, waste dumps, those still active, but also those in conservation that are not vegetated (through specific works or spontaneously) are elements that disturb the overall perception of the landscape, but which can be regarded at the same time as risk factors, especially if negative geotechnical phenomena, such as landslides, occurs.

The investigations presented in this paper led us to the conclusion that, although at present and in the current configuration the Jieț dump is a stable one, at the moment when the works necessary for its reintroduction into the surrounding landscape will be carried out, it is necessary to take into account certain elements. These elements are related especially to its geometry, so that the possible remodeling works do not lead to a decrease of the stability reserve below the limits allowed and recommended by the specialized literature.

For the next period, an inventory of all the dumps in the Jiu Valley Mining Basin is necessary, for which vegetation works and prior studies on their technical condition are required, so as to prevent any risks related to possible negative geotechnical phenomena and make sure that the works can be carried out in complete safety conditions.

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