The risk of landslide occurrence in the waste dump belonging to the Ruget quarry and measures to combat it

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\textbf{Abstract.} The mining waste dump has emerged as a result of lignite extraction from Ruget quarry. The waste dump should have 6 steps with a total height of 90 m (as designed), but, at present, only 5 steps have been constructed (in different stages of execution) due to cessation of the activity. Since the stability analysis showed a high degree of instability for some steps there are needed specific redesigning works (slope angle reduction, terraces, levelling etc.) as well as hydrotechnical works (central and side collector drains and collector tubes at the base of the dump). At present, no properly designed works to eliminate the risk of landslide (not even consolidation) and no ecological rehabilitation projects are in progress. Thus, in this paper there are proposed and designed stabilization works (by reshaping, construction of rock support walls at the base of the dump etc.), as well as recultivation with specific plants, which aim at eliminating the geotechnical risks in the area and the reintegration of the dump in the surrounding landscape.

1 Introduction

Waste dumps from Oltenia mining basin (Gorj county), resulting from lignite exploitation, are considered to be large engineering constructions. They store large volumes of sterile materials and are built on horizontal (the interior ones) or inclined (the exterior ones) terrains.

Instability phenomena may occur either because the designed geometry or the construction technology is not respected, or due to the action of external factors (overloads, precipitations, seismic shocks etc.) and they are responsible of generating risks for workers, mining equipments, as well as for the environmental components in the area of influence of the dump [1-2].

Over time, the instability phenomenon that had occurred in the body of the waste dumps damaged communication ways, blocked watercourses, destroyed private properties and decommissioned the technological lines in the influence area. In these landslides there were involved millions of m\textsuperscript{3} of material and remediation costs amounted to tens of millions of Euros.

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The most important landslides produced in the Oltenia mining basin in recent years are:
the exterior dump of Roşia de Jiu quarry (in 1995, the southern and northern areas);
Ştiucani Valley exterior dump, Jilţ Sud quarry (in 1992 and 2001, eastern area); Mănăstirii
Valley external dump, Lupoaia quarry (in 2000, the southern and northern areas) - blocking
of the Motru River; Rogoazelor Valley external dump, Roşiuţa quarry (between 2001 and
2008, western area); Negomir Valley external dump, Pinoasa quarry (in 2001, southeastern
area); Bujorăscu Mic Valley external dump, Roşiţa quarry, (in 2007, the entire dump).

One of the most used methods in stability analysis for waste dumps is the method of
Fellenius, known in literature as the vertical strips method, which is based on the limit
equilibrium theory. This method has several variants (Bishop, Janbu, Morgenstern),
proposed by different authors, the difference consisting on how the friction and lateral
forces acting on each strip are considered. Most of the specialized software, such as the one
used in this paper, are based on the vertical strip method and its variants [3-5].

In this paper references are made to an external mining waste dump, located on an
inclined terrain (Roşioara Valley), which belongs to former Ruget lignite quarry. The waste
dump is inactive, and on the occasion of field visits aimed at verifying the current technical
condition it was found that in the absence of the works necessary for the ecological
reconstruction, a series of negative geomining phenomena (precursors of landslides and
even superficial landslides) appeared. For this reason, it was considered appropriate to carry
out a set of stability analysis and to identify the simplest solutions for eliminating these
phenomena and to allow for the proper ecological reconstruction of the dump.

2 Location of the waste dump

The perimeter of the Roşioara Valley waste dump (external dump of Ruget quarry) is
located in the north-eastern part of Gorj County, about 40 km east of Tg. Jiu and 20 km
northeast of the town of Tg. Cărbunişti.

It includes the hilly area between Ruget, Roşia de Amaradia and Seciurei villages,
belonging to Roşia de Amaradia commune. Thus, the name of the mining perimeter comes
from the name of Ruget village, being the closest inhabited place (Figure 1).

Fig. 1. Location of Roşioara Valley waste dump.
Roșioara Valley waste dump is constructed on an inclined terrain and occupies a total area of 240.40 ha [6]. Both the quarry and the waste dump are bordered as follows (Figure 1):

- To the north and northeast by Roșia de Amaradia village;
- To the west by Seciuri village and Poiana Seciuri mining perimeter;
- To the south and southeast by Ruget village.

3 The construction of Roșioara Valley waste dump

3.1 Initially designed geometry

For the Roșioara Valley external waste dump, which is the object of this paper, 6 depositing levels were initially designed with a height of 15 m (Figure 2) but only 5 of them were executed. Step no. 6 was not formed as a result of cessation of lignite extraction in Ruget quarry.

- Step 1, between 380 – 395 m;
- Step 2, between 395 – 410 m;
- Step 3, between 410 – 425 m;
- Step 4, between 425 – 440 m;
- Step 5, between 440 – 455 m;
- Step 6, between 455 – 470 m.

![Diagram of the waste dump](image)

**Fig. 2.** Roșioara Valley external waste dump as designed [6].

According to the execution project, the waste dump’s geometry should have the following elements:

- Step’s height of 15 m;
- Step’s slope angle 45 - 50°;
- The total height of the waste dump of 90 m;
- The definitive overall angle for the downstream area β = 18°;
- Total area 165 ha.
The exploitation method used in Ruget quarry is the one by transporting waste rocks to the internal and external waste dumps, enrolling in the group of operating methods with transport on conveyor belts. The exploitation technology is characterized by a continuous system, excavation - loading with bucketwheel excavators, the lignite and the sterile rocks being transported on conveyor belts. Deposition of the sterile rocks was made by using dumping machines [7].

3.2 Geometry of the waste dump in the current situation

At present, the Roşioara Valley waste dump has 5 steps, the construction of the dump being started at the right slope of the valley and advanced by depositing the sterile rocks towards the left slope.

The construction of the external dump (Figure 3) is made between the elevations 315 - 480 m (a total height of 165 m compared to the 90 m designed) and the overall slope angle, \( \beta \), is approx. 30° (as opposed to 18° as designed) and is twinned with the right slope, while on the left slope the waste dump is partially twinned.

![Fig. 3. Roşioara Valley waste dump in present configuration (longitudinal section) [6].](image)

Under these conditions, failure to comply with the designed geometry and on the basis of the field observations (the existence of precursor phenomena of the landslides and even superficial landslides), a stability study is necessary.

This stability study is a mandatory step, prior to starting the ecological reconstruction works of the waste dump and its reintroduction into the surrounding landscape and economic circuit.

The main purpose of this stability analysis is to identify the areas potentially affected by landslides and to identify simple constructive solutions to address these issues so as not to jeopardize the ecological reconstruction of the dump, the machinery and people's lives.
4 Stability analyses

4.1 Stability analysis methods

For the stability analysis of Roșioara Valley waste dump it was used a specialized software for geotechnical studies. This software analyses the stability of natural and artificial slopes of any geometry, both under static and seismic conditions, as well as in the presence of pore water in the deposited rocks or on the dump’s slopes. The problem of the dump’s stability is considered bidimensional and is associated with a plain strain conditions along the surface [1].

Also is accepted the hypothesis that the braking is instantaneous along the sliding surface (for most of the waste dumps from Oltenia the surface is circular). Regarding the mode of transmission of the slip were analyzed both types: progressive sliding, when failure occurs in the middle of the slope, due to compressive stress; regressive sliding, when failure occurs at the base of the dump and its transmitted to the top [4].

The program automatically calculates the stability coefficients, using the methods of Fellenius, Janbu and Bishop, based on the limit equilibrium theory. According to this theory, the sliding prism is divided into vertical strips and the stability of the slope is analyzed in the hypotheses of a limit equilibrium between active a passive forces (Figure 4).

\[
F_s = \frac{\sum_{i=1}^{n} c_i \cdot l_i + \sum_{i=1}^{n} W_i \cdot \cos \alpha_i \cdot \tan \varphi_i}{\sum_{i=1}^{n} W_i \cdot \sin \alpha_i} \quad (1)
\]

![Fig. 4. Forces acting on a strip.](image)

Finally, the critical sliding surface is determined, which corresponds to the minimal stability coefficient.

The method of Fellenius [4, 5, 8] considers a circular sliding surface, and the sliding prism is divided in vertical strips. Numerical solution of the stability coefficient is given, assuming that the forces which occur at the boundary between tow strips (Ei and Xi) are null, by the expression:

\[
F_s = \frac{\sum_{i=1}^{n} c_i \cdot l_i + \sum_{i=1}^{n} W_i \cdot \cos \alpha_i \cdot \tan \varphi_i}{\sum_{i=1}^{n} W_i \cdot \sin \alpha_i} \quad (1)
\]
Janbu’s method [4, 5, 8] used by software is the simplified one, takes into account the shearing forces and uses a correction factor that depends on the type of rocks. The coefficient of stability is given by the relation:

\[
F_s = \frac{\sum_{i=1}^{n} c_i \cdot b_i + \left( \frac{N_i}{\cos \alpha_i - u_i \cdot b_i} \right) \tan \varphi_i}{\sum_{i=1}^{n} W_i \cdot \tan \alpha_i}
\]

(2)

Where \( N_i \) is given by:

\[
N_i = \frac{\left( W_i - c_i \cdot l_i \cdot \sin \alpha_i + u_i \cdot l_i \cdot \tan \varphi_i \cdot \sin \alpha_i \right)}{m}
\]

(3)

Where:

\[
m = \cos \alpha + \frac{\sin \alpha \cdot \tan \varphi}{F}
\]

(4)

Bishop’s method [4, 5, 8] neglects the shear forces between the strips and considers an arbitrary position for the resultants of the normal forces. This method is particularly recommended for circular slip surfaces. The stability coefficient is given by the relation:

\[
F_s = \frac{\sum_{i=1}^{n} c_i \cdot b_i + \left( \frac{N_i}{\cos \alpha_i - u_i \cdot b_i} \right) \tan \varphi_i}{m}
\]

(5)

Where \( m \) is determined by:

\[
m = \left(1 + \frac{\tan \varphi \cdot \tan \alpha_i}{F} \right) \cos \alpha_i
\]

(6)

For Janbu and Bishop methods the equations are solved by successive approximations, starting from an initial value for \( F \) and iterations until the calculated value coincides with the initial one. Signification of notations in formulas:

- \( W_i \) – strip’s weight;
- \( N_i \) – normal component of the force of gravity;
- \( T_i \) – tangential component of the force of gravity;
- \( E_i \) – horizontal forces transmitted to neighboring strips;
- \( X_i \) – vertical forces between neighboring strips;
- \( \alpha_i \) – inclination of the strip (to the horizontal);
- \( n \) – number of considered strips;
- \( b_i \) – strip width;
- \( c_i \) – rock’s cohesion along the strip;
- \( \varphi_i \) – angle of internal friction along the strip;
- \( u_i \) – neutral pressure along the strip;
- \( l_i \) – length of the strip.
Although Fellenius method neglects the forces that occur between the strips, is the simplest method of determining the coefficient of stability. This method leads to reduced values for the stability coefficient and is not recommended for slopes with small inclination and high water pressure [1, 3].

Bishop’s method is applicable only for circular sliding surfaces and satisfies the overall conditions for vertical equilibrium of force moments.

Janbu’s method is based on the balance of forces, is more flexible, and leads to lower values for the stability coefficient than those calculated with Bishop’s method [4, 8].

4.2 Assessing the stability of Roșioara Valley waste dump

In order to determine the geotechnical characteristics of the rocks necessary for the stability analysis and in order to estimate the behavior of the deposited rocks and of those from the base terrain, during the field trips, samples were collected, which were analyzed and tested in the Laboratories of Geomechanics, Earth Mechanics and Rocks Mechanics of the University of Petrosani, according to the standards [9].

The first step in using the software is to model the geometric elements (Figure 5) and to assign the values of the geotechnical characteristics of the material, after which the sliding surfaces are defined. The program calculates the stability coefficients automatically, using the Fellenius, Janbu and Bishop methods for this purpose. Finally, it determines the critical slip surface, which corresponds to the minimum coefficient of stability [1, 3].

![Fig. 5. Longitudinal section (software model).](https://example.com/fig5.png)

Laboratory analysis performed on rock samples collected from the study area revealed the values presented in Table 1.

Following the steps described above, the stability coefficients characteristic of each step of the dump and the general slope were determined, both under natural moisture and saturation of rocks. The results of these analyses are shown in Table 2.
Table 1. Physical and mechanical characteristics of the rocks [9].

| Rock type  | Volumetric weight $\gamma$ [kN/m$^3$] | Cohesion $c$ [kPa] | Angle of internal friction $\phi$ [$^\circ$] |
|------------|-------------------------------------|-------------------|-------------------------------------|
|            | Natural moisture | Saturated | Natural moisture | Saturated | Natural moisture | Saturated |
| Sterile rocks | 20.1 | 23.2 | 29.2 | 26.1 | 17 | 12 |
| Base terrain | 19.0 | 22.1 | 30.1 | 25.9 | 16 | 14 |

Table 2. Results of the stability analyses.

| Waste dump step | Height $h$ [m] | Slope angle $\alpha$ [$^\circ$] | Natural moisture [%] | Saturation [%] |
|-----------------|---------------|-------------------------------|----------------------|----------------|
|                 |               |                               | $S=56\%$            | $S=100\%$       |
|                 |               |                               | Fellenius | Bishop | Janbu | Fellenius | Bishop | Janbu |
| St. 1           | 50            | 32                            | 1.210 | 1.290 | 1.201 | 1.029 | 1.182 | 1.050 |
| St. 2           | 20            | 53                            | 1.532 | 1.601 | 1.522 | 1.399 | 1.421 | 1.397 |
| St. 3           | 15            | 52                            | 2.212 | 2.534 | 2.210 | 1.978 | 2.103 | 1.958 |
| St. 4           | 38.73         | 60                            | 1.193 | 1.209 | 1.188 | 1.010 | 1.031 | 1.008 |
| St. 5           | 13.34         | 43                            | 4.003 | 4.931 | 4.002 | 3.764 | 4.407 | 3.704 |
| General slope   | 165           | 30                            | 3.542 | 3.641 | 3.541 | 3.266 | 3.280 | 3.265 |

Figures 6 - 10 show the critical sliding surfaces and the minimum stability coefficient (values determined for the individual steps of the waste dump).

Fig. 6. Step no. 1.
As can be seen from the stability analysis, the risk of landslides is manifested especially for step I, where the value of the stability factor obtained is slightly above the equilibrium boundary under saturation conditions of the waste material (1.029), and there is the possibility that in the future the action of various factors (overloads, seismic shocks, etc.) may drive the slope unstable.

For step IV, the stability analysis revealed a very low stability factor (1.008), also in saturation conditions, which describes a stability of the slope at the limit. In order to increase the stability reserve, it is recommended to establish and apply the necessary measures such as reshaping the steps, terraces, leveling, revegetation etc.

The rest of the dump’s steps as well as the entire waste dump provides satisfactory stability reserves (over 1.3 recommended by the literature [4-5, 8]), both at natural moisture and in saturation conditions.

In order to eliminate the risk of landslides affecting the Roșioara waste dump, belonging to Ruget quarry, some technical and technological measures aiming at reducing or cancelling the influences of the factors affecting the stability of the slopes are required.

5 Reconfiguration and ecological reconstruction of the waste dump

5.1 For the purpose of increasing the stability reserve

On the basis of the results obtained from the stability analysis, it is proposed to reshape the dump’s step no. IV, by reducing the slope angle to 45°, and the construction of a rockfill support wall, located at the base of the dump (at the base of the dump’s step I), with a height of 10 m, along the entire length of the dumping front.

Reshaping will be done to reduce the slope angle from 60° to 45° by pushing the material across the entire length and width of the step no. IV. The material will be deposited on step no. III berth to reduce its inclination (Figure 11). For the case of Roșioara Valley waste dump, it is recommended to perform a top-down pushing operation.

Considering the average length of the step of 400 m and the longitudinal sectional area required to reduce the slope angle of 378.44 m², the total a volume of material that needs to be moved is of 151,376.993 m³.
The rockfill support wall will be made at the base of the step no. I, over the entire length of the depositing front (Figure 11).

![Rockfill support wall](image)

**Fig. 11.** Reshaping works and the rockfill support wall.

The rockfill support wall will have a height of 10 m and is intended to consolidate the slope and the entire dump’s slopes system.

### 5.2 Preparing the land for ecological reconstruction

Leveling works should create the conditions required to perform regeneration of the soil’s fertility and plant cultivation or conditions for constructive purposes. Leveling works begin as soon as the dump is sufficiently stable as to work in safety conditions [10].

Land leveling is done longitudinally, sometimes even transversally, taking place in two distinct stages. In the first stage, a capital leveling is executed in the redevelopment works, where tolerances of + 10 cm from the reference plane being allowed. In the second stage, a leveling operation is carried out in order to maintain the conditions achieved by the capital one [5].

In the case of forestry recultivation, the most suitable variant for the exterior waste dump of the Ruget quarry, it is sufficient to achieve a capital leveling.

Land leveling is done with bulldozers of different types (S 1300, S 1500, DET 250, DM 550 etc.).

In addition to leveling works, it is necessary to construct collector drains to capture and direct rainwater:

- Side collector drains in the twinning zone with the natural slopes on the right and left side of the waste dump;
- Drainage system at the base of the waste dump (downstream of the rockfill support wall).

The calculation of leveling volumes can be done by several methods, including the network method, contour method, cross section method, physical models and computerized models. The formulas are used for both leveling and slanting works when volumes can be approximated with simple geometric shapes and can be calculated using mathematical formulas [10-11].

All methods of calculating volumes require consideration of the degree of compaction of material, existing and required, using information on the most likely factors affecting the increase or decrease of the volume.
5.3 Ecological reconstruction of the waste dump

To reintroduce the heap into the landscape and the economic circuit, it is recommended to ecologically reconstruct the waste dump as follows: on 60% reforestation and on 40% (the upper platform) agricultural recultivation. For this, after leveling it is necessary to deposit a layer of fertile soil, execution of deep scarification works, application of natural/chemical fertilizers, etc.

The main criteria for the selection of plant species requires consideration regarding the subsequent use, the climate of the area and the role of the plants (primary colonies used for soil formation and/or of economic value) [11].

In order to select suitable species for a particular type of land, the specialists involved in the ecological reconstruction must take into account the local factors and those specific to the land.

For the exterior waste dump of Ruget quarry, it is recommended to choose the species characteristic for the area: beech, oak, garnet, acacia, taking into account the possibilities of their capitalization.

6 Conclusions

Roșioara Valley waste dump appeared as a result of extraction of lignite from the Ruget pit. The current geometry of the waste dump is much different from the designed one (it is 75 m higher; it is constructed in 5 steps instead of 6; their geometry is varied, with slope angles up to 60° and heights up to 50 m; the general slope angle is of 30° instead of 18°) and in these conditions there were noticed superficial landslides and the presence of phenomena precursor to the landslides (tension cracks on platforms, erosions on the slopes, detachment niches).

The stability analysis showed that some steps (I and IV) don’t have a satisfactory stability reserve in the conditions when the waste material was saturated, resulting in the need for specific work to be performed on the dump. The reshaping work refers to step IV and aims to reduce the slope angle from 60° to 45° while for the stabilization of step I and the entire waste dump it is proposed to construct a rockfill support wall with a height of 10 meters over the whole length of the dumping front.

Also in order to ensure the stability reserve required by legislation and also to ensure the conditions necessary for the ecological reconstruction of the waste dump, it is recommended to construct lateral drainage that collects and directs the precipitation waters from the twining area with the natural slopes, to a main drain located downstream the rockfill wall that supports the waste dump (at the base of the first step).

As a result, in this paper are proposed and briefly presented works for the stabilization of the waste dump, and general recommendations are made regarding recultivation and revegetation with plants specific to this type of land. The necessity of these works derives from the fact that at present the ecological reconstruction works of Roșioara Valley waste dump are not properly designed, there are no works to consolidate the land and remove the existing negative geomining phenomena and there is no concrete plan for the reintegration of the waste dump in the surrounding landscape.

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