REVISTA MINELOR

MINING REVUE

A JOURNAL OF MINING AND ENVIRONMENT

selected papers from the 11th edition of
the International Multidisciplinary Symposium
UNIVERSITARIA SIMPRO / 2024
ISSN-L 1220-2053 / ISSN 2247-8590

UNIVERSITAS PUBLISHING
Petroșani, Romania

CONTENTS

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 1-9

INVESTIGATION OF THE ROCK DESTRUCTION INFLUENCE IN THE INCREASED ROCK PRESSURE ZONES ON THE STABILITY OF PREPARATORY MINE WORKINGS

Valentyn NAZARENKO[1], Hanna BRUI[2], Oleksandr KUCHIN[3]*

[1]Technical University "Metinvest Polytechnic" LLC, Faculty of Mining and Metallurgy, Department of Mining, 69008, Zaporizhzhia, Ukraine
[2]Technical University "Metinvest Polytechnic" LLC, Faculty of Mining and Metallurgy, Department of Mining, 69008, Zaporizhzhia, Ukraine
[3]Dnipro University of Technology, Faculty of Architecture, Construction and Land Management, Department of Geodesy, 49005, Dnipro, Ukraine

DOI: 10.2478/minrv-2024-0034

Abstract: *The issue of determining the size of pillars of various types and purposes is very important, as it is closely related to the issues of completeness of excavation of mineral reserves, as well as ensuring the stability of protected workings.*
The purpose of this work is to study the behavior of the massif in the zones of increased mining pressure, to evaluate its stress-strain state for justification of the optimal parameters of pillars, which is a very urgent scientific task in the conditions of the converged formations of the Western Donbass.
To analyze the stress-strain state of the rock massif area in the area of preparatory excavations, falling into the zones of increased mining pressure, the volumetric problem was solved using the finite element method. The problem was solved using Cosmos Works software. In order to determine the size of the pillar satisfying the requirements of completeness of excavation and safety of preparatory workings, this parameter was varied from 25m to 40m with an interval of 2m.
The work contains the results of monitoring the condition of mine workings as the longwall is approaching up to its stoppage. On the basis of modeling of the stress-strain state of the massif with linkage of the actual state of the drifts according to the monitoring results, the optimum parameters of the pillar are determined, which in the considered conditions are 37 meters.
Keywords: *mine workings, pillar, zone of increased rock pressure, stress-strain state, surveyor's measurement*

1. Introduction

The main production processes at the mine to prepare reserves for excavation and coal mining, its transportation and processing are inextricably linked in a single technological chain. One of the main links in this connection is preparatory workings. The experience of mines shows that unsatisfactory condition of preparatory workings is a problem restraining the development of production. Against the background of constant increase in the depth of development of coal seams and intensity of their mining, the mining pressure and vertical stresses of the massif significantly increase, which leads to a sharp deterioration of the conditions for conducting and maintaining preparatory workings [1]. Numerous existing ways and means of ensuring their stability are insufficient in many cases. The methods of arch support [2, 3], steel and rope anchors [4, 5, 6], frame anchoring [7, 8], torqueting [9, 10] or use of hydraulic systems [11] are considered. The issues of maintaining excavations when they fall into the zone of increased mining pressure from mining works on adjacent seams and the additional influence of dynamic support pressure from the moving longwall face have been little studied.

[*] Corresponding author: Hanna Brui, Technical University "Metinvest Polytechnic" LLC, Zaporizhzhia, Ukraine, Contact details: Technical University "Metinvest Polytechnic" LLC, Faculty of Mining and Metallurgy, Department of Mining, 69008, Zaporizhzhia, Ukraine, Tel.: +38050-90-388-76 hanna.brui@mipolytech.education

2. Research object characteristics

To elaborate this issue, we considered the real situation that has developed during the mining of c_{10} seam reserves of PSD Heroes of Kosmos Mine of PJSC DTEK Pavlohradvuhillya (Ukraine).

The longwall face № 1061-bis is prepared for excavation of coal reserves in the eastern wing of the mine field along the strike. The panel length is 920m, the longwall face length is 250m, the average depth of mining is 410m, the dip angle of the seam is 3º. The coal seam c_{10} of G grade is predominantly of simple structure, the geological thickness averages 1,02 meters. The coal seam is hazardous in terms of gas and dust, it is not prone to spontaneous combustion.

Mining and geological conditions of mining are complicated by the presence of inelastic deformation zones formed by 1061-bis ventilation drift, 1061-bis conveyor drift and conveyor chamber. The rocks of the main and immediate roof are fractured, very unstable and prone to sudden caving. The soil of the coal seam is very unstable argillite, prone to intensive heaving and soaking in water in 2-2,5 hours.

The expected water inflow into the excavation from the coal seam is expected to be up to 1,5 m^3/hour, dripping from the roof of the excavation is possible up to 1.5 m^3/hour. When the rocks are soaked, the soil is prone to intensive heaving with loss of bearing capacity.

During mining of the coal seam c_{10} of PSD Heroes of Kosmos Mine, a problematic situation arose in connection with the protection of 1061-bis conveyor and 1061-bis ventilation drifts ahead of the moving 1061-bis longwall face (Figure 1). These preparatory workings were passed after the longwall face № 1061 was mined. The panel length of longwall № 1061 was 790m, the longwall face length was 175m.

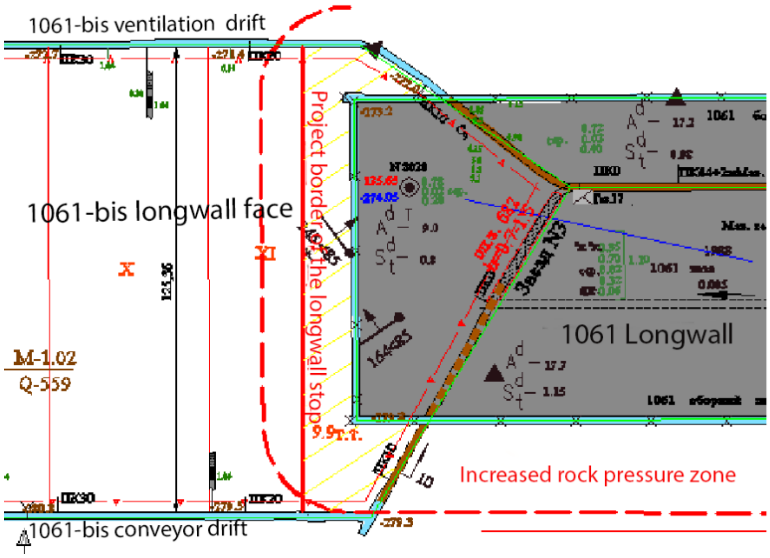


Fig. 1. Excavation from the plan of mine workings on the seam c_{10}

The pillar at the time of longwall 1061-bis longwall stoping was 25 m long. At the time of stopping the face, the preparatory workings were deformed (mostly on the face side) and lost about 60% of their cross-section. Taking into account the actual unsatisfactory condition of the workings, the purpose of this work is to determine the optimal size of the protective pillar, taking into account the maximum possible recovery of coal reserves with minimum deformations of the 1061-bis ventilation and 1061-bis conveyor drifts.

When solving the problem of determining the optimal size of the pillar during mining of the 1061-bis longwall face, the finite element-based computer mathematical modeling method was used. The results of modeling were analyzed together with the data of experimental observations of rock pressure manifestation in the preparatory workings of this longwall face.

The research results can be used in planning mining works with similar mining and geological situation within this seam.

3. Materials and methods

3.1. Analytical research of rational parameters of the pillar during mining of 1061 longwall

The analysis of the normative base [12, 13, 14] and literature sources allowed us to establish that the load on the pillar, other things being equal, depends on the shape and area of mining, the mining system and its elements, the method of rock pressure control [15, 16]. The evolution of the abutment stress, the stress under the mining coal seam and the relief angle were studied [17]. A number of authors study the deformations of the rock mass above the mine by measuring the lowering of the earth's surface [18, 19]. The obtained regularities are used to predict deformations of protected objects on the ground surface and in the subsurface [20]. Thus, the load on the pillar depends on a number of factors, without taking into account which the correct determination of this value is impossible.

The first step in determining the size of the pillar is to study the manifestation of increased rock pressure (IRP) in these conditions, as the main factor determining the load on the pillar part of the massif. Determination of geometrical parameters of the IRP zone from the influence of the 1061st longwall face cleaning works was performed in accordance with the normative document [14]. The boundaries of the IRP zones built on the sections are plotted on the mining works development plan in red color (Figure 1).

When the longwall face approached the zone of increased mining pressure, in order to increase the completeness of excavation of reserves, a decision was made to continue coal mining. At the transition to the zone of high-pressure mining, the rate of advance decreased, which led to the longwall face stoppage due to rock destruction and rock destruction in the sections PK10-PK20 along 1061-bis side drift and in the area of PK10 along 1061-bis conveyor drift.

In this regard, it became an urgent task for this enterprise to optimize and scientifically justify the size of the pillar for the maximum possible full excavation of coal reserves and at the same time to ensure the safety of workings.

3.2. Modeling of the stress-strain state of the massif in the area of the longwall № 1061

One of the methods of research of complex-structured objects in geomechanics is graphical and mathematical modeling of the processes of redistribution of the rock stress-strain state due to anthropogenic influence. The simulated model reproduces in three-dimensional image the process of deformation of the rock massif as artificial cavities are created in it. The most convenient method for studying the manifestations of rock pressure is the modeling method [21, 22]. One of the advantages of the modeling method is the possibility of determining the indicators reflecting the stress-strain state of the massif in the areas of interest, which are practically impossible to carry out in full-scale conditions due to the inaccessibility of the massif areas.

The purpose of the calculations is to evaluate the influence of the 1061-bis longwall face, as well as the zone of previously destroyed rocks from the 1061-bis longwall face on the condition of the 1061-bis ventilation and 1061-bis conveyor drifts, since these preparatory workings serve for ventilation, delivery of materials to the longwall face and transportation of mined coal.

To analyze the stress-strain state of the rock mass in the vicinity of the preparatory workings of the 1061-bis longwall face, a volumetric problem was modeled using the finite element method. The three-dimensional model of the problem to be solved is presented in Figure 2.

The zones of fractured and compacted rocks were modeled by specifying conditional characteristics: Young's modulus *Ep*, Poisson's coefficient *νp*, compressive strength σ_{comp}, which differ significantly from the characteristics of the undisturbed rock mass.

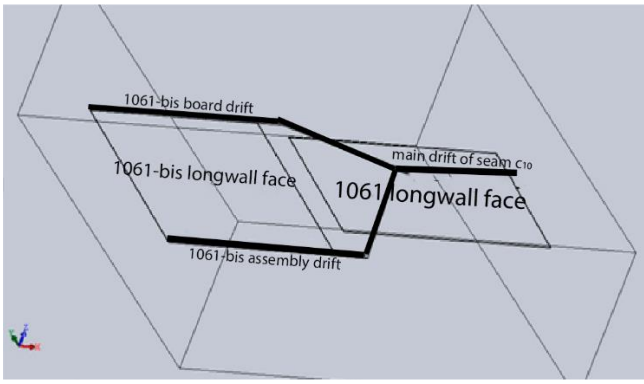


Fig. 2. Three-dimensional model of 1061-bis longwall face

The task was solved using the Cosmos Works software product. The loads to be applied to the constructed three-dimensional model were determined.

The lateral spreading coefficient is determined from the expression:

$$\lambda = \frac{\mu}{1-\mu}$$

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 1-9

In this expression μ is the Poisson's coefficient, which for elastic rocks, not prone to creep, in an intact rock mass can have values ranging from 0,25 to 0,43. For the conditions under consideration, we take it to be 0,3. Hence λ =0,43.

The specific weight (γ) of the rock column for these conditions is equal to 22 kN/m^3.

Let's determine the vertical stress on the whole part of the formation without taking into account the influence of cleaning works:

$$\sigma_y^0 = -\gamma H = 22 \cdot 410 = 9{,}0\mathrm{M}Pa$$

The lateral load on the modeled section of the massif is assumed:

$$\sigma_x^0 = \sigma_z^0 = -\lambda\gamma H = 0{,}43 \cdot 22 \cdot 410 = 3{,}87\mathrm{M}P\mathrm{a}$$

The modulus of elasticity for these conditions is 30 000 MPa.

This model was given a grid parameter of 20 m, and excavations – 1m, which allowed to set the load on all necessary sections quite accurately (Figure 3).

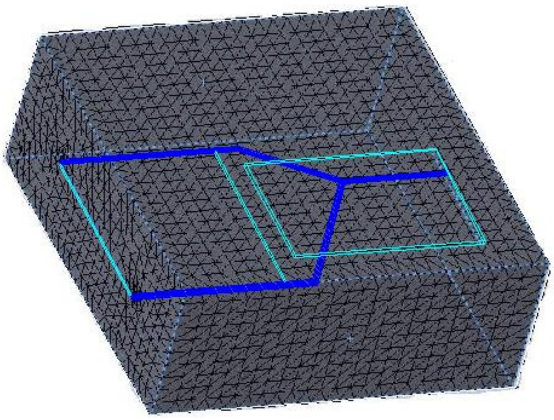


Fig. 3. Three-dimensional model of 1061-bis longwall face using the finite element method

In order to determine the size of the safety pillar that would simultaneously satisfy the requirements of completeness of excavation and safety of preparatory workings, the three-dimensional model for visual assessment of maximum stress distributions was mapped in the 1061-bis plane of the face (Figure 4). After that, the size of the safety pillar was gradually increased by the approximation method. This parameter was varied from 25m to 40m with an interval of 2m. The analysis of the simulation results revealed that the minimum stress on the mine walls to maintain their safety in these areas corresponds to 37 meters. The distribution of normal vertical stresses σu for the case of optimal, in our opinion, target size (37 m) and the actual target at face stoping (25 m) are shown in Figs. 4 and 5, respectively.

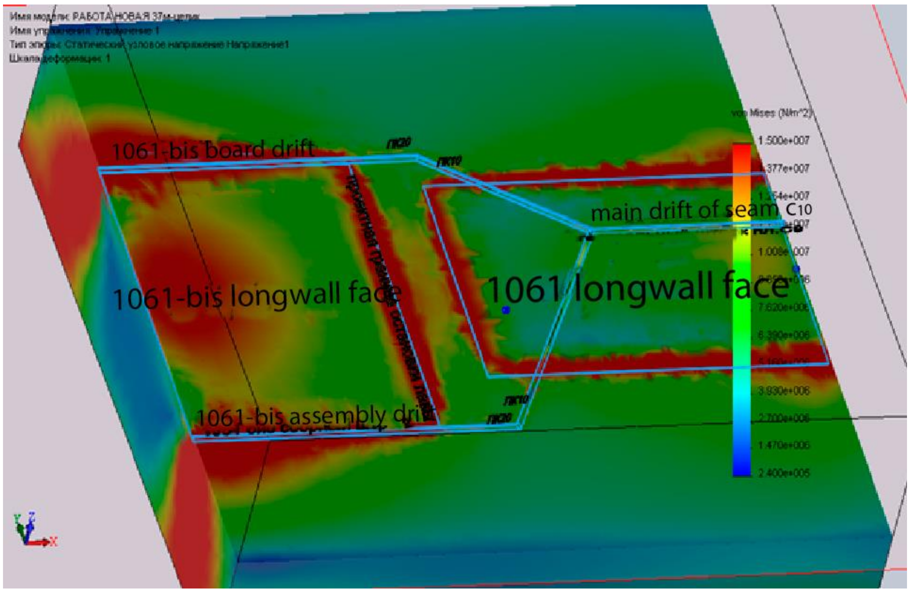


Fig. 4. Tensions in the rock massif at the target size of 37 meters

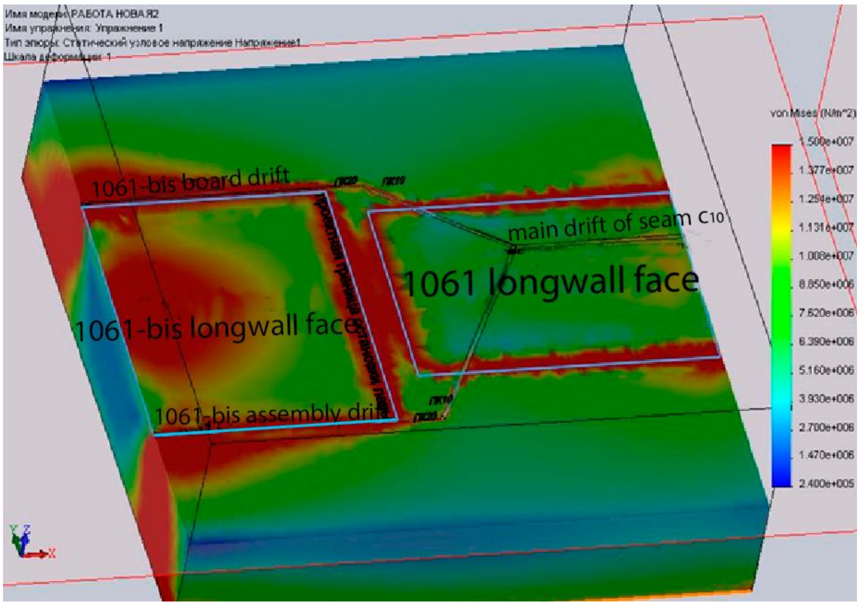


Fig. 5. Tensions in the rock massif at the target size of 25 meters

The highest concentration of vertical tensions in the preparatory workings (red color scale) takes place at the 25-meter pillar. According to the modeling data, rock destruction and, as a consequence, significant deformations of the excavation contour should be expected in the protected sections of 1061-bis ventilation and 1061-bis conveyor drifts.

Thus, based on the values of non-uniform loads on the pillar, obtained as a result of the calculation, it is established that at the pillar size of 37m, the tension along the contour of the preparatory workings will be comparable to the tensions from the influence of the 1061-bis longwall face only. On the contrary, when the size of the pillar is 25 m, corresponding to the size of the actually left pillar, the tensions are 4 times higher than the similar ones in the absence of the influence of the 1061-bis longwall face. The established tension values are critical for the section of 1061-bis ventilation and 1061-bis conveyor drifts, located in the zone of IRP, which led to deformations of the preparatory workings and the need to reinforce them.

4. Results of 1061-bis conveyor and 1061-bis ventilation drifts monitoring

The results of modeling are confirmed by the data of the fastening condition monitoring. At sections PK10-PK20 along the 1061-bis ventilation drift and in the area of PK10 along the 1061-bis conveyor drift, the total vertical convergence was about 0.96m, with intense rock heave. Monitoring of the mine workings condition included visual observations of the fastening behavior, as well as periodic measurements of contour observation stations installed in the 1061-bis ventilation drift (PK10 and PK15) and in the 1061-bis conveyor drift (PK10). A contour station is a wooden stake driven into the rock in the roof and in the sides of the mine workings (Figure 6).

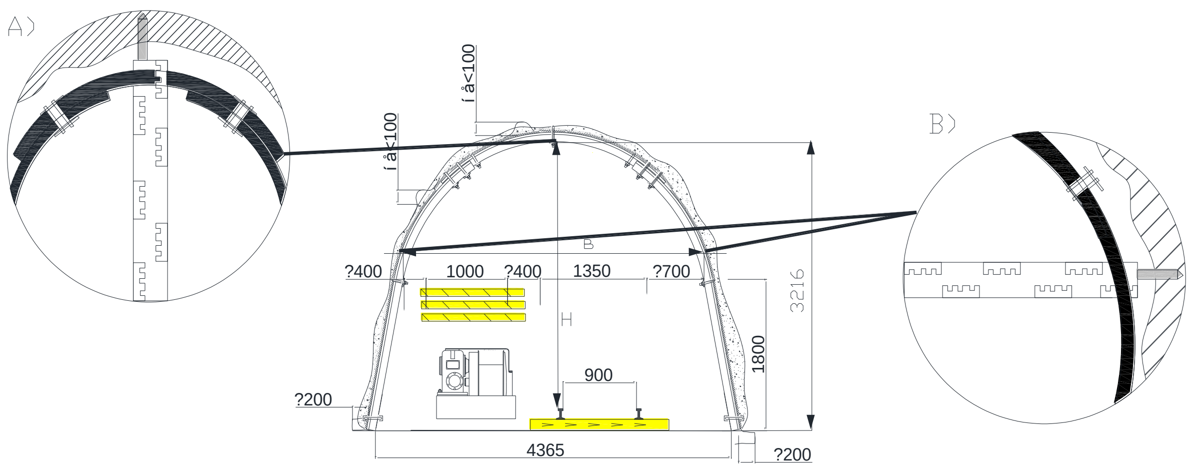


Fig. 6. Fastening of preparatory workings of 1061-bis longwall face and the scheme of measurements; A – measurement of vertical convergence; B – measurement of horizontal convergence

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 1-9

During the measurements of the workings cross-section the total vertical convergence (H) and horizontal convergence of the face (B) were determined depending on the longwall face position.

Systematized and summarized results of observations at contour stations for vertical and horizontal convergence are provided in Figure 7.

The analysis of the obtained convergence results allowed to establish the following. When the longwall face is approaching at a distance of 20 m up to the project border of the longwall stop, the support is not significantly deformed and the convergence does not exceed the background one for these mining and geological conditions. As the longwall face advances, the preparatory workings are significantly deformed due to the increase in horizontal stresses of the massif. This leads to deformation of one of the faces on the face side. Visualization of this process is presented in Figure 8.

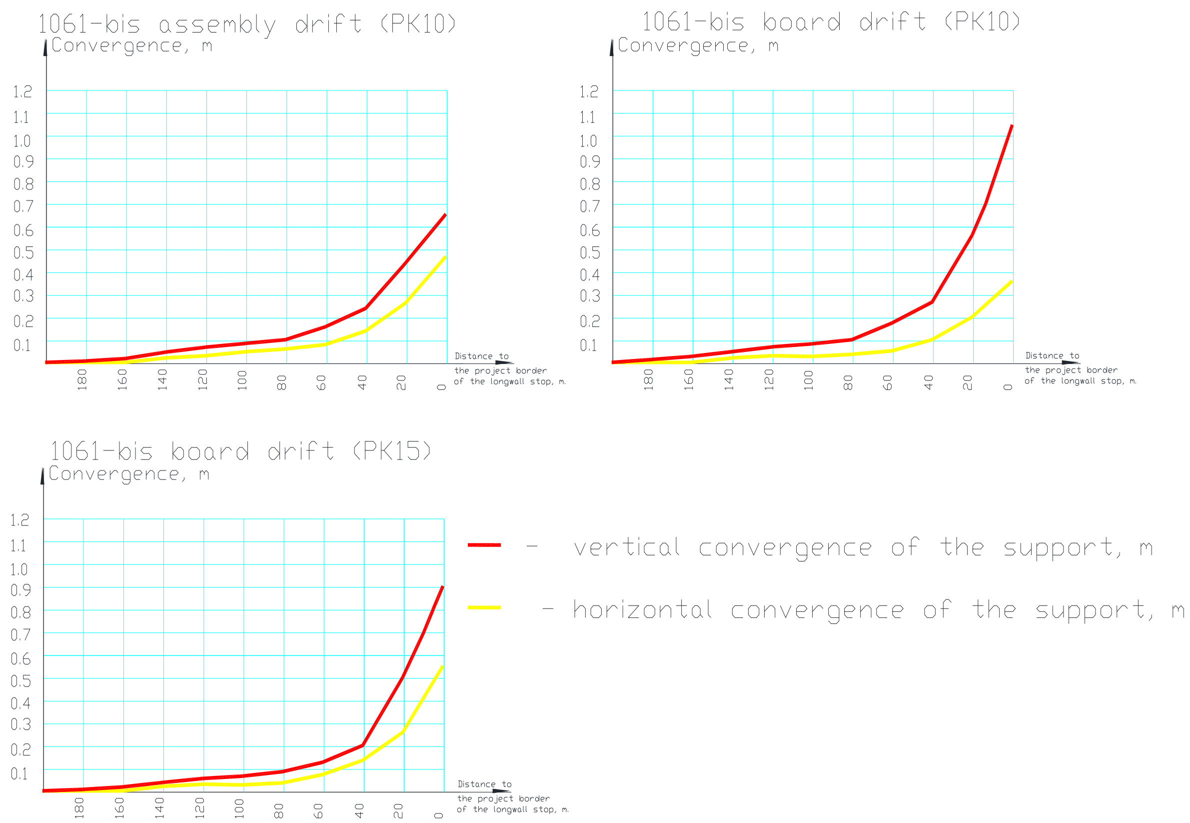


Fig. 7. Graphs of vertical and horizontal support deformations as a function of the distance to the longwall face

Fig. 8. 1061-bis ventilation drift PK10-PK20

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 1-9

Figure 9 shows the results of observations of vertical convergence after longwall shutdown depending on the time of longwall shutdown. The analysis of the results showed that in the first 10-18 days, the pressure on the support of the preparatory workings and, consequently, its deformation is maximum, and starting from the 25-30th day, a noticeable attenuation is observed. At the same time, the preparatory workings lost about 60% of their original cross-section on the 30th day, therefore, on the 45th day after stopping the face 1061-bis longwall face, work was started to restore the fastenings of deformed sections of the workings. It was not possible to further monitor the condition of the face and the contour rock mass.

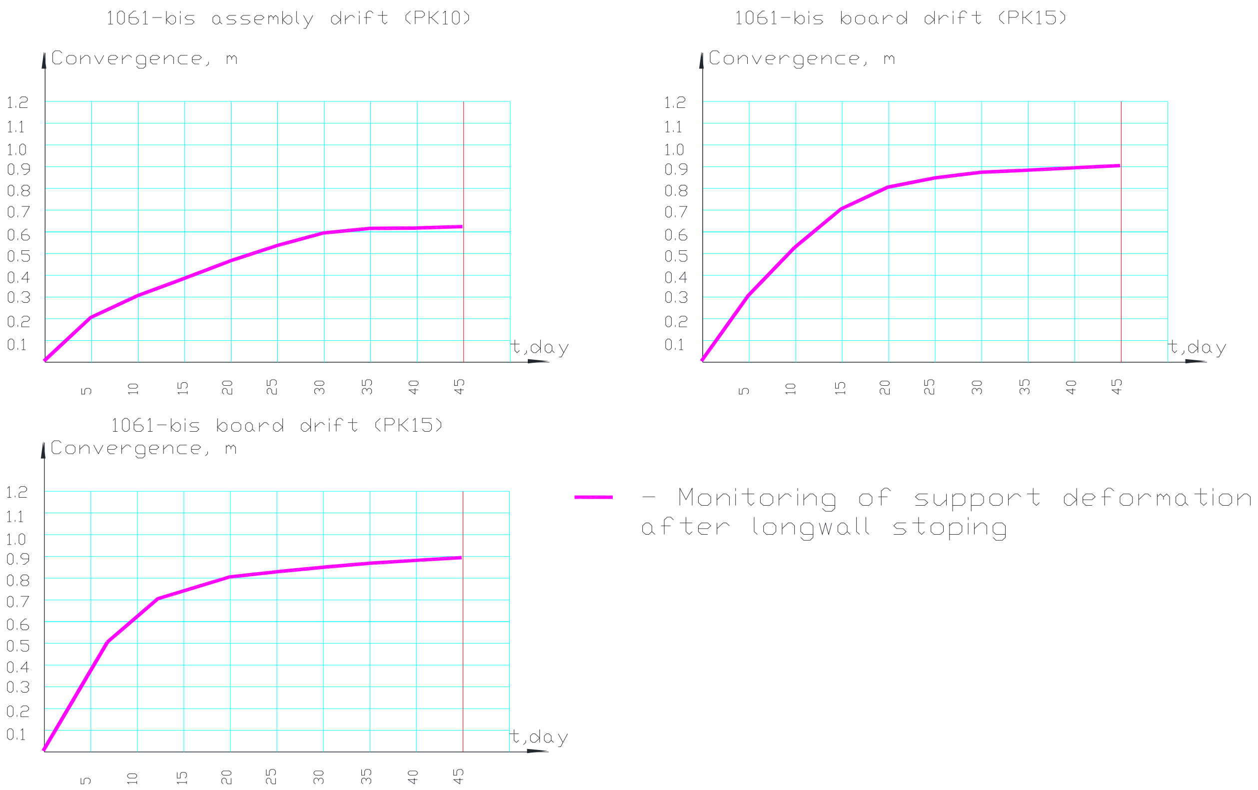


Fig. 9. Graphs of vertical and horizontal deformations of the support as a function of longwall stoping time

5. Conclusions

Analysis of the model of stress-strain state of the massif for the conditions of mining 1061 longwall face c_{10} of PSD Heroes of Kosmos Mine of PJSC DTEK Pavlohradvuhillya has shown that the highest concentration of stresses in the preparatory workings takes place at a 25-meter hedge. According to the modeling data, rock destruction and, as a consequence, significant deformations of the excavation contour and fastenings should be expected at the protected sections of 1061-bis ventilation and 1061-bis conveyor drifts. The results of modeling are confirmed by the data of the fastening condition monitoring. At sections PK10-PK20 along 1061-bis ventilation drift and in the area of PK10 along 1061-bis conveyor drift the total vertical convergence amounted to about 0,96 m, and intensive rock heave was observed.

Thus, based on the values of vertical load on the pillar, obtained as a result of modeling, it was established that at the pillar size of 37m, the stresses along the contour of preparatory workings will be comparable to the tensions from the influence of the 1061-bis longwall face only. On the contrary, when the size of the pillar is 25 m, corresponding to the size of the actually left pillar, the tensions are 4 times higher than in the absence of the influence of the 1061-bis longwall face. These tensions are critical for the section of 1061-bis side and 1061-bis prefabricated drifts located in the increased rock pressure zone, which led to deformations of the preparatory workings and the need to rebuild the fastenings.

Based on the modeling of the stress-strain state of the massif with the linkage of the actual state of the drifts according to the monitoring results, the optimum parameters of the pillar were determined, which in the conditions under consideration are 37 meters.

References

[1] **Cheng G., Li L., Zhu W., Yang T., Tang C., Zheng Y., Wang Y.**, 2019
Microseismic investigation of mining-induced brittle fault activation in a Chinese coal mine, Int. J. Rock Mech. Min. Sci, 2019, No. 123, 104096, https://doi.org/10.1016/j.ijrmms.2019.104096.

[2] **Li Q., Li J., Zhang J., Wang C., Fang K., Liu L., Wang W.**, 2019
Numerical Simulation Analysis of New Steel Sets Used for Roadway Support in Coal Mines, Metals, 2019, No. 9, 606, https://doi.org/10.3390/met9050606

[3] **Rułka K., Mateja J., Kowalski E., Skrzyński K., Stałęga S., Wojtusiak A., Schinohl J.**, 2021
Simplified Rules for the Selection of Frame Support for Roadway Workings in Hard Coal Mining Plants, Central Mining Institute Publishing House: Katowice, Poland, pp. 1–30. (In Polish)

[4] **Xie Z., Zhang N., Wei Q., Wang J., Sharifzadeh M.**, 2021
Study on Mechanical Properties and Application of a New Flexible Bolt, Appl. Sci., 2021, No. 11, 924, https://doi.org/10.3390/app11030924

[5] **Wang P., Zhang N., Kan J., Wang B., Xu X.**, 2021
Stabilization of Rock Roadway under Obliquely Straddle Working Face, Energies, 2021, No. 14, 5759, https://doi.org/10.3390/en14185759

[6] **Wang J., Apel D.B., Xu H., Wei C., Skrzypkowski K.**, 2022
Evaluation of the Effects of Yielding Rockbolts on Controlling Self-Initiated Strainbursts: A Numerical Study, Energies, 2022, No. 15, 2574, https://doi.org/10.3390/en15072574

[7] **Šňupárek R., Konečný P.**, 2021
Stability of roadways in coalmines alias rock mechanics in practice, J. Rock Mech. Geotech. Eng, 2021, No. 2, pp. 281–288, https://doi.org/10.3724/SP.J.1235.2010.00281

[8] **Shan R., Li Z., Wang C., Wei Y., Bai Y., Zhao Y., Tong X.**, 2021
Research on the mechanism of asymmetric deformation and stability control of near-fault roadway under the influence of mining, Eng. Fail. Anal., 2021, No.127, 105492, https://doi.org/10.1016/j.engfailanal.2021.105492

[9] **Mei Y., Li W., Yang N., Wang G., Li T., Sun T.**, 2020
Failure Mechanism and Optimization of Arch-Bolt Composite Support for Underground Mining Tunnel, Adv. Civ. Eng, 2020, No.2020, 5809385, https://doi.org/10.1155/2020/5809385

[10] **Kang H., Jiang P., Wu Y., Gao F.**, 2021
A combined "ground support-rock modification-destressing" strategy for 1000-m deep roadways in extreme squeezing ground condition, Int. J. Rock Mech. Min. Sci., 2021, No. 142, 104746, https://doi.org/10.1016/j.ijrmms.2021.104746

[11] **Liu H., Jiang Z., Chen W., Chen F., Ma F., Li D., Liu Z., Gao H.**, 2022
A Simulation Experimental Study on the Advance Support Mechanism of a Roadway Used with the Longwall Coal Mining Method, Energies, 2022, No.15, 1366, https://doi.org/10.3390/en15041366

[12] **Ministry of Energy and Coal Industry of Ukraine**, 2001
Location, security and support of mine workings in the processing of coal seams in mines. Guiding normative document. Standard, Kyiv (in Ukrainian), 148 p

[13] **Ministry of Energy of Ukraine**, 2022
Guidelines for ensuring the stability of face workings for reuse in coal mines (in Ukrainian), https://ips.ligazakon.net/document/RE39001?an=20, (accessed on 10 November 2022)

[14] **Ministry of Energy and Coal Industry of Ukraine**, 1984
Instructions for controlling mining pressure in mine workings under (above) pillars and edge parts when developing coal seams up to 3.5 m thick with a dip angle of up to 35º, (in russian), 62 p

[15] **Burtan Z., Zorychta A., Cieślik J., Chlebowski D.**, 2014
Influence of mining operating conditions on fault behavior, Arch. Min. Sci., 2014, No. 59, pp. 691–704, DOI: 10.2478/amsc-2014-0048.

[16] **Skrzypkowski K., Zagórski K., Zagórska A., Derek B. Apel, Jun Wang, Huawei Xu, Lijie Guo**. 2022
Choice of the Arch Yielding Support for the Preparatory Roadway Located near the Fault. Energies, 2022, No. 15, 3774, https://doi.org/10.3390/en15103774

[17] **Wei Yang, Bai-quan Lin, Yong-an Qu, Zi-wen Li, Cheng Zhai, Li-li Jia, Wu-qiang Zhao**, 2011
Stress Evolution with Time and Space During Mining of a Coal Seam, Int. J. Rock Mech. Min. Sci., 2011, No. 48, pp. 1145-1152, https://doi.org/10.1016/j.ijrmms.2011.07.006

[18] **Kuchin O., Brui H., Yankin O.**, 2023
Modeling of Spatial Displacement of Points on the Earth's Surface Based on the Results of Geodetic Observations (in Ukrainian), Prostorovyi rozvytok: Naukovyi zbirnyk, KNUBA, 2023, No. 3, pp. 122-131, https://doi.org/10.32347/2786-7269.2023.3.122-133

[19] **Kuchin O., Brui H., Yankin O., Ishutina H.**, 2023
The relationship between lowering the Earth's surface and bearing pressure above the advancing longwall face, JGD, 2023, Vol. 1(34), pp. 28-36, https://doi.org/10.23939/jgd2023.01.028

[20] **Bazaluk, O., Kuchyn, O., Saik, P., Soltabayeva, S., Brui, H., Lozynskyi, V., Cherniaiev, O.**, 2023
Impact of ground surface subsidence caused by underground coal mining on natural gas pipeline, Scientific Reports, 2023, No. 13, 19327. https://doi.org/10.1038/s41598-023-46814-5

[21] **Yasitli N., Unver B.**, 2005
3D Numerical Modeling of Longwall Mining with Top-coal Caving, Int J Rock Mech Min Sci, 2005, Vol. 42, Issue 2, pp. 219-235, https://doi.org/10.1016/j.ijrmms.2004.08.007

[22] **Unver B., Yasitli N.**, 2006
Modelling of Strata Movement with a Special Reference to Caving Mechanism in Thick Seam Coal Mining, Int J Coal Geol., 2006, Vol. 66, Issue 4, pp. 227-252, DOI: 10.1016/j.coal.2005.05.008.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 10-16

GEOLOGICAL MODELS AND STABILITY ANALYSIS

Adrian FLOREA[1], Ciprian DANCIU[2]*

[1]University of Petrosani, Romania, adrianflorea@upet.ro
[2]University of Petrosani, Romania

DOI: 10.2478/minrv-2024-0035

Abstract: *Geological models are built to serve various purposes (e.g. reserve evaluation, rock stability analysis, etc.). Several software packages dedicated to geological modeling and rock stability analysis are currently available. The paper presents the workflow for rock stability analysis performed with Slide3 software from Rocscience. An important step is to build the 3D geological model both from the perspective of geometry and rock properties. Doing this in Slide3 is not an easy task and for this reason, we turned to GEOVIA Surpac. The steps were exemplified for the northern area of the Ruschita marble deposit.*
Keywords: *geological modeling, slope stability analysis, Slide3 Rocscience software, GEOVIA Surpac software, Ruschita marble*

1. Introduction

To perform a slope stability analysis, several software packages are currently available. One of these is Slide3 from Rocscience. Slide3 is designed to be as straightforward as possible to use, for a fully 3D numerical analysis program. The general workflow involves the following steps: 1. Project Settings (Units, Analysis Methods, etc.), 2. Geometry (Add Geometry, Set External, etc.), 3. Groundwater, 4. Define/Assign Materials, 5. Support, 6. Loads, 7. Surface type/Search Method (Slope Limits), 8. Compute and 9. Results [1].

Geometry is by far the most complicated aspect of creating a Slide3 model. Slide3 models can range from simple 2D extrusions to complex 3D geometry requiring many steps to create.

A wide array of geometry modeling tools allows the creation of any complexity of 3D slope model with any number of material regions. Since the steps required to create Slide3 model geometry will vary greatly depending on the model and its complexity, and there are multiple ways to achieve tasks, it is impossible to provide a simple checklist of required steps for geometry creation that apply to all models.

In the case of very complex 3D geometry, importing the 3D model created with other modeling software is much easier than building the 3D geometry in Slide3. In the following, it is presented how the 3D model of the northern area of the Ruschita marble quarry was built, using GEOVIA Surpac 6.9 for this purpose.

2. Location and general information on Ruschita marble deposit

The Ruschita marble is a metamorphic stone with high crystallinity and medium-size crystals (until 0.2-0.5 mm). Has the basic color from white and grey to pink, with many intermediary nuances generally given by grey veins and less by impurities from the internal structure. Ruschita marble can be found at Parliament buildings in Bucharest (Romania), Wien (Austria), Budapest (Hungary) and many other places around the world [2].

Located in Poiana Rusca mountains (Figure 1), developed in a large metamorphic area, the marble deposit from Ruschita perimeter is the most important Romanian source of ornamental stone, the old quarry has been operative since 1883.

* Corresponding author: Florea Adrian, assoc.prof. Ph.D. eng., University of Petrosani, Mining Faculty, Department of Environmental Engineering and Geology, Petrosani, Romania, Contact details: University of Petrosani, 20 University Street, adrianflorea@upet.ro

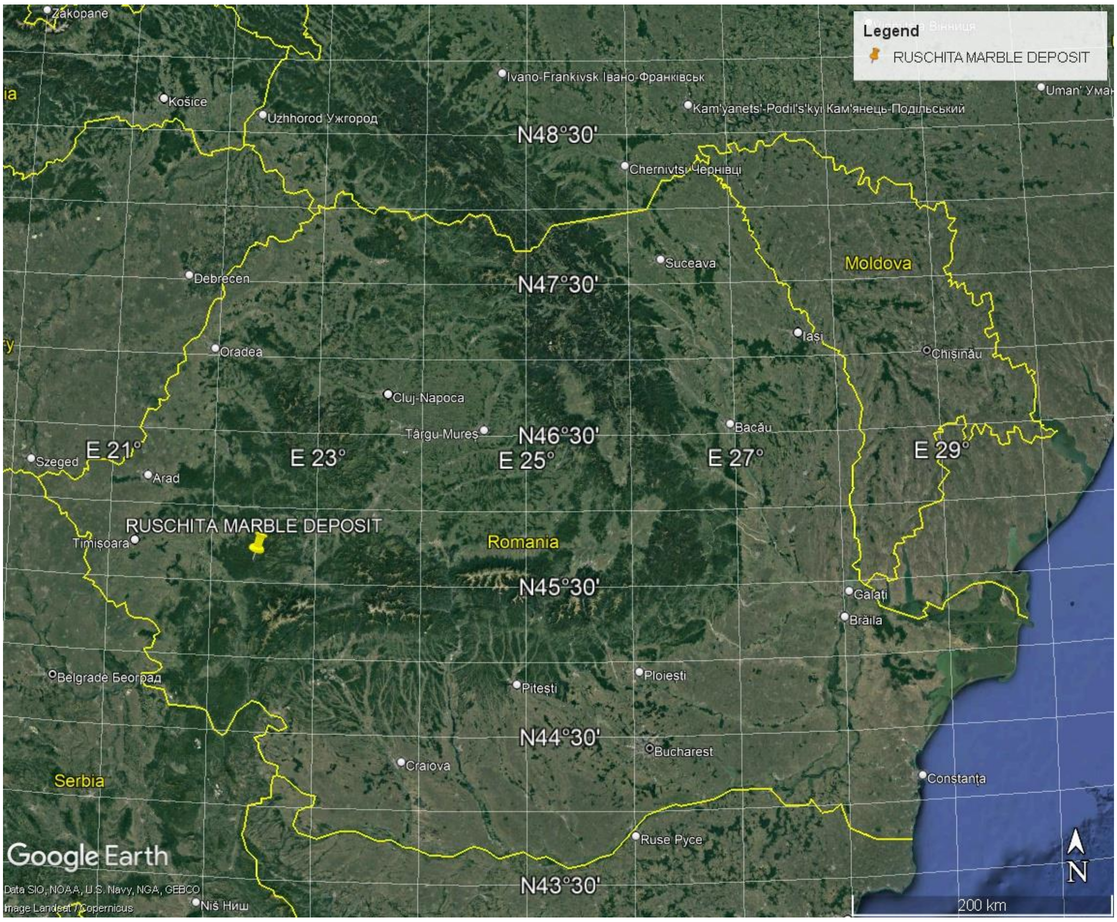


Fig. 1. Location of the Rușchița marble deposit

The northern area of the old Ruschita quarry has a complex 3D geometry, involving areas with marble, schist, mixed materials and heaped marble rocks of irregular shape and variable sizes (from cm to tens of cm). The general slope of the old Ruschita quarry extends from elevation 630 to elevation 748 (Figure 2).


Fig. 2. Overview of the Rușchița quarry before the start of the inner dumping on the floor of the old quarry

After an attempt at underground exploitation of the marble reserve in the northern area of the old quarry, it was abandoned due to the low degree of recovery of the extracted marble in blocks and on the floor of the old quarry started the dumping of marble rocks of irregular shape and variable sizes with no commercial value. At the time of modeling, the inner dump had an extension of 80 meters at the top and a vertical development between elevations 630 and 671, being used as a temporary storage for the marble extracted in the form of blocks (Figure 3).

Fig. 3. Overview of the Rușchița quarry with the inner dump on the floor of the old quarry

3. Model of the northern area of the Ruschita marble deposit

In addition to the available geological information, two exploratory drillings were carried out with core recovery, V101 vertical executed in marble at elevation 734, with a length of 50 m and O102 horizontal at elevation 688, with a length of 105 m which intercepted marble zone, mixed zone (transition from marble to schist) and schist zone.

With the help of a drone, a flight was made to acquire surface points. The cloud of points obtained with the drone together with the situation plan in .dwg format [3] was the basis of the modeling in GEOVIA Surpac [4] of the current situation of the terrain morphology and the configuration of the steps of the northern slope of the old Ruschita quarry (Figure 4).

Considering the need to import the information into SLIDE3 to build the geometry for the stability assessment, a virtual box was built in GEOVIA Surpac and all the modeled elements were cut out, keeping only the part inside the virtual box.

Based on the existing information on the situation plan and those obtained from the exploratory drillings, the marble-mixed and mixed-schist contact planes were modeled (Figure 5).

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 10-16

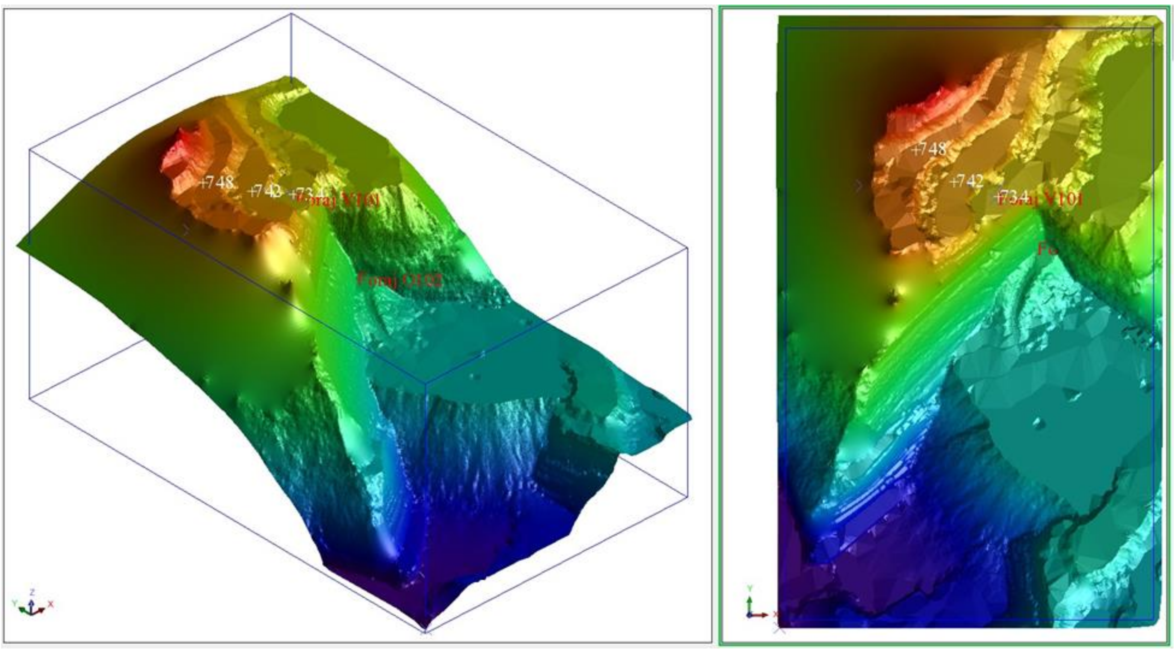


Fig. 4. The current situation of the northern slope of the old Ruschita quarry

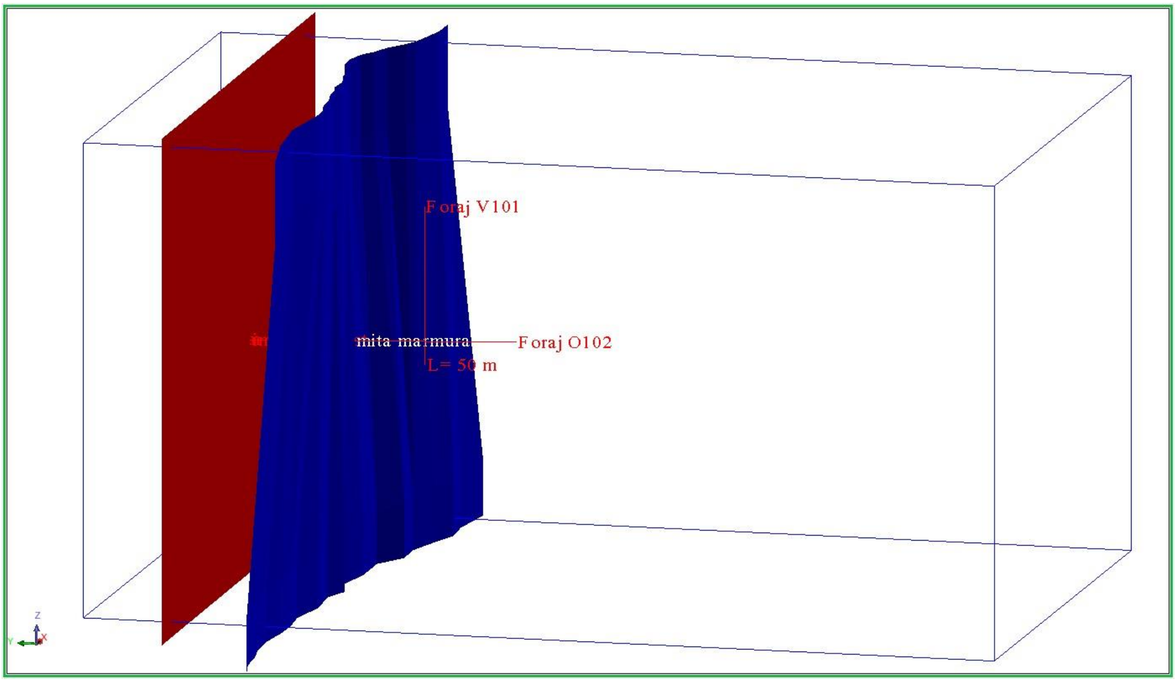


Fig. 5. Marble–mixed (blue) and mixed–schist (red) contact planes together with the two exploratory boreholes

The existing information on the older situation plans allowed the modeling of the slopes of the old quarry, currently covered by the inner dump [5].

All this information was imported into SLIDE3 and the 3D geometry of the northern area of the old Ruschita quarry was built. It is composed of the following areas:

- marble reserve of the northern area of the old Ruschita quarry (Figure 6),
- inner dump of the old Ruschita quarry (Figure 7),
- schist model behind the marble (Figure 8),
- mixed zone model, with an estimated width of approx. 30 m, that has in its composition gray marbles, breccia marbles with limonitic veins, intensely cracked cherry marbles, reddish-white to cherry cracked marbles, pink marbles, schist marbles, calcareous shale, amphibolite schist with calcareous intercalations, gray-green massive schist, caverns, cavernous crystalline limestone, brown clay, pyrite mineralization (Figure 9),

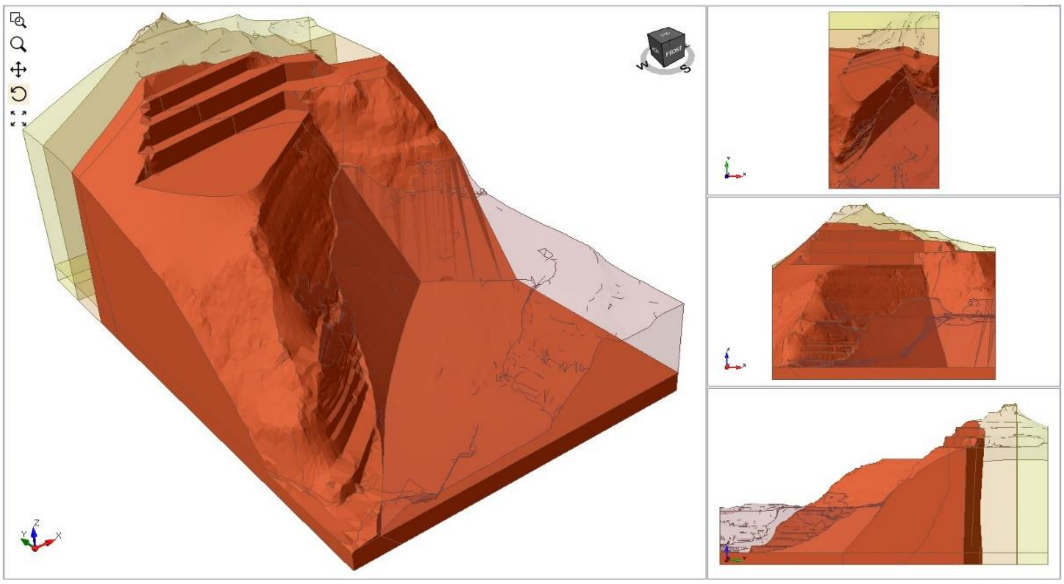


Fig.6. Marble reserve model

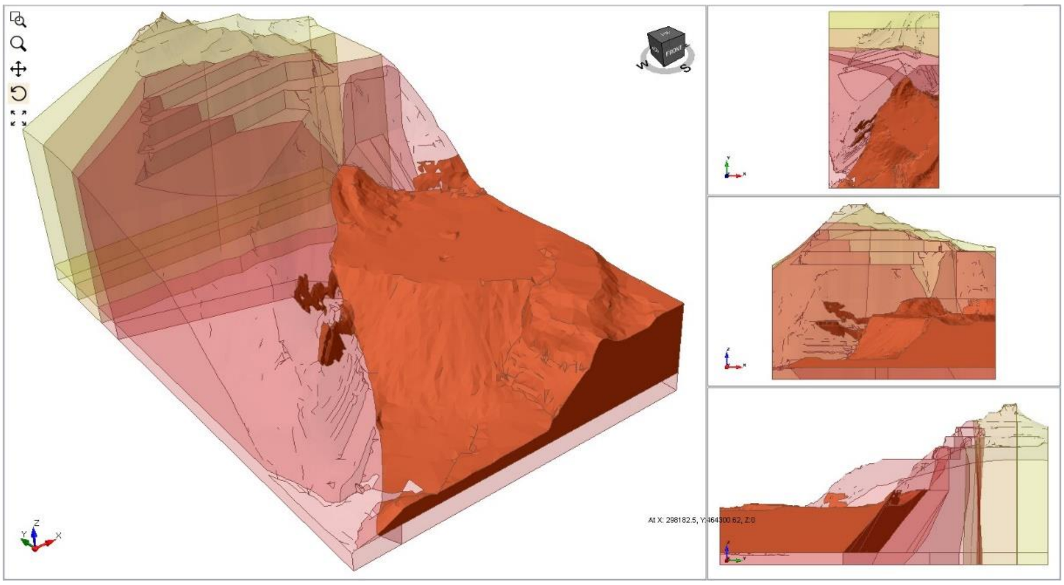


Fig.7. Inner dump model

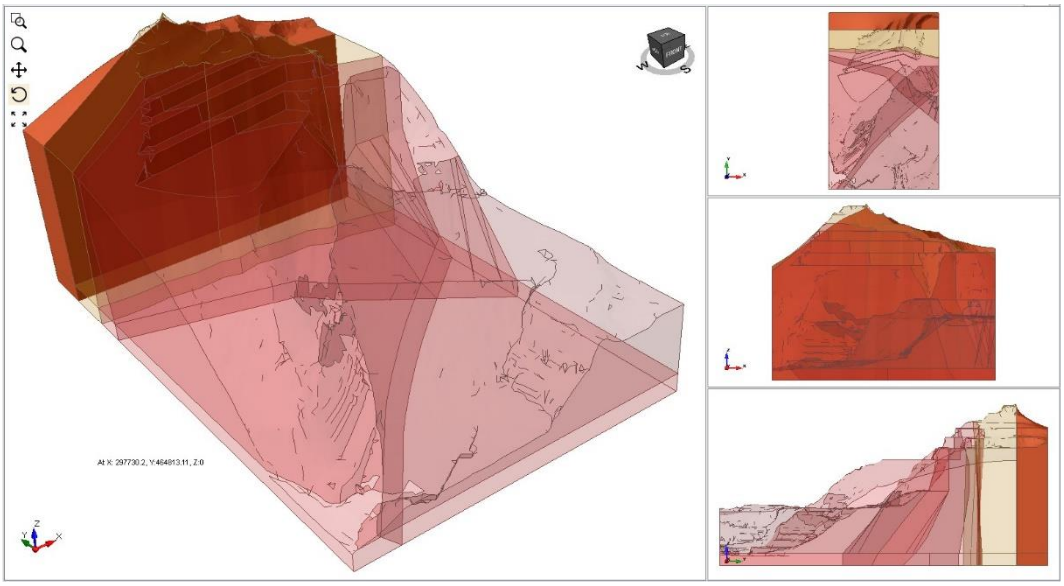


Fig.8. Schist model

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 10-16

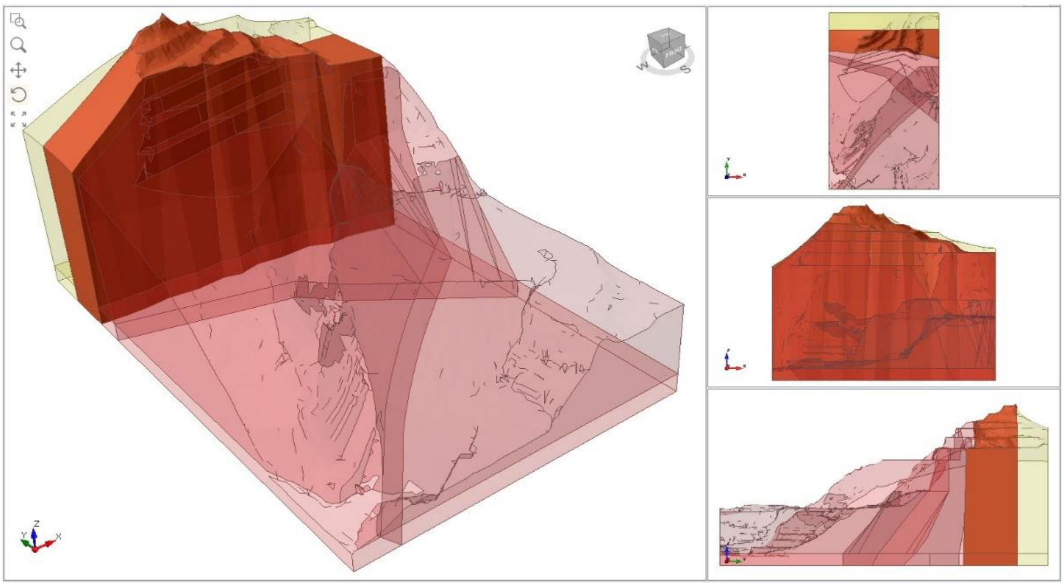


Fig.9. Mixed zone model

4. Conclusions

Using GEOVIA Surpac facilitated the construction of this complex 3D geological model of the northern area of the old Ruschita quarry to perform the stability analysis in Slide3.

The cores recovered from the two drillings were processed in the form of cylindrical samples on which the physical-mechanical properties of the intercepted rocks were determined in the rock mechanics laboratory at the University of Petroșani. The values determined for the rocks in a saturated state (table 1) were used to evaluate the stability of the northern area of the old Ruschita. In this case, the minimum value of the stability factor Fs is 2.6 in the inner dump area and the stability factor's value in the slope area of the quarry is greater than 4 (Figure 10).

To increase the value of the stability factor Fs in the area of the inner dump, it is proposed to divide the initial step of the dump into two steps of approximately 20 meters height with a berm between them of 10 meters wide, located at elevation 651.

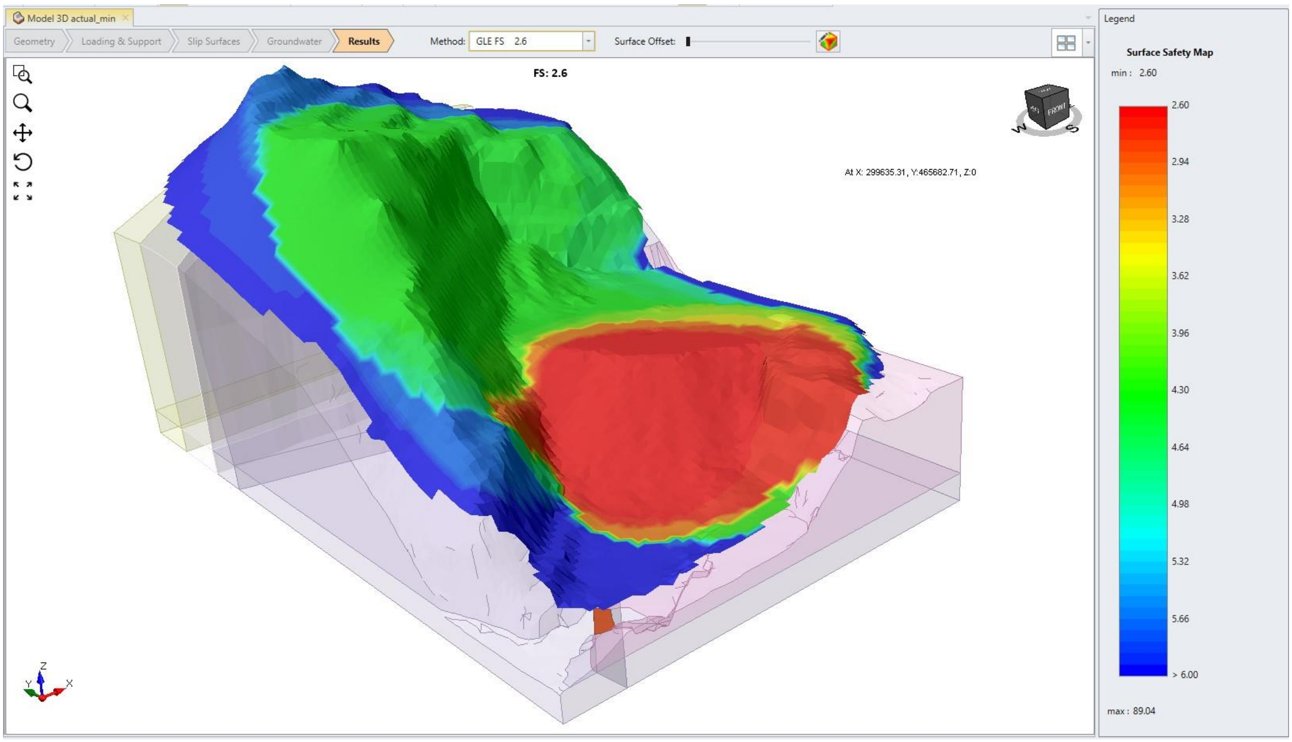


*Figure 10. Stability analysis considering the minimum values
of the mechanical properties of the rock mass (under saturated conditions)*

Table 1. The minimum values of the mechanical properties of the rock massif determined with RocData taken into account for the assessment of the stability

Rock type	**Unit weight [kN/m^3]**	**c [kPa]**	**φ [º]**	**σrtmassif [kPa]**
Marble	27.1	741	43.674	110
Schists	29.1	797	45.473	81
Mixed rocks	28	740	43	81
Heaped rocks	27	188	24.533	8

Note. Marble is the rock as it is seen in Figure 6, Schists is the rock as it is seen in Figure 8, Mixed rocks is the rock as it is seen in Figure 9 and Heaped rocks is the rock as it is seen in Figure 7.

References

[1] *** , 2024
https://www.rocscience.com/help/slide3/documentation#page-content-1 (accessed on 01 July 2024)

[2] **Cetean, V.**, 2013
Ruschita Romanian marble – 130 years of official exploitation and 130 m depth of architectural beauty around the world. EGU General Assembly Conference, Vienna, Austria 7-12 April, 2013

[3] **Marmosim S.A.**, 2021
Ruschița Top Nord 2021 situation plan with the location of boreholes V101 and O102

[4] **Florea A., Lazar M., Lorinţ C.**, 2014
Subsidence modeling at Valea Arsului - Vulcan colliery. Conference Proceedings of 14th Int. Multidisciplinary Scientific GeoConferences SGEM2014, Section: Exploration and Mining/Mineral Processing. DOI:10.5593/SGEM2014/B13/S3.076

[5] **Marmosim S.A.**, 2017
Rușchița quarry 2017 situation plan

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 17-24

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

Izabela-Maria APOSTU[1], Constantin RADA[2], Florin FAUR[3]*

[1]University of Petrosani, Petroșani, Romania, izabelaapostu@upet.ro
[2] University of Petrosani, Petroșani, Romania, constantin.rada1965@gmail.com
[3]University of Petrosani, Petroșani, Romania, florinfaur@upet.ro

DOI: 10.2478/minrv-2024-0036

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 Berbeşti 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].

[*] Corresponding author: Apostu Izabela-Maria, Lect.dr.eng., University of Petrosani, Petrosani, Romania (University of Petrosani, University Street no. 20, izabelaapostu@upet.ro)

a. b. c.

Fig. 1. Slope slides; a. Ruget open-pit; b. Berbeşti 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 Berbeşti 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 Berbeşti 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 Berbeşti 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 Berbeşti mining basin was divided into 4 mining perimeters respectively: Gilort - Amaradia, Amaradia - Tărâia, Tărâia - Cernişoara, and Cernişoara – Bistrița [9].

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

At this point, Berbeşti 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, Berbeşti, and Panga open-pits (Figure 3).

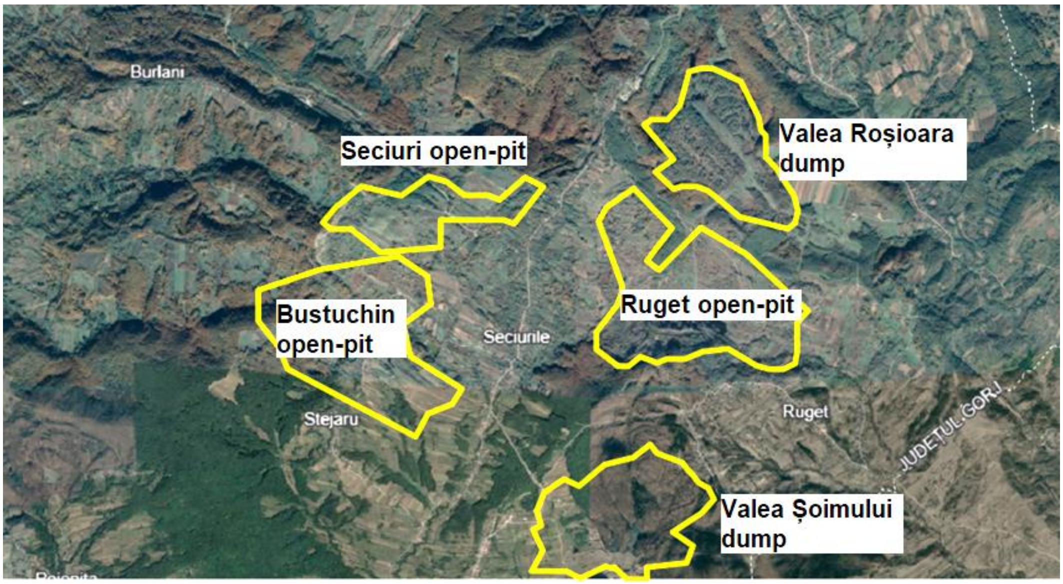


Fig. 2. Mining perimeters with suspended activity [13]

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

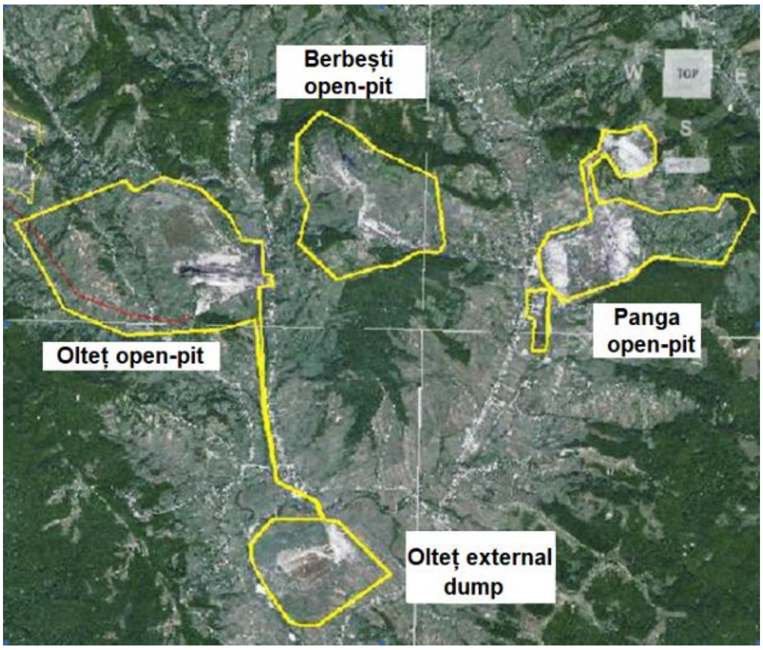


Fig. 3. Mining perimeters in operation [13]

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 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.

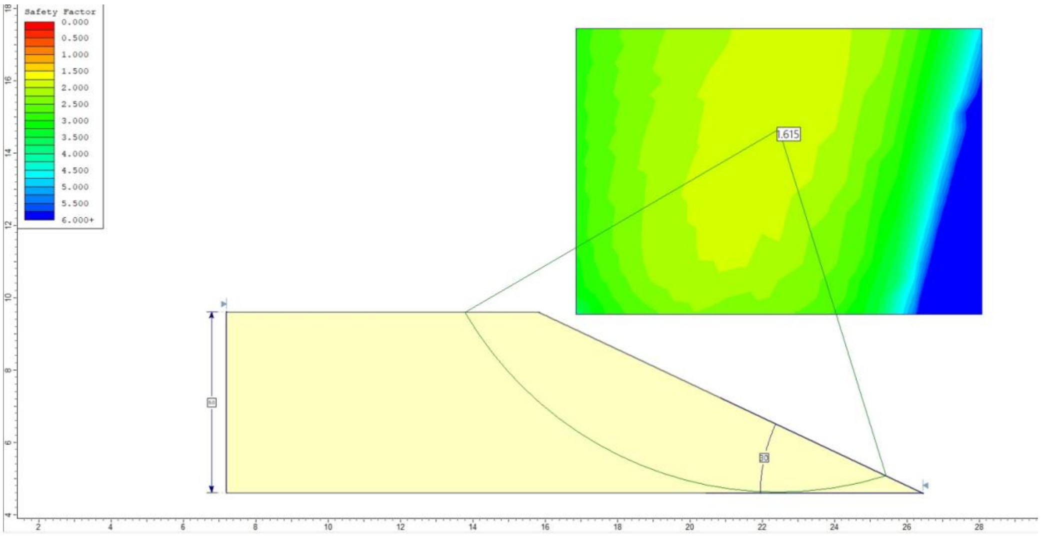


Fig. 5. Stability analysis for the dump step having h = 5 m and α = 30° (Fs = 1.615)

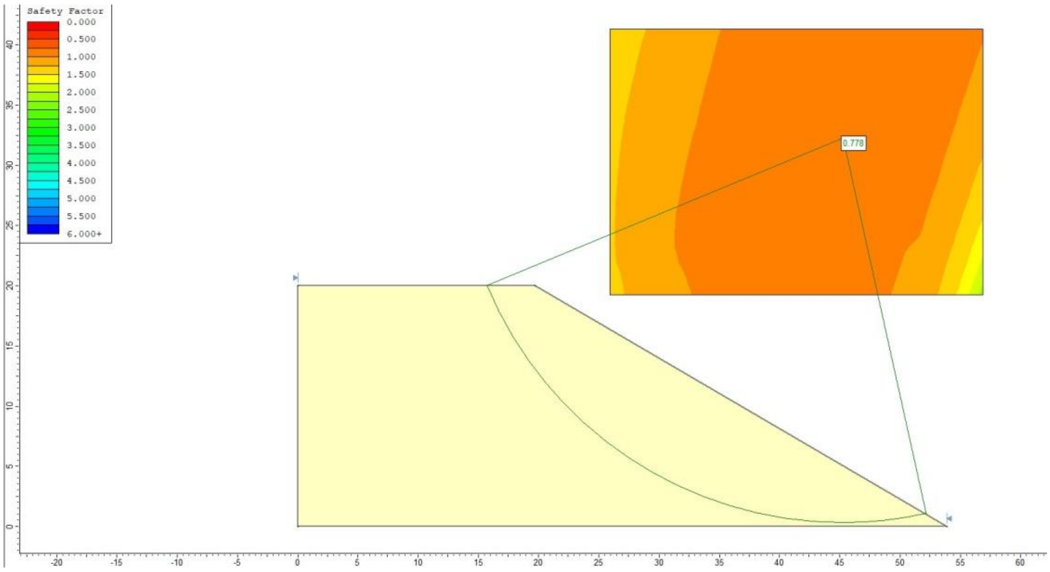


Fig. 6. Stability analysis for the dump step having h = 20 m and α = 30° (Fs = 0.778)

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).

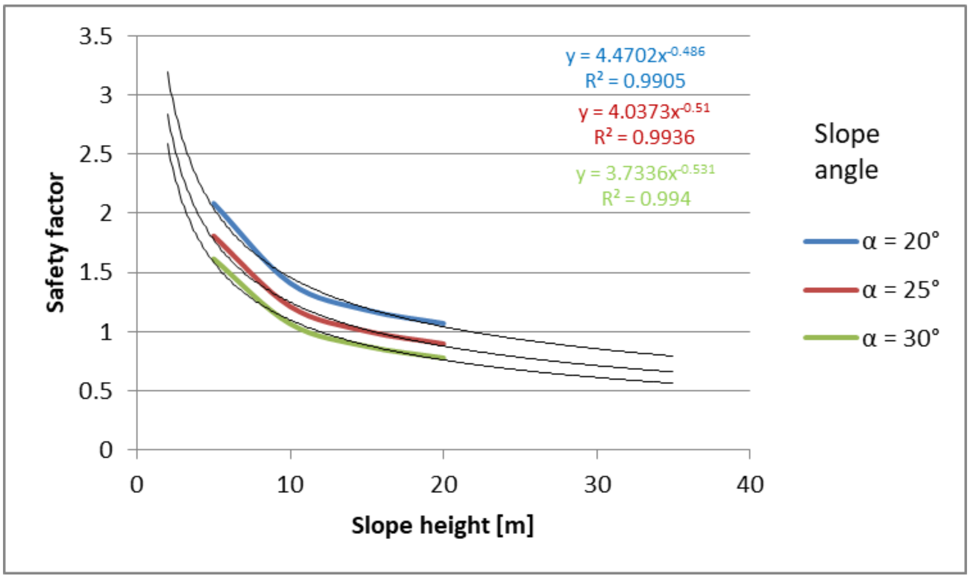


Fig. 7. Variation of the safety factor as a function of the slope height at different values of the slope angle (power function)

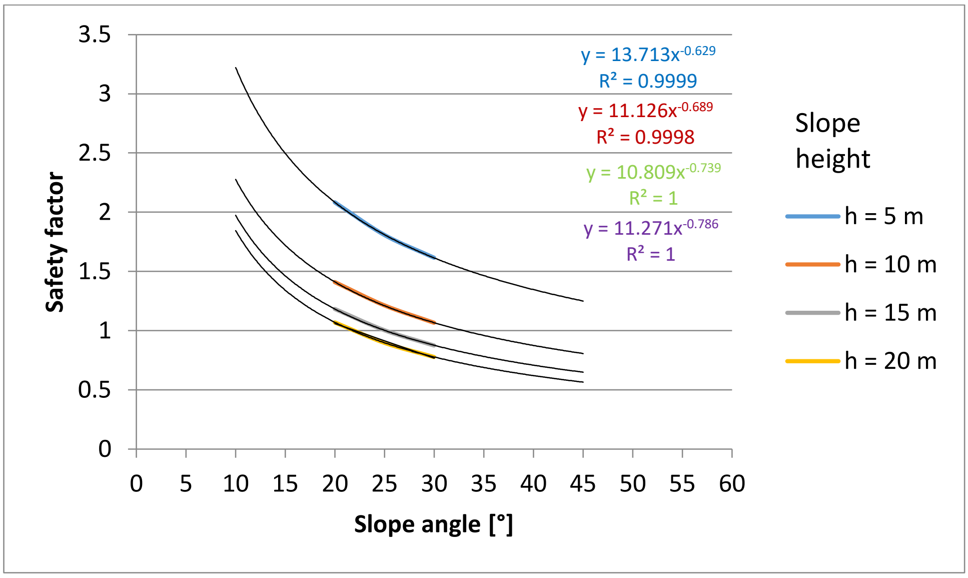


Fig. 8. Variation of the safety factor as a function of the slope angle at different values of the slope height (power function)

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 Berbeşti 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

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

[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

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 25-31

ENVIRONMENTALLY FRIENDLY TECHNOLOGIES OF INTEGRATED OPEN PIT-UNDERGROUND MINING

Mykola STUPNIK[1], Vsevolod KALINICHENKO[2], Olena KALINICHENKO[3], Oleksandr SHEPEL[4], Volodymyr PILCHYK[5]*

[1]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine
[2]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine, kalinichenko@knu.edu.ua
[3]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine
[4]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine
[5]SE "Eastern Mining and Processing Plant", Zhovti Vody, Ukraine

DOI: 10.2478/minrv-2024-0037

Abstract: *Kryvyi Rih iron ore basin is one of Ukraine's oldest. Over 150 years of open pit mining has resulted in significant areas of arable land disturbed by open pits, dumps and tailings facilities. In Kryvyi Rih region, operation of open pits, dumps and tailings facilities results in worsened environmental conditions.*
Deep open pits and high dumps change the topography of the region. Open pits, dumps and tailings facilities not covered with vegetation contribute to bad air pollution by emitting large amounts of dust.
To settle the environmental issues and preserve the nature in the basin, gradual transition from the technology of open-pit mining to integrated open pit-underground and subsequent underground mining is developed and proposed.
In addition, the present paper addresses one of the main problems of geomechanical stabilization of the rock massif when constructing underground mines in areas of possible influence of open pit fields, and studies issues of controlling the stress-strain state of the rock massif during transition from the open-pit to integrated technology of deposit mining.
The research conducted enables substantiation of technologies involving formation of internal waste rock dumps during integrated open pit-underground mining. The paper presents the results of the research on the stress-strain state of the massif during transition from the open-pit to integrated mining technology and proposes environmentally friendly technologies of integrated open pit-underground mining of deposits with waste disposal in the worked out space of underground mines and open pits.
The results obtained are highly relevant and very important in both scientific and practical fields.
Keywords: *integrated open pit-underground mining, ore, environmentally friendly technologies, deposit, geomechanical stabilization, stress-strain state of the rock massif*

1. Introduction

Kryvyi Rih iron ore basin is one of Ukraine's oldest. Over 150 years of open pit mining has resulted in significant areas of arable land disturbed by open pits, dumps and tailings facilities.

Every year, thousands of tons of dust from open pits, dumps and tailings facilities worsen the state of the environment and pollute the air in Kryvyi Rih region.

Deep open pits and high dumps change the topography of the region. Open pits, dumps and tailings facilities not covered with vegetation contribute to bad air pollution by emitting large amounts of dust.

Thus, development of environmentally friendly technologies for integrated open pit and underground mining of deposits is an urgent scientific and practical task which is important for further sustainable development of mining regions of Ukraine.

[*] Corresponding author: Vsevolod Kalinichenko, Kryvyi Rih National University, Faculty of Mining and Metallurgy, Contact details:11 Vitalii Matusevych Str., KryvyiRih, 50027, Ukraine, kalinichenko@knu.edu.ua; Tel.: +380-67-56-82-260

2. The choice of object to study

Modern advances in mining technologies enable introduction of innovative mining processes which until recently were considered impossible in the mining industry [1, 2, 3].

In the context of an increase in the depth of deposit mining and deterioration of mining and geological characteristics of deposits, the toughening of environmental requirements for mining technologies has led to the search for new technological iron ore extraction flowsheets [4, 5, 6].

The present article deals with ways to solve the main problems of sustainable development of mining regions, in particular Kryvyi Rih iron ore basin.

In the authors' opinion, the main way of sustainable development of the basin while preserving the nature of the region involves gradual transition from open pit mining of iron ore deposits to integrated open pit-underground and subsequent underground mining.

To accomplish this task, it is necessary to solve the problem of geomechanical stabilization of the rock massif when constructing underground mines in zones of open pit field influence.

The geomechanical condition of the rock massif is the main factor when selecting a mining technology and methods of mining minerals. The study of the stress-strain state and the value of actual stresses in the rock massif enables a general picture of the geomechanical condition of the massif at the stage of modern technology design [7, 8, 9].

Factors of the selected technology that influence the stress-strain state of the rock massif can be determined through modeling the geomechanical conditions under multifactorial dependences. When choosing a mining method, multifactorial modeling enables justification of the choice of the optimal technology for mining a deposit considering technological and environmental requirements [4, 5, 6].

Multifactorial modeling of transition from technologies of open pit mining of magnetite quartzites to those for integrated open pit and underground extraction of iron ore raw materials is the first task in shaping a new strategy for development of Kryvyi Rih iron ore basin. In the course of such modeling, a set of studies should be conducted to offer progressive, environmentally friendly combined technologies for mining magnetite quartzites [9, 10].

Such problems should be solved applying analytical methods of studying the rock massif, especially when dealing with dangerous zones of mutual influence of open pits and underground mine workings during mining the deposit by integrated open pit and underground methods [11, 12, 13, 14, 15].

The results of the research on combined technologies are necessary both at the design stage and further on when developing technologies for transition from open pit mining of mineral deposits to integrated open pit and underground extraction of iron ore raw materials.

A special task of such technologies consists in studying the possibility of disposing mining waste in the mined-out space of open pits. Such technologies can settle three main tasks:

– first, disposal of waste rocks in the mined-out space of open pits frees up large areas of arable land that are potentially allotted for dumps;

–second, filling up open pits potentially increases areas that can be used in economic activities in the future;

– third, absence of open pits and dumps improves the environment of the basin.

Thus, the present work aims to study the geomechanical condition of the rock massif during transition from open pit mining technologies to those of integrated open pit-underground and subsequent underground mining of iron ore raw materials, that enables solving an important problem of sustainable development of Kryvyi Rih iron ore basin and improving the environment of the region.

3. Research methods

To study the geomechanical condition of the rock massif by analytical methods, the software package "Ansys 22" is used to calculate the stress-strain state of the massif around open pits and underground mine workings and simulate the behaviour of the rock massif when applying combined mining methods.

The calculations are performed for the conditions of Kryvyi Rih iron ore basin, where magnetite quartzites are now mined by the open pit method.

The average depth of the open pit is accepted 350 m. At depths over 350 m, the cost of mining is equal to and sometimes exceeds the cost of the underground mining method. Considering the critical influence of open pit mining on the environmental condition of the basin, the optimal solution undoubtedly consists in transition to integrated open pit-underground and subsequent underground mining of magnetite quartzites.

Figure 1 presents the initial design model of combined open pit-underground mining for calculating stresses and strains in the combined massif during open pit-underground mining of the deposit applying the proposed technology with the initial stage of mining waste disposal in the mined-out space of the open pit.

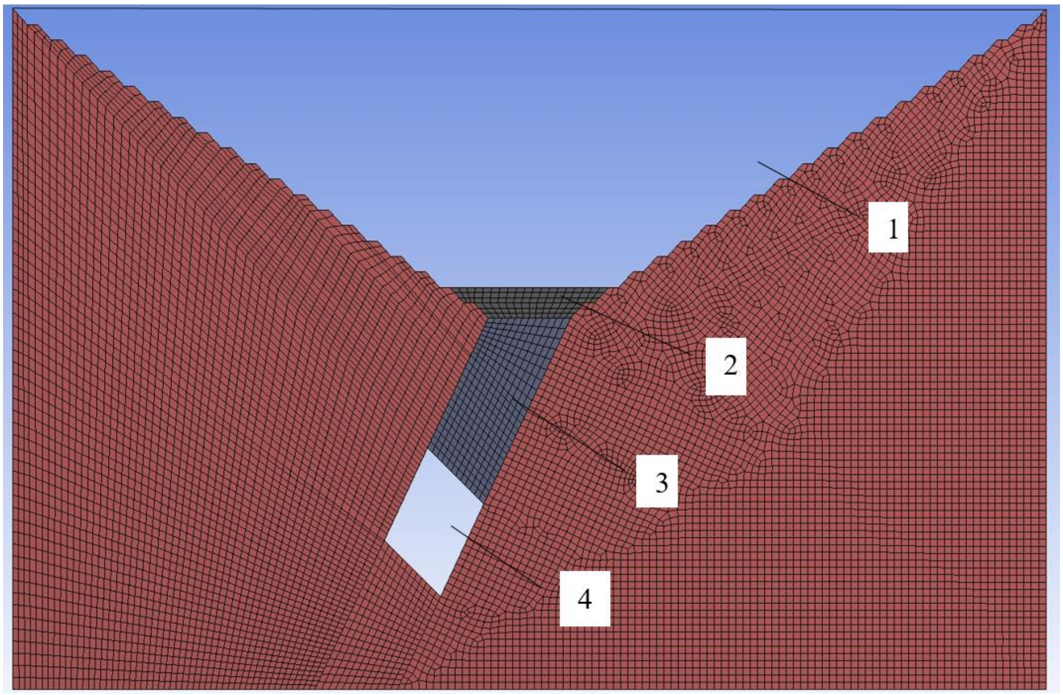


Fig. 1. Finite element grid for calculating stresses and strains in the combined massif at the initial stage of filling up the open pit; 1 – the open pit, 2 – waste rocks, 3 – the barrier pillar, 4 – the mined-out part of the ore deposit

The idea behind the presented design model of combined open pit-underground mining consists in dividing the massif into a finite element grid. The size of the initial design model is assumed to be adequate to the size of the area of applying the combined ore mining technology under study.

In this case, to build stress diagrams using the finite element method, the 3D model is divided into quadrilaterals with a side size of 5 m, (Fig. 2).

Figure 2 presents the initial design model of combined open pit-underground mining for calculating stresses and strains in the combined massif during open pit-underground mining of the deposit applying the proposed technology with mining waste disposal in the mined-out space of the open pit at the final stage of filling up the open pit.

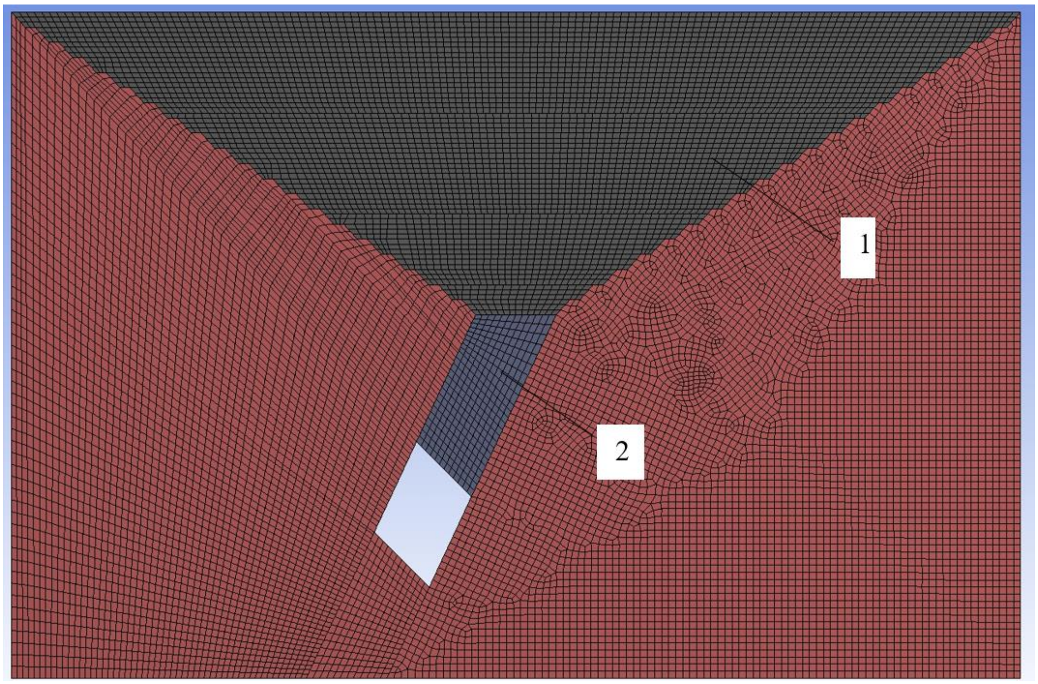


Fig. 2. Finite element grid for calculating stresses and strains in a combined massif at the final stage of filling up the open pit; 1 – the open pit at the final stage of filling it up with waste rocks, 2 – the barrier pillar

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 25-31

4. Research results

The authors research on the problems of controlling the stress-strain state of the rock massif during transition from the open pit to complex technology of deposit mining.

The technologies for creating internal waste rock dumps when applying integrated open pit-underground mining methods are studied and substantiated.

Figure 3 visualizes distribution of principal stress isolines in the massif in the case of open integrated pit-underground mining of a magnetite quartzite deposit with the room ore mining system and creation of a barrier pillar in the combined massif at the initial stage of filling up the open pit with waste rocks.

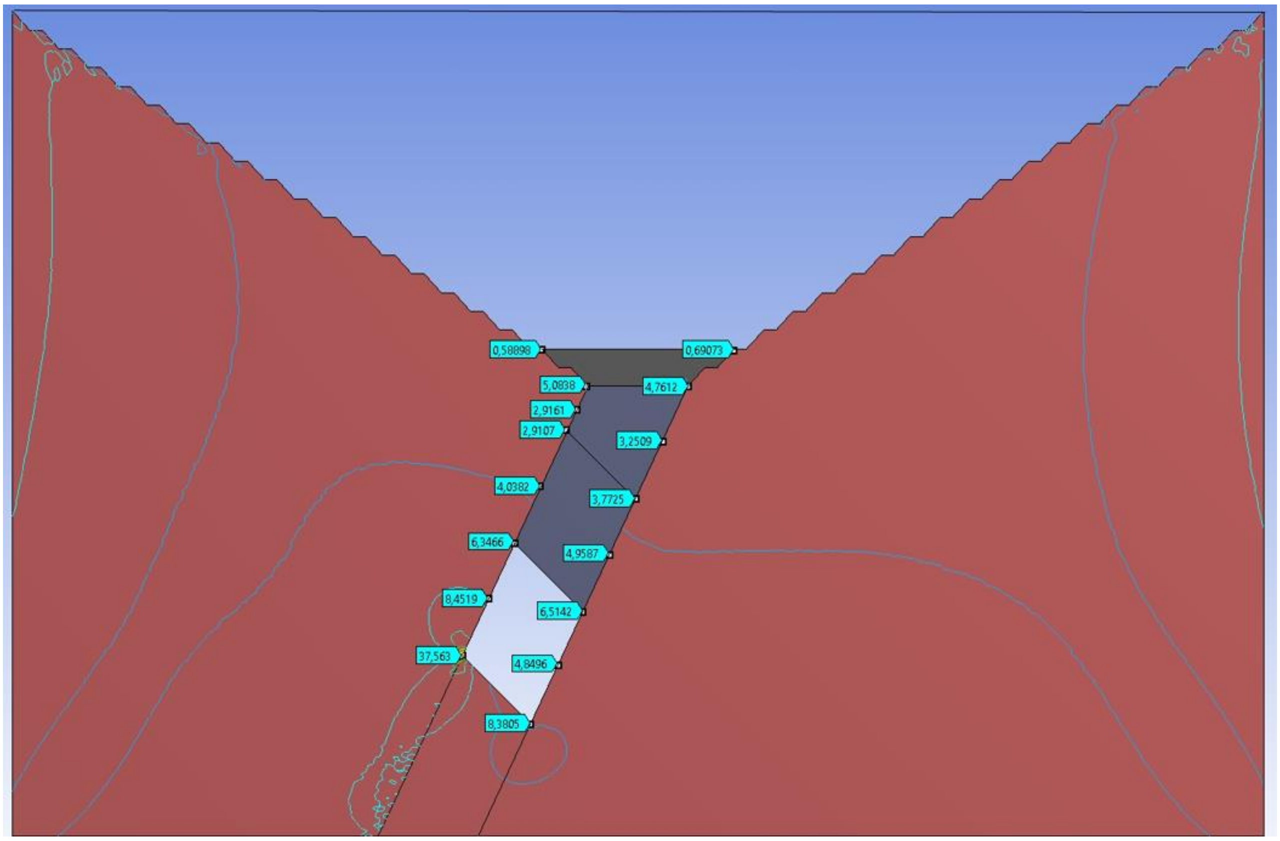


Fig. 3. Distribution of principal stress isolines in the combined massif at the initial stage of filling up the open pit with waste rocks

The research is conducted for conditions of creating of both an ore barrier pillar and an artificial barrier pillar from a consolidating backfill.

Underground extraction of magnetite quartzites is conducted by the room mining system. In the case of using an artificial barrier pillar from a consolidating backfill, the mining technology consists in the following.

After the complete drawing of the broken ore from the upper room, the mined-out space is backfilled with a consolidating backfill creating an artificial barrier pillar that separates the open pit mining operations from the lower room of the next underground level.

Further underground mining of minerals, magnetite quartzites in this case, is conducted by room mining systems under protection of an artificial pillar of a consolidating backfill.

In the case of creating an artificial barrier pillar from a consolidating backfill, formation of an internal dump for waste rocks or other mining wastes is conducted after the artificial barrier pillar acquires its design strength.

The analysis of the obtained calculations enables a general picture of stress field distribution in the combined massif.

The highest absolute value of stress is reached near the corners of the room.

Slight concentration of stresses is observed in the corners at the bottom of the room.

Significant maximum stresses σ1 in the corners of the room are explained by compressive stresses.

Depthwards into the ore massif, the stresses σ1 decrease, and their distribution pattern becomes more uniform.

The maximum value of stresses at the open pit bottom is 5.0838 MPa.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 25-31

When transiting from open pit to combined open pit-underground, or underground method of mining magnetite quartzites in Kryvyi Rih iron ore basin, the authors find it reasonable to support the following basic principles of developing transitional technologies.

Vertical shafts of the underground mine should be sunk in the footwall of the deposit.

According to the practice of underground mining of magnetite quartzites, the most rational height of the underground level should make 80 m – 90 m.

During the research, all the proposed design models are brought to a single modelling scale to enable studying the stress-strain state of the combined massif with high accuracy of the results obtained.

Figure 4 visualizes distribution of principal stress isolines in the massif in the case of integrated open pit-underground mining of a magnetite quartzite deposit applying the room ore mining method and creation of a barrier pillar in the combined massif at the final stage of filling up the open pit with waste rocks.

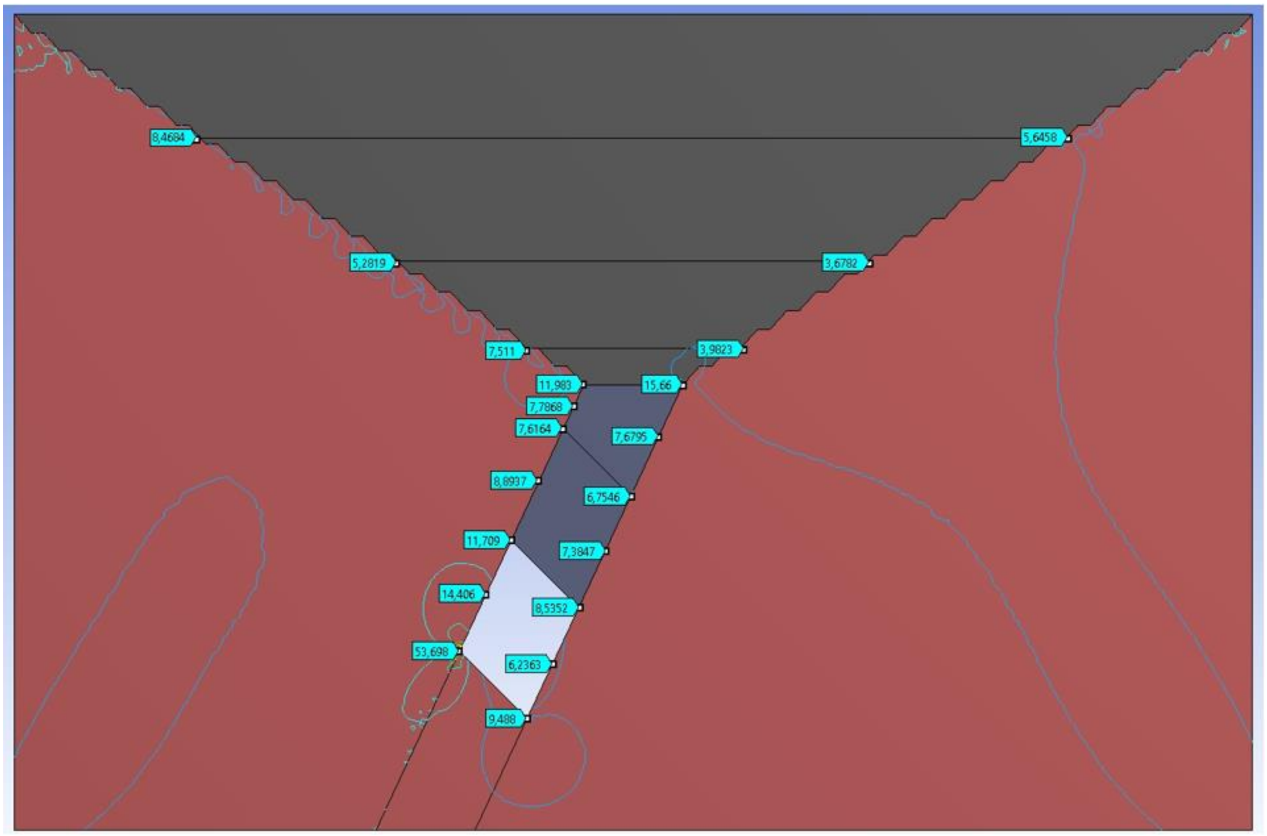


Fig. 4. Distribution of principal stress isolines in a combined massif at the final stage of filling up the open pit with waste rocks

When the open pit is completely filled with waste rocks, the maximum value of stresses at the bottom of the open pit increases to 15.66 MPa. But such stresses are observed in the footwall and are tangential to the artificial massif. Accordingly, the load from the column of waste rocks is redistributed mainly to the host rocks of the footwall.

Figure 5 shows the dependence of the value of maximum stresses in the combined massif on the height of the internal dump.

The maximum value of principal stresses in a combined massif that depends on the height of the internal dump can be determined by the equations 1.

$$\sigma_1 = 4{,}1757\ln(h_{id}) - 9{,}3295;\ R^2 = 0{,}9865 \quad (1)$$

σ_1 is the maximum value of principal stresses, MPa; h_{id} is the height of the internal dump of waste rocks, m.

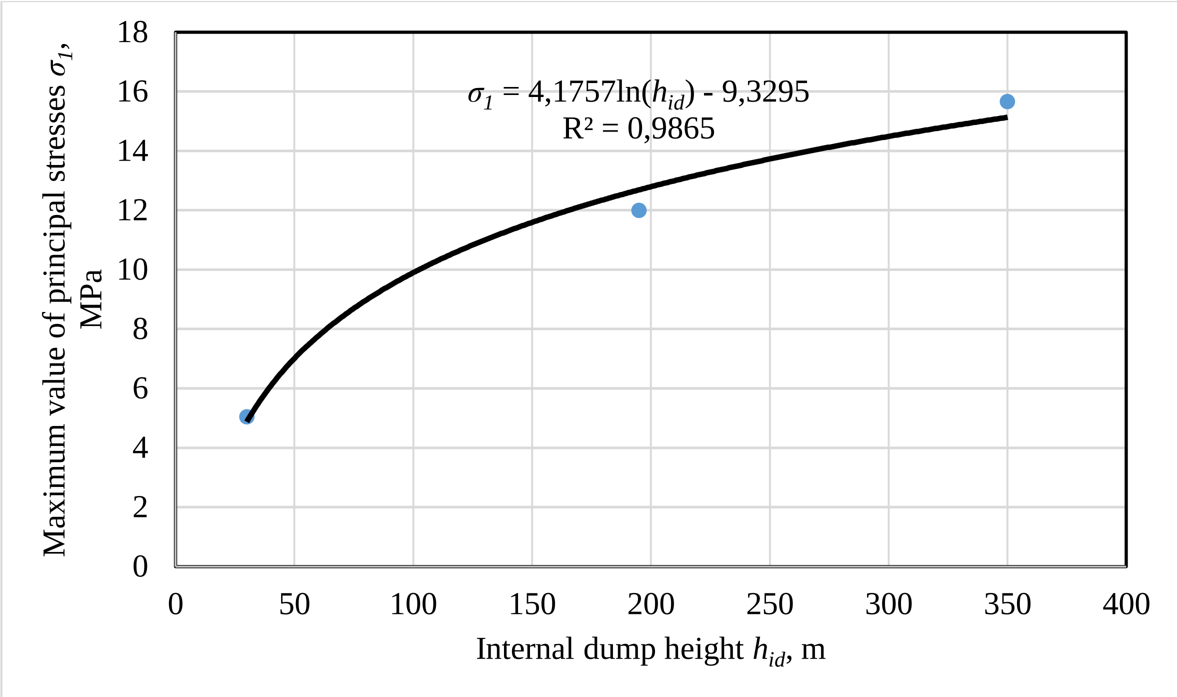


Fig. 5. Dependence of the value of maximum stresses in a combined massif on the height of the internal dump

The complete filling up of the open pit with waste rocks frees up large areas of fertile agricultural land that are potentially alloted for new dumps.

In addition, filling up the open pit shell with waste rocks and subsequent reclamation of the restored surface will partially restore the safe environmental state of the mining basin.

5. Conclusions

The stress-strain state of the rock massif during transition from open pit mining of iron ore deposits to integrated open pit-underground and subsequent underground mining of minerals is studied. Expediency of this transition considering the geomechanical condition of the massif is proved.

The conducted studies enable recommending environmentally friendly integrated technologies for open pit-underground mining of deposits with solution of the following problems: disposal of waste rocks in the mined-out space of open pits, which frees up large areas of arable land potentially alloted for dumps; return of industrial territories to economic activities by filling up open pits with mining waste and their subsequent reclamation; improvement of the environment of the basin due to absence of open pits and dumps.

The results obtained are relevant and possess important scientific and practical significance.

References

[1] **Stupnik M.I., Kalinichenko O.V., Kalinichenko V.O.**, 2012
Economic evaluation of risks of possible geomechanical violations of original ground in the fields of mines of Kryvyi Rih basin. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, pp. 126-130

[2] **Stupnik M.I., Kalinichenko O.V., Kalinichenko V.O.**, 2012
Technical and economic study of self-propelled machinery application expediency in mines of Krivorozhsky basin. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 5, pp. 39-42

[3] **Stupnik M., Kalinichenko V., Fedko M., Pysmennyi S., Kalinichenko O., Pochtarev A.**, 2022
Methodology enhancement for determining parameters of room systems when mining uranium ore in the SE "SkhidGZK" underground mines, Ukraine. Mining of Mineral Deposits, 16 (2), pp. 33–41. https://doi.org/10.33271/mining16.02.033

[4] **Stupnik M., Kalinichenko V., Kalinichenko O., Pochtarev A.**, 2021
Technological measures to enhance efficiency of mining ore from stopes applying self-propelled equipment. E3S Web of Conferences, 280, no. 08010

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 25-31

[5] **Stupnik M., Kalinichenko V., Kalinichenko O., Shepel O., Hryshchenko M.**, 2023
Scientific and technical problems of transition from open pit to combined technologies for raw materials mining. IOP Conference Series: Earth and Environmental Science, 1254 (1), no. 012070

[6] **Pysmennyi S., Fedko M., Chukharev S., Rysbekov K., Kyelgyenbai K., Anastasov, D.**, 2022
Technology for mining of complex-structured bodies of stable and unstable ores. IOP Conference Series: Earth and Environmental Science, 970(1), no. 012040. https://doi.org/10.1088/1755-1315/970/1/012040

[7] **Pysmennyi S., Chukharev S., Khavalbolot K., Bondar I., Ijilmaa J.**, 2021
Enhancement of the technology of mining steep ore bodies applying the "floating" crown. E3S Web of Conferences, 280, no. 08013. https://doi.org/10.1051/e3sconf/202128008013

[8] **Pysmennyi S., Chukharev S., Kyelgyenbai K., Mutambo V., Matsui A.**, 2022
Iron ore underground mining under the internal overburden dump at the PJSC "Northern GZK". IOP Conference Series: Earth and Environmental Science, 1049 (1), no. 012008. https://doi.org/10.1088/1755-1315/1049/1/012008

[9] **Pysmennyi S., Peremetchyk A., Chukharev S., Fedorenko S., Anastasov D., Tomiczek K.**, 2022
The mining and geometrical methodology for estimating of mineral deposits. IOP Conference Series: Earth and Environmental Science, 1049 (1), no. 012029. https://doi.org/10.1088/1755-1315/1049/1/012029

[10] **Kyelgyenbai K., Pysmennyi S., Chukharev S., Purev B., Jambaa I.**, 2021
Modelling for degreasing the mining equipment downtime by optimizing blasting period at Erdenet surface mine. E3S Web of Conferences, (280), no. 08001. https://doi.org/10.1051/e3sconf/202128008001

[11] **Pysmennyi S., Fedko M., Chukharev S., Sakhno I., Moraru R., Panayotov V.**, 2023
Enhancement of the rock mass quality in underground iron ore mining through application of resource-saving technologies. In IOP Conference Series: Earth and Environmental Science 1156 (1), no. 012029. https://doi.org/10.1088/1755-1315/1156/1/012029

[12] **Pysmennyi S., Chukharev S., Peremetchy A., Fedorenko S., Matsui, A.**, 2023
Study of Stress Concentration on the Contour of Underground Mine Workings. Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society, 1 (51), pp. 69–78. http://doi.org/10.29227/IM-2023-01-08

[13] **Pysmennyi S., Chukharev S., Kourouma I.K., Kalinichenk V., Matsui A.**, 2023
Development of Technologies for Mining Ores with Instable Hanging Wall Rocks. Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society, 1 (51), pp. 103–112. http://doi.org/10.29227/IM-2023-01-13

[14] **Peremetchyk A., Pysmennyi S., Shvaher N., Fedorenko S., Podoynitsyna T.**, 2023
Modeling and Prediction of Iron Ore Quality Indicators. Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society, 1 (51), pp. 127–136. http://doi.org/10.29227/IM-2023-01-15

[15] **Bazaluk O., Rysbekov K., Nurpeisova M., Lozynskyi V., Kyrgizbayeva G., Turumbetov T.**, 2022)
Integrated monitoring for the rock mass state during large-scale subsoil development. Frontiers in Environmental Science, 10, no. 852591. https://doi.org/10.3389/fenvs.2022.852591

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

COPPER MINING'S GREEN REVOLUTION – SUSTAINABLE TECHNIQUES AND TECHNOLOGIES SHAPING THE FUTURE

Rodica (STEPANEK) CUJBA[1], Maria LAZĂR[2]*

[1]University of Petrosani, Petroșani, Romania, rodica-1998@mail.ru
[2] University of Petrosani, Petroșani, Romania, marialazar@upet.ro

DOI: 10.2478/minrv-2024-0038

Abstract: *This paper traces the evolving landscape of copper mining, delving into the industry's shift towards sustainable practices and technologies. In this context, a critical case study is presented, with an emphasis on the mining of copper ore from Roșia Poieni. This case study analyzes the application of sustainable techniques in mining operations, assessing their effectiveness, feasibility and potential challenges. It is also evaluated the implementation of renewable energy sources, waste recycling initiatives and the adoption of clean technologies within the operations of the Roșia Poieni quarry. In addition, the study investigates the socio-economic ramifications of these sustainability efforts on the local community surrounding the mine. The research begins with an overview of traditional extraction methods and highlights the importance of adopting green alternatives. Examining sustainable technologies in copper mining and processing, the paper explores the integrate ion of renewable energy, waste recycling and clean technologies to reduce emissions. The social impact of these sustainable practices is explored, including the benefits to local communities and increased workplace safety. Despite the challenges faced, the industry holds economic opportunities in adopting sustainable techniques. The paper concludes with a comprehensive overview of the industry's outlook, highlighting the importance of balancing technological advances with environmental responsibility in shaping the future of copper mining.*
Keywords: *Copper, mining, sustainability, green technology, impact*

1. Introduction

Copper, a vital component in various industries, has long been extracted through traditional mining methods, often at the expense of environmental degradation. However, a paradigm shift is underway in the copper mining industry, with an increasing focus on sustainable techniques and technologies. This change responds to environmental issues and supports the worldwide movement for responsible resource management. This document explores the evolution of copper mining practices, emphasizing the integration of sustainable technologies shaping the industry's future. From innovative extraction methods to digitalization and community involvement, each section delves into the multifaceted aspects driving the green revolution in copper mining. This exploration aims to shed light on the promising advancements, challenges, and opportunities in adopting environmentally conscious practices, ultimately contributing to a more sustainable and responsible copper mining landscape.

2. Global copper mining

Sustainability emphasizes the manner of using natural resources in a way that fulfills present request without compromising the ability of future generations to meet their own requirements. Sustainable development, which emphasizes striking a balance between social equity, environmental protection, and economic growth, is closely linked to this idea. Sustainable exploitation includes managing resources so that they remain available and productive over time, ensuring that ecosystems are conserved and human well-being both now and in the future.

[*] Corresponding author: Cujba (Stepanek) Rodica, PhD stud.eng., University of Petrosani, Petrosani, Romania (University of Petrosani, University Street no. 20, rodica-1998@mail.ru)

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

Sustainable mining point out practices and strategies designed for minimizing the negative environmental, social and economic impacts associated with mining activities, also contributing to increasing the positive impact. This involves responsible mining methods that ensure the conservation of natural resources, the protection of ecosystems and well-being for local communities.

Sustainable mining practices include:

• Implementation of techniques that reduce pollution, protect water resources, prevent soil degradation, and promote biodiversity conservation. This includes proper management of waste and tailings to avoid contamination of the environment.

• Communication with local people to understand and address their preoccupations, contributing to local economic development. This also involves promoting safe working conditions and providing training and education opportunities for workers.

• Ensuring that mining activities contribute positively to the economy by generating revenue, creating jobs, and supporting local businesses. This includes transparent and equitable distribution of profits and taxes generated from mining operations.

• Reference to national and international laws and standards, implementing robust corporate social responsibility programs, and integrating environmental, social, and governance (ESG) principles into business practices. This helps in gaining trust from stakeholders and mitigating risks associated with mining operations.

Utilizing advanced technologies and innovative solutions to improve operational efficiency, reduce environmental footprint, and enhance worker safety. This includes exploring renewable energy options and adopting circular economy principles to maximize resource utilization [1].

Sustainable mining requires collaboration among mining companies, governments, communities, and other stakeholders to establish and enforce regulations, share best practices, and invest in sustainable technologies and initiatives. By embracing sustainable exploitation, the mining industry can assist in achieving of the Sustainable Development Goals (SDGs), especially that have to do with fair labor, economic expansion, decreasing inequality, and responsible production and consumption.

According to the United States Geological Survey (USGS), global copper reserves were estimated at 1 billion tons in 2023. Nations possessing substantial reserves of copper include Chile (190 million tons), Australia (100 million tons), Peru (120 million tons), Russia (80 million tons), Mexico (53 million tons), and the United States (50 million tons), among others. In terms of production, global copper output from ore in 2023 was 22 million tons. The leading copper-producing countries were Chile (5 million tons), Peru (2.6 million tons), China (1.7 million tons), and the United States (1.1 million tons).

According to a World Bureau of Metal Statistics (WBMS) report, there will be a 65,800-ton supply deficit in 2023 as a result of the world's refined copper production being 27.6261 million tons and consumption being 27.6919 million tons.

As stated by to the International Copper Study Group (ICSG), the global refined copper market experienced a supply shortage of 87,000 tons in 2023, down from a deficit of 434,000 tons in 2022.

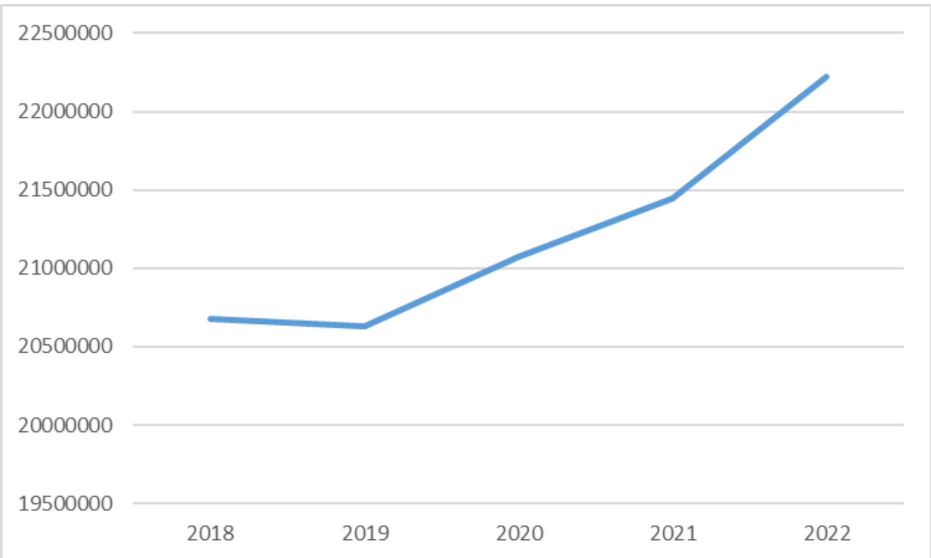


Fig. 1. Evolution of world production of copper (metric tons) [2]

According to figure 1, the world production of copper experienced a minor decline initially but then stabilized and subsequently increased significantly from 2020 to 2022. This reflects a growing demand and possibly increased capacity and efficiency in copper production processes globally. The substantial rise in recent years highlights copper's critical role in various industries, especially those related to technological and green energy advancements.

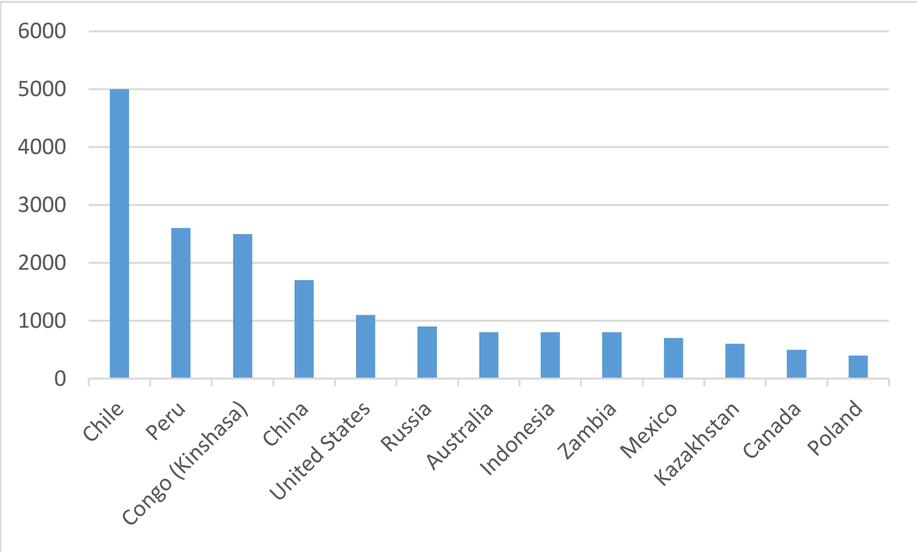


Fig. 2. Copper production by country (thousand metric tons) (2023) [3]

According to the graph above (Figure 2), we can see that, Chile is the leading copper producer in 2023, with production significantly higher than any other country. Peru and Congo (Kinshasa) also have substantial copper production, while other countries like the United States, China, and Russia have relatively lower but notable production levels. The chart shows a steep drop in production figures from the top producer to the lowest among these countries.

Further on a comprehensive overview of sustainable exploitation, consumption and responsible production politics for five top copper – producing countries in 2023 is presented.

2.1 Copper production in Chile

The Chilean Copper Commission reports that in 2023, the country's output of copper fell by 0.5% to 5.33 million tons, the lowest since 2008. The decline in production was ascribed to difficult mining conditions, reduced ore grades, scarcity of water, and setbacks in significant investment projects (Figure 3).

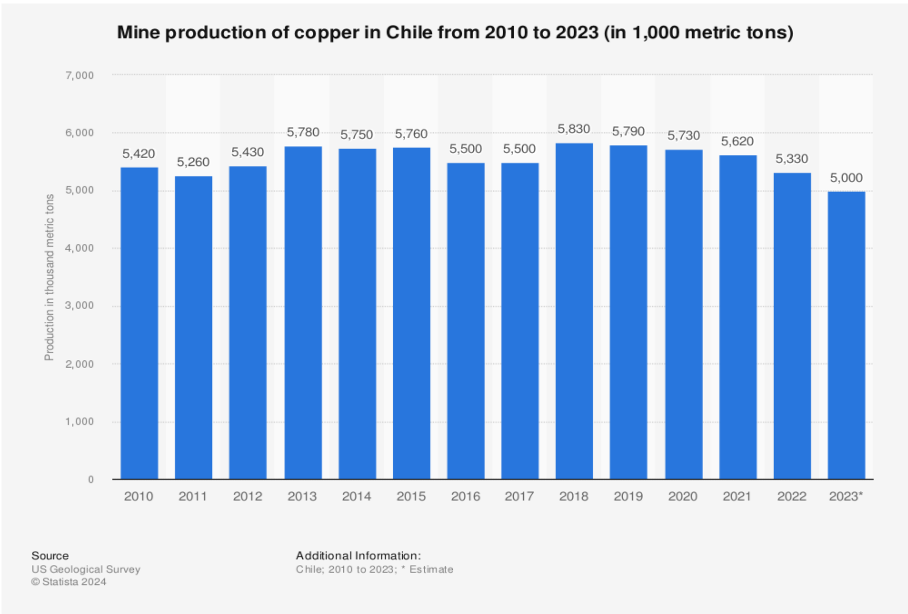


Fig. 3. Mine production of copper in Chile from 2010 to 2023 [4]

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

The mining industry in Chile deal with several significant challenges, one major issue is atmospheric pollution from smelting processes, leading to substantial investments in emission control technologies to reduce pollutants like sulfur dioxide and arsenic, another critical challenge is the impact on land use, where mining operations cause landscape modifications, erosion, and soil pollution, adversely affecting human health and biodiversity [5].

In 2023, Chile, being the world's top copper producer and a significant player in lithium production, has been focusing on sustainable exploitation, consumption, and responsible production of these minerals. The country's mining sector contributes significantly to its economy, accounting for 13.6% of its GDP in 2022 and 58% of total exports. The sector faces challenges such as investment uncertainties due to potential changes in the mining code through a new constitution and environmental concerns related to water usage and carbon footprint.

To address sustainability, the Chilean mining sector is investing in new technologies and practices aimed at reducing environmental impact and improving efficiency. These investments include:

- Renewable energy - by 2023, an estimated 63% of electricity used in mining operations is projected to come from clean energy sources, significantly reducing the sector's carbon footprint.
- Water management - the mining sector uses less than 4% of the total water consumed in Chile, with approximately three-quarters of the water used being recirculated. This practice minimizes the strain on water resources, especially in arid regions where mining operations are prevalent.
- Automation and remote operations - mining companies are adopting advanced technologies to enhance operational efficiency and safety, thereby reducing the environmental impact and improving working conditions.

Despite these efforts, the sector faces regulatory uncertainties, particularly concerning the management of lithium concessions following the announcement of plans to nationalize the lithium industry. This has left key questions unanswered regarding the future regulatory framework for lithium extraction.

Moreover, the Chilean government introduced a tax reform bill in July 2022, increasing mining royalties. This move aims to ensure that the economic benefits derived from mining activities are shared more equitably with the Chilean society, contributing to sustainable development [6].

In summary, Chile's approach to sustainable exploitation, consumption, and responsible production of copper and lithium in 2023 involves a combination of technological innovation, regulatory adjustments, and environmental stewardship. These efforts are designed to mitigate the environmental impact of mining, ensure the long-term viability of the sector, and align with the country's broader sustainability goals.

2.2 Copper production in Democratic Republic of Congo

According to a report from the Central Bank of the Democratic Republic of the Congo, the country produced 2.84 million tons of copper in 2023, more than Peru's 2.76 million tons, making it the second-largest producer of copper in the world. In terms of copper exports, Congo still lags behind Peru.

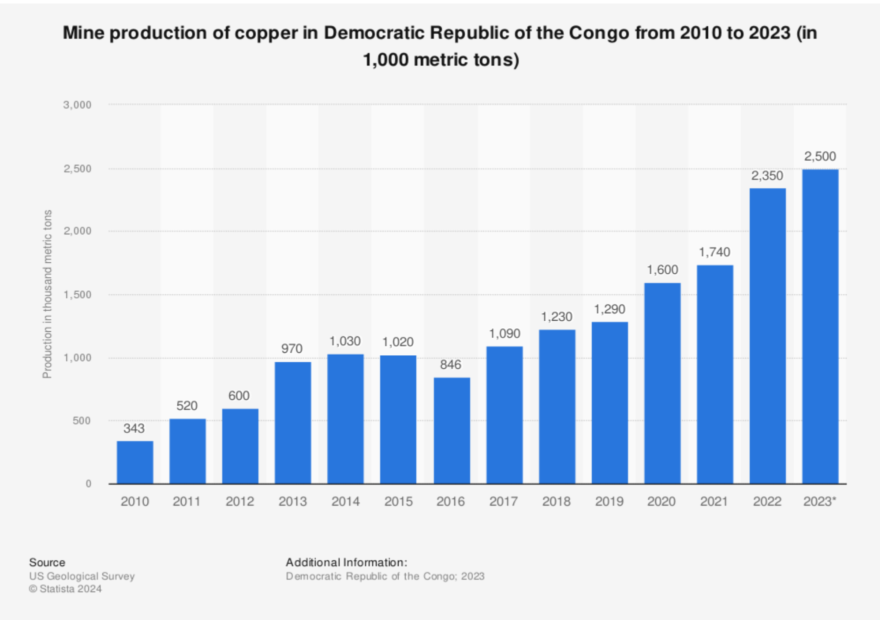


Fig. 4. Mine production of copper in Democratic Republic of the Congo [7]

The Democratic Republic of the Congo has produced (Figure 4) 1.62 million tons more copper in 2023 than it did in 2018 - a notable increase over the previous five years.

The Republic of Congo faced significant challenges in achieving sustainable exploitation, consumption, and responsible production of copper. The industrial mining of copper, particularly for rechargeable batteries, has led to severe human rights abuses, including forced evictions, sexual assault, arson, and beatings. Communities have been displaced from their homes and farmlands to accommodate the expansion of mining operations by multinational corporations.

The growing global demand for clean energy technologies has increased the need for copper and cobalt, essential components of lithium-ion batteries used in electric vehicles and mobile phones. This demand has exacerbated the situation, leading to more forced evictions and threats against local populations. There have been repeated breaches of legal safeguards and international human rights standards, with a lack of accountability and access to justice for those affected [8].

Efforts to promote transparency in the mining sector and create alternative sources of employment have been supported by organizations like the BMZ, aiming to harness the country's natural resources for sustainable development. However, the implementation of these measures has been slow, and much work remains to be done to ensure that mining activities contribute positively to the country's economic and social development [9].

The Extractive Industries Transparency Initiative (EITI) has been implemented in the DRC since 2007 to manage revenues from the extractive sector better and ensure they benefit the citizens. Despite these efforts, the country continues to face challenges related to corruption, mineral smuggling, and the impact of mining on the environment and local communities [10].

Responsible business conduct (RBC) is encouraged in the DRC through initiatives like the Global Compact Network DRC, which promotes sustainable and socially responsible policies among businesses. However, the legal framework to protect consumer rights and prevent adverse business impacts is lacking. Reports of child labor in artisanal mines have led to international pressure for reforms, with some progress made in eliminating the worst forms of child labor.

Environmental implications of copper mining in the DRC are significant, with negative impacts on biodiversity, air quality, and contributions to global warming. The extraction process involves deforestation and road construction, leading to habitat loss and increased greenhouse gas emissions [11].

Addressing these challenges requires a comprehensive approach that includes enforcing stricter regulations, promoting transparency, ensuring responsible business practices, and investing in sustainable development initiatives. It is crucial to balance the economic benefits of mining with the protection of human rights, the environment, and the well-being of local communities.

2.3 Copper production in Peru

According to the Ministry of Mines and Energy in Peru, the country's copper production increased by 13% year over year to a record high of 2.76 million tons in 2023 (Figure 2) from 2.44 million tons in 2022 (Figure 5). Due to sales from previous year's inventory, 2.95 million tons of copper were exported in 2023 - more than the yearly production.

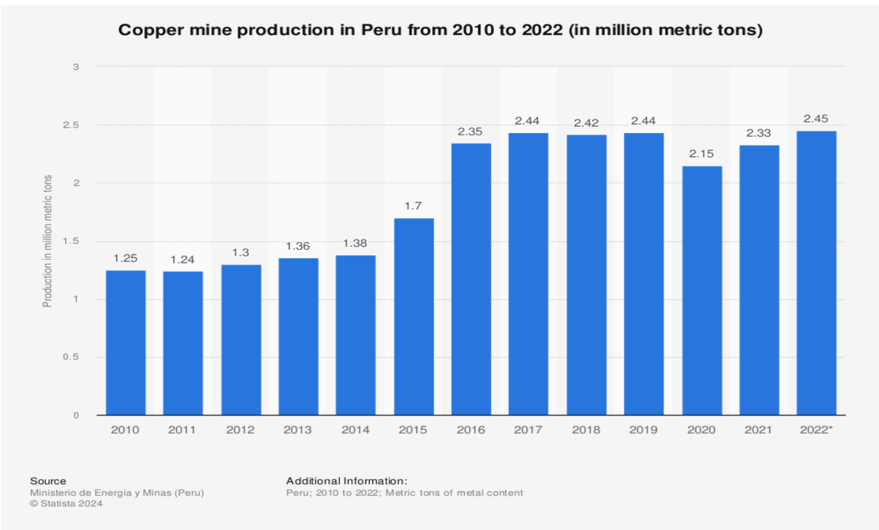


Fig. 5. Copper mine production in Peru [12]

The primary factors behind the increase in Peru's copper production include the full resumption of operations at the Las Bambas copper mine and the increased output from the Anglo American Group's Quellaveco copper mine in the Moquegua region. Quellaveco alone accounts for 11.6% of Peru's copper production, making it the world's fourth-largest copper mine.

Peru's copper production faced both opportunities and challenges in terms of sustainable exploitation, consumption, and responsible production. The country approved the expansion of the Cerro Verde mine, a significant copper producer, indicating a commitment to increasing copper output. This expansion, along with developments in other projects such as Cotabambas, Conga, Galeno, La Granja, and Michiquillay, aims to boost Peru's copper production to compete with Chile's levels.

However, Peru's copper industry is grappling with several structural issues, including declining ore grades, water scarcity, inadequate infrastructure, environmental disputes, and conflicts with local communities. These factors lead to operational disruptions and hinder production growth. The industry's future depends on addressing these challenges through improved mining policies, community engagement, and environmental stewardship [13].

Global copper production in 2023 saw an increase, with Peru playing a key role alongside Chile and the Democratic Republic of the Congo (DRC). Despite facing operational challenges, Peru's contribution to the global copper supply was significant, supported by projects like Quellaveco, Las Bambas, Toquepala, and Antapaccay [14].

2.4 Copper production in China

SMM data indicates that China's output of copper concentrate in metal content was 1.83 million tons in 2023, marking a decrease of 6.6% from 1.96 million tons in 2022 (Figure 6). Many factors contribute to this decline in output: lower copper grades, decreased production, aging domestic copper mines, and environmental regulations forcing the closure of many small private copper mines. More specifically, output reductions of about 50,000 to 60,000 tons were achieved at Western Mining, where the reduction was 13,000 tons, and at China Gold's Jiama Copper Gold Polymetallic Mine, they exceeded 40,000 tons.

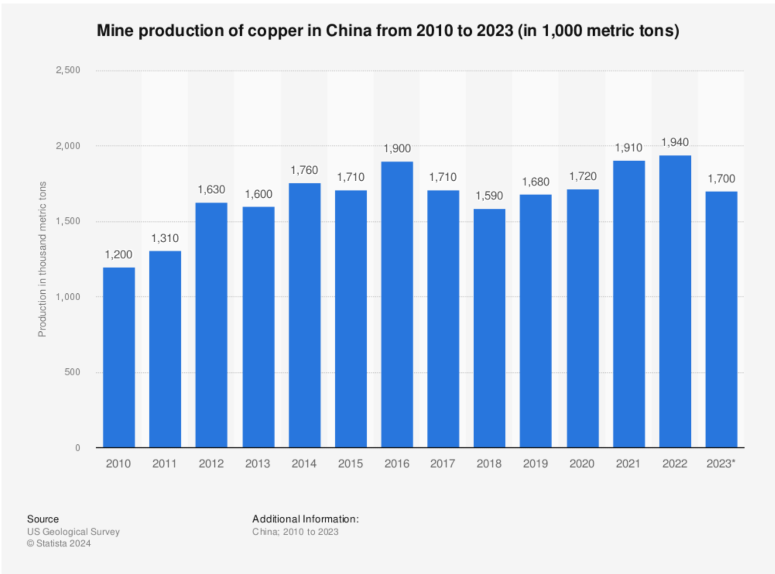


Fig. 6. Mine production of copper in China [15]

China's approach to sustainable exploitation, consumption, and responsible production of copper is influenced by several key factors, including domestic demand, global supply dynamics, and environmental considerations. As the world's largest consumer of copper, China's policies and actions significantly impact the global copper market.

The recovery of China's property market is a critical driver of copper demand. The Chinese government's comprehensive rescue package for the property sector, announced in November 2022, is expected to lead to a robust rebound in building and construction, which accounts for about 30% of total copper end-use in China.

China's push towards clean energy and the electrification of transportation also drives copper demand. Copper is a core material for renewable power grids and electric vehicle (EV) infrastructure, positioning it as a strategic resource in China's transition to a greener economy.

While China is a significant copper producer, it relies heavily on imports due to its vast consumption. Supply disruptions in key producing regions like Chile and Peru, due to factors such as road blockades and tax disputes, raise concerns about potential copper shortfalls. These disruptions can affect global copper prices and availability.

Low copper inventories in major exchanges, including the London Metal Exchange (LME) and the Commodity Exchange Inc. (COMEX), coupled with rising demand, suggest a tightening market. However, inventories in the Shanghai Futures Exchange (SHFE) grew following the Lunar New Year, indicating a seasonal adjustment rather than a fundamental shift in supply-demand dynamics [16].

The environmental impact of copper mining and processing is a concern globally, including in China. Sustainable practices, such as reducing water usage and minimizing waste, are increasingly important. However, detailed policies or initiatives specifically targeting the sustainability of copper production within China in 2023 are not explicitly mentioned in the provided sources.

Regulatory landscape influences the sustainability and responsibility of copper production and consumption. While the sources do not detail specific regulatory changes in 2023, the overall trend suggests a focus on stabilizing the property market and supporting clean energy transitions, which indirectly influence copper demand and production practices.

In conclusion, China's approach to copper in 2023 is shaped by its role as the leading consumer, with policies aimed at stimulating demand through the recovery of the property market and clean energy initiatives. Global supply risks and environmental considerations play a crucial role in shaping the sustainability and responsibility of copper production and consumption practices.

2.5 Copper production in U.S.A

According to data from the US Geological Survey (USGS), copper output from mines in the United States in 2023 totaled approximately 1.1 million tons. This marked a decrease (Figure 7) of 130,000 tons compared to 2022. The largest reductions came from the three largest projects in the US: Morenci, Bingham Canyon, and Safford. Specifically, Morenci saw a decrease of 38,000 tons, Bingham Canyon decreased by 28,000 tons, and Safford decreased by 18,000 tons, resulting in a combined reduction of 84,000 tons from these three projects alone.

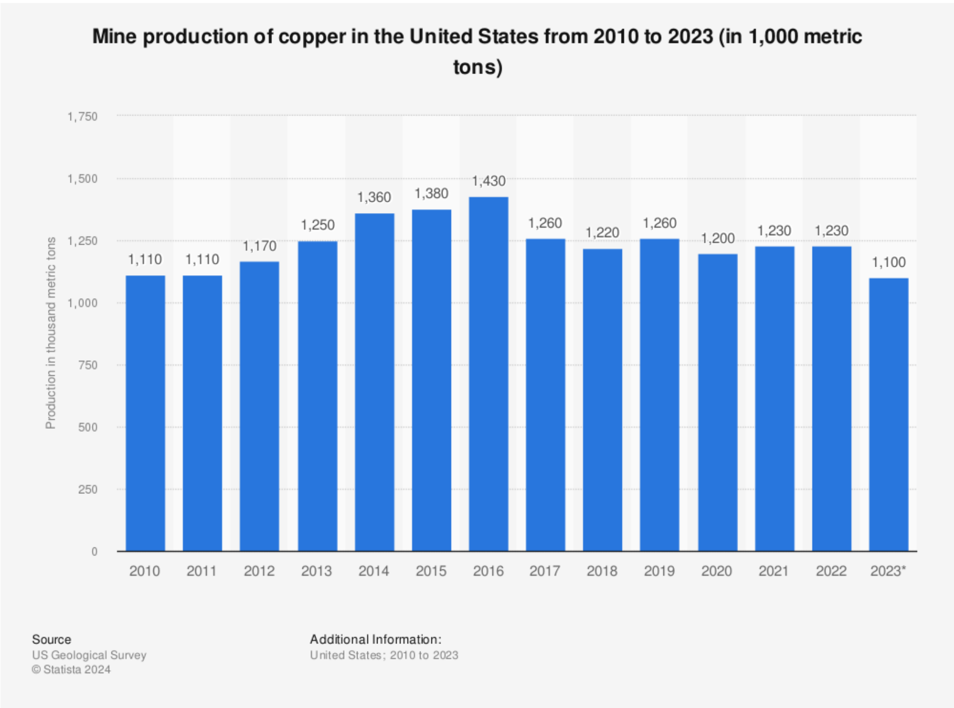


Fig. 7. Mine production of copper in the U.S. [17]

The United States continued to emphasize sustainable exploitation, consumption, and responsible production in its copper mining sector. The country's copper production, primarily concentrated in the western states like Arizona, Nevada, New Mexico, and Utah, faced challenges due to declining ore grades, regulatory hurdles, and environmental considerations. Despite these challenges, the U.S. mining industry has been actively pursuing strategies to enhance sustainability and efficiency.

Key strategies and developments in the U.S. copper mining sector in 2023 include:

Adoption of responsible mining guidance - U.S. copper miners have increasingly adopted guidelines for responsible mining to achieve sustainability goals. The International Copper Association (ICA) created the Copper Mark in 2019, an assurance system for responsible copper production. Over 25% of globally mined copper is now produced by Copper Mark-assured sites, indicating a commitment to environmental, social, and governance (ESG) standards.

Investment in digitalization and technology - in order to decrease their environmental impact and increase operational efficiency, miners are investing in digitalization and new technologies. This includes automation, remote operations, and data analytics to optimize mining processes and resource management [18].

Focus on recycling and low-carbon products - with the growing demand for sustainable copper, companies are investing in recycling facilities and developing low-carbon copper products, approximately 32% of copper used annually comes from recycling, and efforts are underway to increase the recovery rate from electronic scrap and other complex applications.

Community engagement and environmental considerations - projects like the Resolution Copper project, a joint venture between Rio Tinto and BHP, have faced opposition from Native American groups and delays due to environmental and social impact assessments. Engaging with local communities and incorporating their feedback into project planning has become crucial for gaining approval and ensuring the sustainability of mining operations [19].

Regulatory challenges and policy adjustments - the U.S. mining sector navigates a complex regulatory landscape, with ongoing discussions around mining policies, environmental protections, and community relations. Companies are striving to maintain their sustainability profiles while adapting to changing regulatory environments.

In summary, the U.S. copper mining industry in 2023 focused on enhancing sustainability through responsible mining practices, technological innovations, recycling initiatives, and community engagement. These efforts aim to ensure that copper production supports the country's clean energy transition while minimizing environmental impact and promoting social responsibility.

3. Conventional techniques in copper mining

Conventional methods of copper ore involve a series of physical, chemical, and electrochemical processes, with the conversion of copper ores depending on the ore source, local environmental regulations, and other factors. Here are the key traditional methods (Figure 8):

1. Mineral Processing

The first step in mineral processing for copper involves liberating the copper minerals and eliminating waste materials like silica, pyrite, alumina, and limestone. Using this method, valuable nonferrous minerals and copper minerals are concentrated to create a product that contains 20–30% copper. To guarantee that the copper minerals are separated from the waste materials, called gangue, the ore is crushed several times and finely ground after being received from the mine.

For oxide ores, crushing and grinding should only be done to the degree necessary to expose the mineral surfaces to the leaching agent. On the other hand, selective flotation, which calls for the ideal level of liberation, typically comes after the crushing and grinding stage for sulfide ores. During the flotation process, air bubbles are created by mechanically and pneumatically stirring the finely ground ore, water, and special reagents. These bubbles attract the copper minerals, carrying them to the surface where they are collected as froth, leaving the gangue minerals behind. This froth is then dewatered and filtered to produce a filter cake that is sent to a copper smelter [20].

Oxide ores are generally processed using hydrometallurgy, which involves heap leaching, solvent extraction, and electrowinning. Sulfide ores, on the other hand, are processed using pyrometallurgy, which includes froth flotation, thickening, smelting, and electrolysis. Froth flotation is a key process in separating copper minerals from gangue by adding chemicals that make the copper particles hydrophobic, allowing them to attach to air bubbles and be skimmed off for further processing [21].

2. Smelting or Leaching

The second step eliminates a significant amount of impurity elements, especially sulfur and iron in the case of sulfide ores. Procedures like smelting or leaching can be used to accomplish this. Comminution is the process of crushing the rock to create small particles in order to treat sulfide ores, such as chalcopyrite. The gangue is then extracted from these particles by froth flotation [22].

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

3. Refining

The final step entails refining to get rid of any remaining impurity elements and create a 99.99 % pure copper product. Usually, electrolysis is used to accomplish this, depositing copper ions as copper on the cathode. Traditionally, lead-based alloys were used as the anodes for this process, however, more recent techniques employ titanium or stainless steel.

4. Electrolysis

Electrolysis is a crucial step in the refining process, where copper ions are deposited as copper on the cathode. The anodes for this process were traditionally lead-based alloys, but newer methods use titanium or stainless steel. The cathode is either a strip of very pure copper which the new copper plates on to, or stainless steel which it has to be removed from later [23].

5. Solvent Extraction (SX) and Electrowinning (EW)

In order to obtain impure solutions of copper sulfate from oxidized ores, which are composed of silicates, carbonates, and sulfates, the crushed ore is leached with sulfuric acid. The SX/EW process involves using solvent extraction (SX) to concentrate these solutions and traditional electrowinning (EW) to remove the copper content [24].

The extraction methods are always being improved and developed to extract copper as efficiently as possible from a wide range of ores that come from sources all over the world.

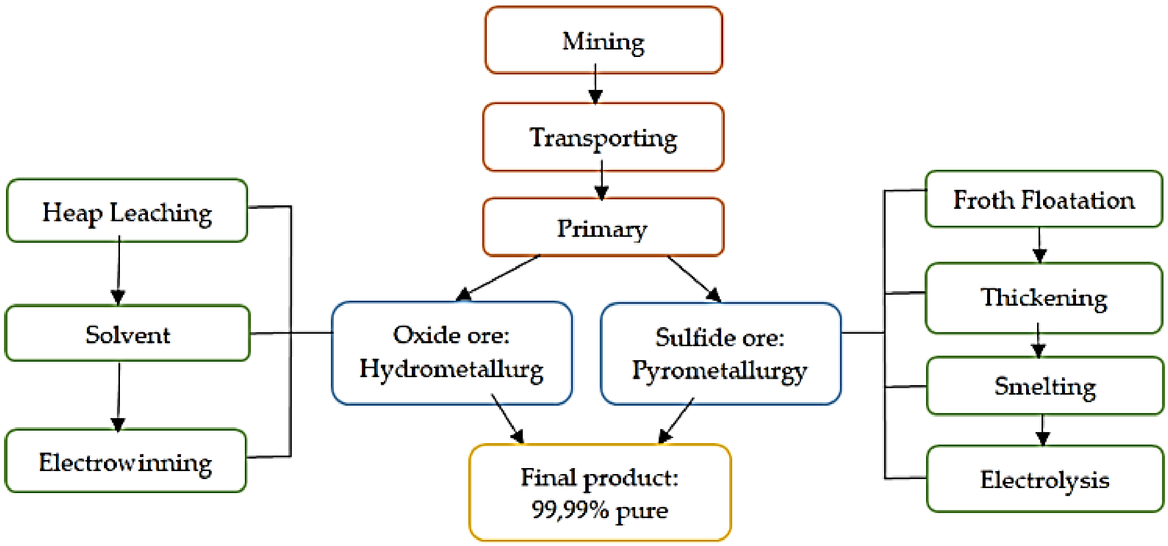


Fig. 8. Copper ore (Oxide ore and Sulfide ore) processes

The environmental impact of conventional techniques of extraction for copper ore is significant and multifaceted, affecting both the immediate surroundings of mining operations and broader environmental and social impacts. Here are the key environmental impacts:

Water pollution

Traditional copper mining methods, especially open-pit mining, can lead to severe water pollution. Heavy metals, chemicals, and other pollutants can contaminate nearby water sources as a result of mining operations. This pollution can affect the quality of drinking water and aquatic ecosystems, posing risks to both human health and biodiversity.

Air quality

The dust and emissions from mining activities can significantly degrade air quality in the surrounding areas. Heavy machinery and the use of chemicals for leaching minerals contribute to air pollution, which can have negative effects on respiratory health and the overall quality of life for local communities.

Soil contamination

Mining activities can lead to soil contamination, affecting agricultural lands and ecosystems. The use of chemicals for leaching minerals can leave behind residues that can contaminate soil, posing risks to agricultural productivity and the health of local flora and fauna.

Land use and landscape alteration

Open-pit mining, in particular, can cause significant alterations to the landscape, including the creation of large holes in the ground and the displacement of local wildlife. These changes can have long-term impacts on local ecosystems and biodiversity [25].

Energy consumption

The energy-intensive nature of traditional copper mining processes, including milling and smelting, contributes to high greenhouse gas emissions. This energy consumption is a major factor in the environmental impact of copper production, contributing to climate change and air pollution [26].

Waste management

Traditional mining operations often generate large volumes of waste, including tailings (residual waste from the leaching process), which can be harmful to the environment if not properly managed. The disposal of these wastes can lead to soil and water contamination, further exacerbating the environmental impact. [27]

Impact on indigenous cultural sites

Mining activities can also pose risks to Indigenous cultural sites, including archaeological sites and sacred lands, which can be irreversibly damaged or destroyed by mining operations.

These environmental impacts highlight the need for sustainable mining practices and technologies that minimize the environmental footprint of copper ore extraction.

4. Case study – Rosia Poieni

Rosia Poieni is situated in the Apuseni Mountains, a mountain range that is part of the larger Carpathian Mountain system in western Romania. The Roşia Poieni mining objective (Figure 9) covers an area of 50 km^2 and is situated on the territory of Lupşa commune, Alba County, in the area Poieni, Vîrsii, Curmătura peaks and the southern slope of the Valley Aries, and from a geographical point of view it falls within the unit structural Metaliferi Mountains. The region is characterized by its rugged terrain and rich mineral resources.

Mining in the Apuseni Mountains dates back to ancient times, with evidence of Roman activity in the area. Rosia Poieni has been a focal point for mining operations for several decades, particularly since the mid-20th century, when industrial-scale mining began.

The open-pit mining operation began in 1978 in the Abrud - Muşca - Bucium area, with copper production commencing in 1983. Feasibility studies identified the Roşia Poieni deposit as the largest disseminated copper and gold deposit in Romania and the second largest in Europe, containing 65% of Romania's copper reserves. The mining area spans 21.9 km² and is situated within the territories of Lupşa, Bucium, Bistra, and Roşia Montană communes, in the northeastern Metaliferi Mountains. The region features rugged terrain with deep valleys and elevated platforms, shaped by volcanic activity. There are multiple sloughy areas, negative forms, and dislevelments on the valley slopes, on platforms as well as in valley terraces or meadows. The area surrounding the deposit is primarily covered by clays and Senonian marls, which have poor consistency. The high relief energy, especially between elevations of 900 m and 400 m, also contributes to the frequent erosion of the land [28].

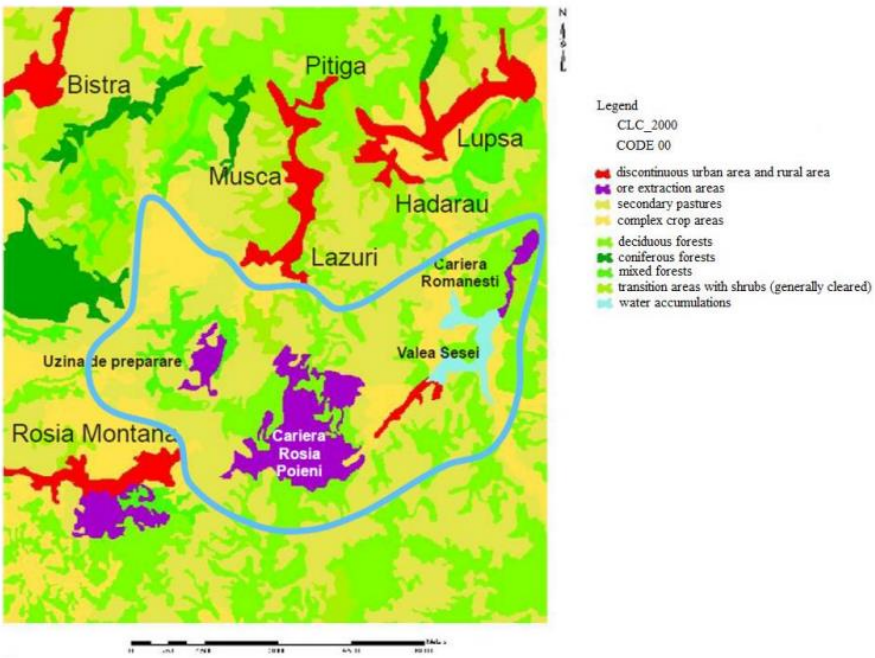


Fig. 9. The perimeter of Roşia Poieni mining project (blue line) [29]

4.1 Current state of Rosia Poieni copper mine

The current state of the Roșia Poieni Copper Mine (Figure 10), is characterized by its significant environmental and social impacts, as well as its economic contributions to the country.

With estimated reserves of 1.5 billion tonnes of ore grading 0.36% copper, Roșia Poieni represents the largest copper reserve in Romania and the second largest in Europe. Miocene eruptive sub-volcanoes (fundoaia andesites or micro-diorite) enclose it.

Fig. 10. Rosia Poieni copper mine [30]

The Fundoaia body measures 660 m (2,170 ft)÷740 m (2,430 ft)/820 m (2,690 ft)÷956 m (3,136 ft). Its shape is that of a vertical column rising to a height of 1,180 m (3,870 ft) (+1,030 m (3,380 ft) → −150 m (−490 ft). The eruptive body interacts with sedimentary Cretaceous rocks and andesite necks (Poieni, Curmătura, Melciu, Piatra Tichileu, and Jgheabului Hills) via tectonic breccia. The porphyry copper deposit is primarily composed of tiny veinlets, nests, and disseminations (0.02·- 3 cm) of magnetite, chalcopyrite, and pyrite; gold is also present in the chalcopyrite and pyrite; and secondary minerals, which are developed in microdioritic rocks, include bornite, covellite, chalcocite, sphalerite, galena, molybdenite, germanite, malachite, and azurite [29].

The mine has been a source of environmental concern, particularly due to its waste management practices. Since its opening in the 1980s, the operator has dumped mining waste into surrounding valleys, leading to the creation of a vast settling basin in the Șesii valley. This basin has expanded significantly, covering more than 130 hectares and receiving over 130 million tonnes of tailings, with 14,000 tonnes arriving daily. The tailings contain various metals, including copper, iron, zinc, lead, and arsenic, posing a risk to the environment and local communities.

The discharge of acidic sludge into watercourses has led to a phenomenon known as "acid mine drainage," which has significantly increased the acidity of the water. This has raised concerns about the impact on local ecosystems and the quality of water sources.

The mining activities have had a profound impact on local communities. The construction of a settling pond near the village of Curmătură led to the eviction of more than 300 families from their homes. Additionally, the expansion of the Geamăna settling basin has erased the village of Geamăna, highlighting the displacement and relocation challenges faced by local communities [30].

Despite the environmental and social challenges, the Roșia Poieni Copper Mine remains a significant economic asset for Romania. It produces around 11,000 tonnes of copper annually, representing 65% of the total copper reserves in the country. The mine is owned by CupruMin, a state-owned company, and its operations contribute to the national economy.

The mine employs approximately 550 people, with daily mining activities involving the extraction of 14,000 tonnes of rock. The ore is processed into a powder containing 20% copper, which is then exported, primarily to China, where it is transformed into copper metal.

4.2 Methods of copper ore exploitation at Rosia Poieni

The Rosia Poieni Copper Mine, located in the Apuseni Mountains of Romania, employs several methods for the exploitation of copper ore.

The mine utilizes open-pit mining, a method that involves extracting copper ore from the earth's surface. This technique is characterized by the removal of a large volume of earth and rock to access the ore beneath. The open-pit method is particularly effective for deposits of copper ore that are found in large, shallow layers.

Once the ore is extracted, it is sent to the ore processing plant. Here, the ore is crushed and chemically

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

treated, specifically using the flotation method. This process involves the use of chemicals to separate the copper ore from the waste rock. The ore is then concentrated into a powder containing 20% copper. This concentrated ore is the product that is exported, primarily to China, where it is transformed into copper metal.

A significant portion of the mining activities involves the management of waste rock. Half of the mined rock is sent to the ore processing plant, while the other half is dumped into a waste rock pile on the edge of the pit. This waste rock pile is a notable environmental concern, as the mining waste has been dumped into surrounding valleys, leading to the creation of a vast settling basin in the Şesii valley. This basin has expanded significantly, covering more than 130 hectares and receiving over 130 million tonnes of tailings, with 14,000 tonnes arriving daily. The tailings contain various metals, including copper, iron, zinc, lead, and arsenic, posing a risk to the environment and local communities.

The mining operations at Rosia Poieni have raised significant environmental and social concerns. The dumping of mining waste into the surrounding valleys has led to the creation of a vast settling basin, which has expanded significantly over the years. This basin has become a significant environmental concern, as the acidic sludge contains various metals that pose a risk to the environment and local communities. Additionally, the mining activities have led to the displacement of local communities, with over 300 families being forced from their houses in order to make room for the first settling pond close to Curmătură village.

The main exploitation activities at Rosia Poieni are [31] (Figure 11):

- Extracting the mining mass through drilling, blasting, loading, and transportation in a open – pit mine;
- Store the quarry waste in the tailing dumps at Geamăna, Cuibaru and Obârșia Muntari;
- The traditional methods of processing copper ore, which include crushing, grinding, flotation, and filtration to produce copper concentrate;
- Thickening, gravitational transport and sterile hydromass storage in Valea Şesei and Valea Ştefancei tailings ponds;
- Tailings ponds, where flotation tailings from the preparation plant are stored, and tailings dumps, where the quarry sterile obtained from the extraction activity of mining mass are stored, are the tailings dumps for which the environmental balance sheet assessment is made.

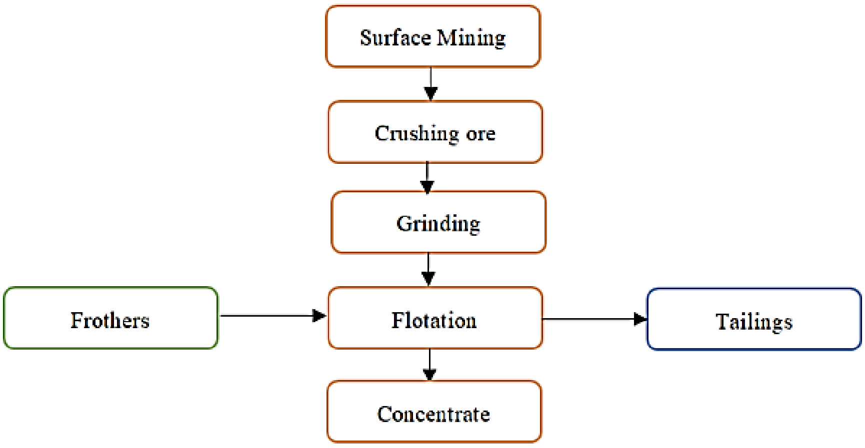


Fig. 11. Methods of copper ore exploitation at Rosia Poieni

The extraction of the mining mass in the Roşia Poieni Quarry is carried out:

- in steps with a height of 15 m.
- no. of steps: 24
- steps width: 12 m
- final height at the hearth of the quarry: 760 mdM, current height of the hearth of the quarry 850 m
- pit depth: 360 m
- drilling methods are applied

The mining mass extracted from the quarry is loaded (Figure 12) with electric excavators type EKG 4.6 m^3, 5 m^3 and 8 m^3 Caterpillar front loaders with a bucket of 12.5 m^3, in 55 and 110 t type DAC and 91 t type KOMAKTSU and Caterpillar, which are directed as follows:

- tailings (overburden) at Cuibarului and Geamăna dumps;

• the ore is transported to the gyratory crusher KKD 1500/180, and after crushing the crushed ore is transported to the preparation plant;

The leg with a relay of conveyor belts with Lt = 2440 m and width l = 1.4 m [32].

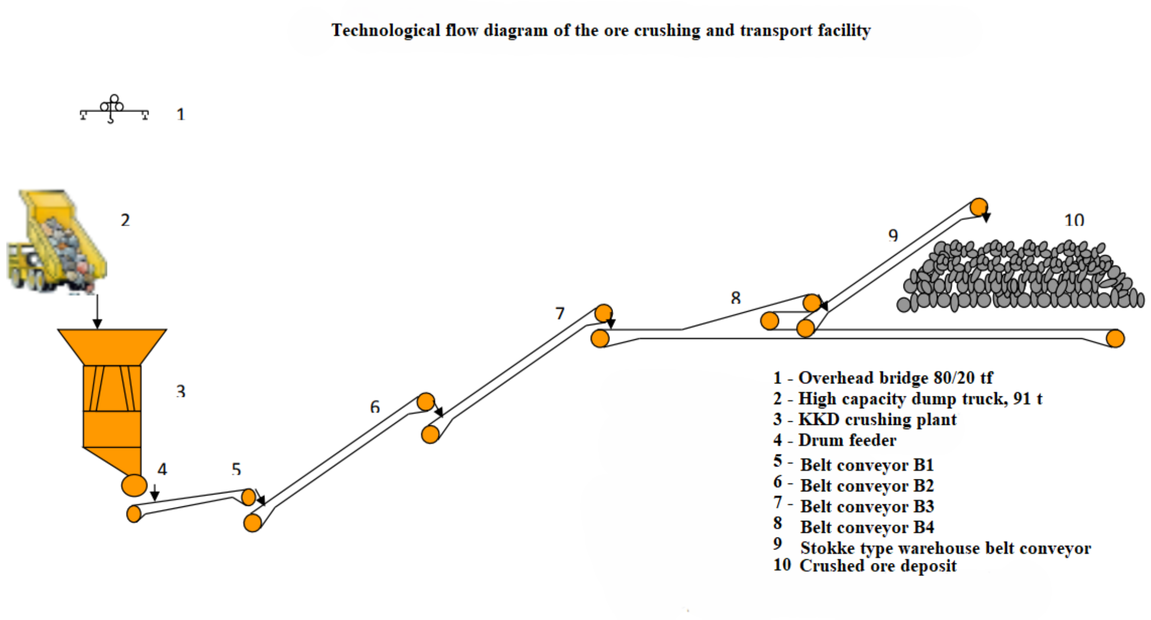


Fig. 12. Technological flow diagram of the ore crushing and transport facility [32]

Preparation plant Dealul Piciorului

There are 2 grinding-flotation lines in operation at the preparation plant, each line having an annual processing capacity of approx. 2,000,000 t/year.

The main technological phases of the current preparation process are (Figure 13):

- crushing of ore extracted from the quarry from size 0 - 1,200 mm, to 0 - 300 mm in the rotary crusher type KKD - 1500/180;
- transport of the crushed ore to the storage of the preparation plant is done with a bus lane relay with a total length of 2,440 mm provided at the end of unloading with a "Stoker" type unloading installation;
- wet grinding of the ore in two stages and its classification in batteries of hydrocyclones;
- selective flotation of copper ore in two modernized preparation lines equipped with 17 m^3 flotation cells, followed by two re-flotations of the primary concentrate. The first two refloats are done in pneumo-mechanical cells of 5.7 m^3 and the third re-flotation can be done in pneumo-mechanical cells of 2.8 m^3 (if this is the case with regard to the quality of the obtained copper concentrate, respectively its content between 18 ÷ 20 % Cu). The dosed flotation reagents are: lime, collecting reagents, foaming reagents.
- thickening of the concentrate in mechanical thickeners with peripheral actuation by Φ 25 m up to densities of 1900 ÷ 2,300 g/l;
- drying of the thickened concentrate is done by filtering with a filter press type PF-25 A1H60 (LAROX) with a filtration surface of 25.2 m^2;
- the storage of the filtered concentrate is done on an open platform, in view shipping to beneficiaries;
- the tailings thickening is carried out in thickeners with a diameter of Φ 80 m at dilution of 2.25:1 liquid/solid with water recirculation in the technological flow of the preparation plant;
- the hydraulic gravity transport of the thickened tailings through steel pipes of and PEHD, with total length L= 7.66 km at the Valea Şesei settling pond;
- decanting and storing tailings in the Valea Şesei settling pond or in case of damage in the settling pond Valea Ştefancei 2 [33].

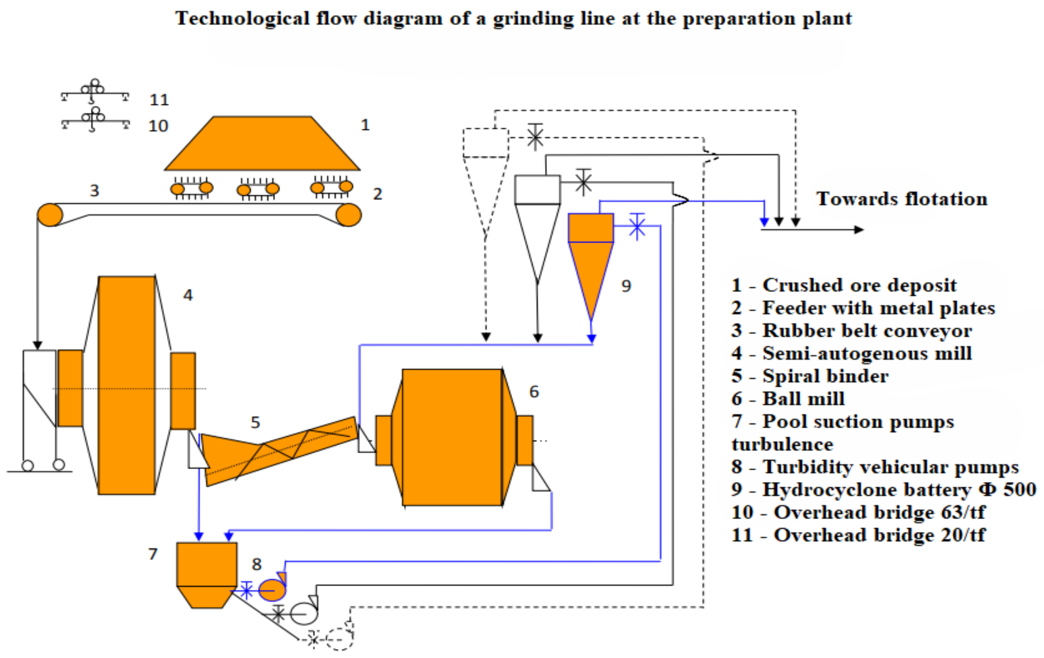


Fig. 13. Tehnological flow diagram of a grinding line at the preparation plant [33]

In summary, the Rosia Poieni Copper Mine employs open-pit mining and ore processing methods to extract and concentrate copper ore. However, the mining activities have raised significant environmental and social concerns, particularly related to waste management and the displacement of local communities.

4.3 The impact on the environment generated by the Rosia Poieni mining operatios

The exploitation of Rosia Poieni, Europe's second-largest copper mine, has significant environmental impacts due to its mining practices and waste management. Here are the key environmental concerns [34]:

- Water contamination

Mining activities at Rosia Poieni have led to severe contamination of both surface and underground water sources. The acidification and movement of metals, including copper, iron, zinc, lead, and arsenic, have negatively affected the water quality across the region. This contamination affects the Arieş river basin, impacting not just the immediate area but also areas as far as 80 km downstream.

- Soil and air pollution

Tailings and waste rock are produced in huge quantities during the mining process, which are often dumped in nearby valleys. This practice leads to soil contamination and can contribute to air pollution through dust emissions. The continuous dumping of tailings into settling basins like the one near Geamăna village has resulted in the expansion of these basins, covering extensive land areas and posing risks to the surrounding ecosystem.

- Habitat destruction

The creation of settling ponds and natural ecosystems are being destroyed and local communities are being uprooted as a result of the growth of mining operations. For instance, more than 300 families were evicted to build a settling pond near Curmătură village, and the village of Geamăna has been partially submerged (Figure 14) by the expanding settling basin.

- Biodiversity loss

The pollution and habitat destruction resulting from mining activities have led to a loss of biodiversity. Incidents such as the death of thousands of fish in the Arieş river due to negligence in activating control devices highlight the direct impact on aquatic life. The overall degradation of the environment threatens the survival of various species in the region.

- Legal and regulatory issues

Despite the environmental damage, there has been limited action against the mining company, Cupru Min. Fines imposed by local authorities have been minimal compared to the extent of the damage, indicating a lack of effective enforcement of environmental regulations. Additionally, the European Court of Justice condemned Romania in 2016 for breaching its obligations under EU directives on waste management from extractive industries, underscoring the broader regulatory challenges [35].

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

Fig. 14. Geamăna village in 1970, before flooding and in present [36]

In summary, the exploitation of Rosia Poieni has led to widespread environmental degradation, affecting water resources, soil quality, air quality, and biodiversity. The ongoing issues highlight the need for stricter environmental regulations and enforcement to mitigate the adverse effects of mining activities.

4.4 Recommendations for implementing policies, techniques and sustainable technologies in the Rosia Poieni mining exploitation

To enhance environmental sustainability and operational efficiency at the Rosia Poieni Mining Exploitation, consider implementing the following policies, techniques, and sustainable technologies:

Policies:

• Environmental impact assessment (EIA) - mandate comprehensive EIA's before initiating new mining activities to assess potential environmental impacts and develop mitigation strategies.

• Adopt sustainable land management practices - implement practices that balance environmental protection, economic viability, and social equity. This includes managing land use changes, minimizing ecosystem disturbances, and ensuring water quality management.

• Waste management - implement strict waste management protocols to minimize pollution and promote recycling of mining waste where possible [37].

• Secure financial guarantees for environmental liabilities - ensure that mining companies establish and maintain adequate financial guarantees for environmental liabilities, including waste management and site rehabilitation. This helps mitigate the financial risks associated with environmental damage and ensures funds are available for remediation efforts [38].

• Community engagement - establish regular dialogue with local communities to address concerns and ensure transparency in operations.

• Enhance environmental and social governance - Urge mining firms to implement ethical and environmentally friendly procedures that support sustainable growth. This involves creating and sharing value across economic, environmental, and social dimensions, and considering environmental and social practices as part of the company's competitive advantage.

Techniques:

• Precision mining - utilize advanced drilling and blasting techniques that reduce overburden removal and increase ore extraction efficiency.

• Water management - develop sophisticated water management systems to recycle water within the mining process, reducing freshwater consumption and minimizing wastewater discharge.

• Revegetation and land rehabilitation - after mining activities cease, prioritize the rehabilitation of mined areas through revegetation using native plant species to restore ecological balance.

Sustainable Technologies:

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 32-50

• Renewable energy integration Examine ways to power mining operations with renewable energy sources, like wind turbines or solar panels, to lessen dependency on fossil fuels.

• Electric vehicles - transition to electric vehicles and machinery within the mine site to lower carbon emissions and improve air quality.

• Smart monitoring systems - deploy IoT-based monitoring systems to track environmental parameters like air quality, soil health, and water levels in real-time, enabling proactive management and intervention [39].

• I-Rox technology, developed by I-Pulse Inc. and I-ROX SAS, utilizes pulsed-power technology to deliver short, high-intensity bursts of energy that can efficiently shatter rocks and mineral ores. This method targets the tensile weaknesses in rocks, offering a potentially revolutionary approach to mining processes, especially in the areas of crushing and grinding ores, which are traditionally the most energy- and capital-intensive aspects of mining [40].

It is mentioned that Ivanhoe Mines and I-ROX are working together to investigate the possible integration of I-Pulse technology throughout Ivanhoe's operations. The goal of this partnership is to change the way that mining affects the economy and environment by utilizing the mining and processing experience of Ivanhoe Mines, as well as the pulsed-power technology and knowledge of I-Pulse and I-ROX.

Traditional mining processes, particularly comminution (crushing and grinding), are highly energy-intensive, accounting for approximately 4% of global electrical energy consumption. I-Rox technology aims to significantly reduce this power usage through the application of pulsed-power technology, which uses short, high-intensity bursts of energy to fracture rocks [41].

The reduction in energy consumption directly translates to a decrease in carbon emissions, aligning with the mining industry's goals of moving towards carbon neutrality. I-Rox aims to cut the carbon footprint of mines worldwide by as much as 80% [42].

By adopting these measures, Rosia Poieni Mining Exploitation can significantly reduce its environmental footprint, enhance operational efficiency, and contribute positively to the local community and ecosystem.

5. Conclusions

In conclusion, the implementation of sustainable techniques and technologies at Rosia Poieni Mining Exploitation is both feasible and essential for mitigating environmental damage, enhancing community engagement, and guaranteeing the mining industry's long-term sustainability. By adopting strategies such as comprehensive rehabilitation and restoration, effective water and waste management, energy efficiency improvements, community engagement, and rigorous monitoring and compliance, Rosia Poieni can transition towards a model of sustainable mining.

These approaches not only address immediate environmental concerns but also contribute to the broader goals of environmental sustainability and innovation in the rehabilitation of abandoned mining sites. The successful application of these methods requires collaboration between the mining company, local communities, and regulatory bodies to ensure that all stakeholders benefit from the adoption of sustainable practices.

Moreover, the integration of innovative technologies and practices can lead to significant improvements in operational efficiency, reduced environmental impact, and enhanced social responsibility. This aligns with global trends towards sustainable development in the mining sector, emphasizing the importance of balancing economic growth with environmental stewardship and social equity.

By integrating these sustainable practices, Rosia Poieni Mining Exploitation can mitigate its environmental footprint, enhance community relations, and ensure the longevity of its operations through responsible resource management.

Therefore, the potential for implementing sustainable techniques and technologies at Rosia Poieni is substantial, offering a pathway towards responsible mining that benefits both the environment and the community.

References

[1] **Malan, S.,** 2021
How to advance sustainable mining, Earth Negotiation Bulletin, International Institute for Sustainable Development (IISD). Available online: https://www.iisd.org/system/files/2021-10/still-one-earth-sustainable-mining.pdf (Accessed on 14 March 2024)

[2] **Reichl, C., Schatz, M.,** 2022
World Mining Data 2022, Minerals Production, Vol. 37, Vienna.

[3] **Venditti, B., Parker, S.,** 2024
Visualizing Copper Production by Country in 2023. Available online: https://www.visualcapitalist.com/visualizing-copper-production-by-country-in-2023/ (Accessed 14 March 2024)

[4] **Jaganmohan, M.,** 2024
Chile: copper mine production 2010 – 2023. Available online: https://www.statista.com/statistics/254845/copper-production-of-chile/ (Accessed on 16 March 2024)

[5] **Ghorbani, Y., & Kuan, S. H.,** 2016
A review of sustainable development in the Chilean mining sector: past, present and future, International Journal of Mining, Reclamation and Environment, 31 (2), pp. 137–165.

[6] *****, 2023
Mining, Chile - Country commercial guide. Available online: https://www.trade.gov/country-commercial-guides/chile-mining (Accessed on 16 March 2024)

[7] **Jaganmohan, M.,** 2024
Copper mine production in DR Congo 2010 – 2023. Available online: https://www.statista.com/statistics/1276790/copper-production-in-democratic-republic-of-the-congo/ (Accessed on 16 March 2024)

[8] *****, 2023
Democratic Republic of the Congo: Industrial mining of cobalt and copper for rechargeable batteries is leading to grievous human rights abuses, Amnesty International, Press release from 12 September 2023. Available online: https://www.amnesty.org/en/latest/news/2023/09/drc-cobalt-and-copper-mining-for-batteries-leading-to-human-rights-abuses/ (Accessed on 24 March 2024)

[9] ****,** 2023
Democratic Republic or the Congo, BMZ. Available online: https://www.bmz.de/en/countries/democratic-republic-of-the-congo (Accessed on 03 April 2024)

[10] **U.S. Department of State**, 2023
Report: 2023 Investment Climate Statements: Democratic Republic of the Congo. Available online: https://www.state.gov/reports/2023-investment-climate-statements/democratic-republic-of-the-congo/ (Accessed on 09 April 2024)

[11] *****, 2021
Wilson Centre, Press release from 1 September 2021. Available online: https://www.wilsoncenter.org/blog-post/drc-mining-industry-child-labor-and-formalization-small-scale-mining (Accessed on 14 April 2024)

[12] **Jaganmohan, M.,** 2024
Copper mine production in Peru 2010 – 2023. Available online: https://www.statista.com/statistics/789003/copper-production-peru/ eru: copper production 2023 | Statista

[13] **Barnes, J., Mpangala, L.,** 2024
Peru greenlights Cerro Verde expansion, Project blue, Press release from 11 June 2024. Available online: https://projectblue.com/blue/news-analysis/909/peru-greenlights-cerro-verde-expansion (Accessed on 15 June 2024)

[14] *****, 2023
Global copper supply in 2023 will be supported by increased output from the DRC, Peru, and Chile, Mining technology, Press release from 17 November 2023. Available online: https://www.mining-technology.com/analyst-comment/global-copper-supply-2023/ (Accessed on 15 June 2024)

[15] **Textor, C.,** 2024
China's copper mine production 2010 – 2023. Available online: https://www.statista.com/statistics/254847/copper-production-of-chile/ (Accessed on 15 June 2024**)**

[16] **Reddy, R.,** 2024
Copper Update: China's Demand and Renewed Supply Risks to Be Supportive of a Market Rebound, Globalx, Press release from 12 April 2024. Available online: https://www.globalxetfs.com/copper-update-chinas-demand-and-renewed-supply-risks-to-be-supportive-of-a-market-rebound/ (Accessed on 28 May 2024)

[17] **Jaganmohan, M.,** 2024
Copper mine production in the U.S. 2010 – 2023. Available online: https://www.statista.com/statistics/254849/copper-production-of-the-us/(Accessed on 28 May 2024)

[18] **Butler, R.,** 2024
How copper miners can remain competitive amid transition towards the greener economy, EY, Press release from 07 March 2024. Available online: https://www.ey.com/en_us/insights/mining-metals/sustainable-and-efficient-operations-for-copper-miners (Accessed on 30 May 2024)

[19] *****,** 2024
Western USA Copper Production and Development, Global business reports, Press release from 05 April 2024. Available online: https://www.gbreports.com/article/western-usa-mining-copper-production-and-development

[20] **Butts, A., Taylor, J. C., and Schlechten, A. W.,** 2023
Copper processing, Encyclopedia Britannica. Available online: https://www.britannica.com/technology/copper-processing Ores (Accessed on 02 June 2024)

[21] **Stanley, J., Wilkinson, S.T., Moreno Ramírez, D., Maier R.M., & Chief, K.,** 2015
Tribal Mining Educational Modules: Copper Mining and Processing. Available online: https://www.superfund.arizona.edu/resources/learning-modules-english/copper-mining-and processing (Accessed on 3 June 2024)

[22] *****,** 2024
Copper extraction, Wikipedia. Available online: https://en.wikipedia.org/wiki/Copper_extraction (Accessed on 4 June 2024)

[23] **Clark, J.,**
The extraction of copper, Supplemental Modules and Websites (Inorganic Chemistry). Available online: https://batch.libretexts.org/print/url=https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Supplemental_Modules_and_Websites_(Inorganic_Chemistry)/Descriptive_Chemistry/Elements_Organized_by_Block/3_d-Block_Elements/1b_Properties_of_Transition_Metals/Metallurgy/The_Extraction_of_Copper.pdf (Accessed on 7 June 2024)

[24] **Calcutt, V.,** 2001
Introduction to copper: Mining and extraction. Available online: https://www.copper.org/publications/newsletters/innovations/2001/08/intro_mae.html

[25] *******, 2021
How the rise of copper reveals clean energy's dark side, The guardian, Press release from 09 November 2021. Available online: https://www.theguardian.com/us-news/2021/nov/09/copper-mining-reveals-clean-energy-dark-side (Accessed on 15 June 2024)

[26] *****,** 2021
Copper production and environmental impact, Greenspec. Available online: https://www.greenspec.co.uk/building-design/copper-production-environmental-impact/ (Accessed on 16 June 2024)

[27] ***, 2024
Rosia Poieni copper mine, Wikipedia. Available online: https://en.wikipedia.org/wiki/Ro%C8%99ia_Poieni_copper_mine (Accessed on 17 June 2024)

[28] ***, 2018
The dark side of Rosia Poieni, Europe's second largest copper mine, Mining SEE, Press release from 18 February 2018. Available online: https://www.miningsee.eu/dark-side-rosia-poieni-europes-second-largest-copper-mine/ (Accessed 19 June 2024)

[29] **Toderas, M.,** 2021
Mining risks at exploitation in Roșia Poieni open pit mine, Romania, Revista Minelor – Mining Revue, 27 (1), pp. 1-11.

[30] **Toderas, M., Filatiev, M.,** 2021
Slopes stability analysis from Rosia Poieni open pit mine, Romania, MATEC Web of Conferences. 342 no. 02005.

[31] **Toderaș M.,** 2022
Determination of Mining Risks at Exploitation in Rosia Poieni Open Pit Mine, Romania. Techniques and Innovation in Engineering Research, Vol. 3, pp. 66–87.

[32] *****,** 2018
Carier, CupruMin. Available online: ttps://cuprumin.ro/wp-content/uploads/2018/05/CARIERA-cu-desene.pdf. (Accessed on 25 June 2024)

[33] *****,** 2018
Uzina, CupruMin. Available online: https://cuprumin.ro/wp-content/uploads/2018/05/UZINA-cu-desene.pdf (Accessed on 25 June 2024)

[34] **Lazăr, M, Faur, F.**, 2013
Identification and assessment of the risk and impact generated by Roşia Poieni quarry and Dealul Piciorului processing plant, Annals of the University of Petroşani, Mining Engineering, 14, pp. 129–143. https://www.upet.ro/annals/mining/pdf/Annals%20of%20UPET%20-%20Mining%20Engineering%20Vol%2014-2013%20(XLI).pdf

[35] *****,** 2016
The dark side of Rosia Poieni, Europe's second largest copper mine, SystExt. Available online: https://www.systext.org/node/697#:~:text=With%20no%20regard%20for%20the,zinc%2C%20lead%20and%20even%20arsenic (Accessed on 20 June 2024)

[36] **Chapple, A.,** 2017
This Church Spire Is All That Remains Of A Village, Soon It Will Be Buried Completely, Photography. Available online: https://www.boredpanda.com/geamana-village-sinking-industrial-waste-romania-amos-chapple/?utm_source=share&utm_medium=top&utm_campaign=user (Accessed on 20 June 2024)

[37] *****,** 2024
Sustainable Mining Practices: 5 Strategies to Consider, Veriforce. Available online: https://veriforce.com/blog/sustainable-mining-practices-5-strategies-to-consider (Accessed on 26 June 2024)

[38] **Popović, V., Miljković, J.Z., Subić, J., Andrei, J.V., Nedelcu, A., Nicolăescu, E**., 2015
Sustainable Land Management in Mining Areas in Serbia and Romania, Sustainability, 7, 11857-11877

[39] **Smith D., Wentwort, J.,** 2022
Mining and sustainability of metals, Parliamentary Office of Science and Technology (POST). Available online: hhttps://researchbriefings.files.parliament.uk/documents/POST-PB-0045/POST-PB-0045.pdf (Accessed on 27 June 2024)

[40] *******, 2024
New Copper Technologies, Goehring & Rozencwajg Associates, Press release from 05 March 2024. Available online: https://blog.gorozen.com/blog/new-copper-technologies#:~:text=Friedland%20has%20also%20advanced%20a,The%20implications%20could%20be%20transformative (Accessed on 02 July 2024)

[41] *****,** 2023
Ivanhoe Mines, I-PULSE. Available online: https://www.ivanhoemines.com/wp-content/uploads/2023/07/20230615_ipulse_hpx_loan_conversion_vf2.pdf (Accessed on 02 July 2024)

[42] *******, 2024
I-ROX Breakthrough in Mineral extraction, Ipulse. Available online:https://www.ipulse-group.com/our-businesses/i-rox/ (Accessed on 01 July 2024)

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 51-55

DYNAMIC ANALYSIS OF A BUCKET WHEEL EXCAVATOR BOOM USING FEA

Alex JUHÁSZ[1*], *Zoltán VIRÁG*[2]

[1, 2] University of Miskolc, Faculty of Earth and Environmental Sciences and Engineering, Institute of Mining and Energy, H-3515, Miskolc-Egyetemváros, Hungary

DOI: 10.2478/minrv-2024-0039

Abstract: *Bucket wheel excavators are the most widely used technology for lignite extraction and overburden removal in opencast mining. This is due to their high efficiency and ability to handle a wide range of geological conditions. The loads on the bucket wheel and dipper can vary significantly during excavation due to difficult-to-penetrate inclusions and the changing geological environment. This can lead to vibrations that can damage the excavator, especially the structural components directly or indirectly involved in the excavation. To investigate the effects on the main structural elements, it is essential to examine the natural frequencies. In this study, we investigate the natural frequencies and vibration modes of the boom structure of a bucket wheel excavator using a model developed in a previous study. The behavior of the structure is examined using a 3D finite element model under the action of loads and effects during use.*

Keywords: *bucket wheel excavator, boom structure, natural frequencies, mode shapes, finite element analysis, open-pit mining, lignite mining, overburden removal*

1. Introduction

Open-pit mining plays a crucial role in developed countries with advanced mining industries. It is the dominant method for producing construction raw materials and also plays a significant role in ore and mineral mining. In energy production, due to market competition, brown coal and lignite are almost exclusively produced by open-pit mining. The extraction of these low-calorific coals is only economical through open-pit mining, accounting for over 90% of production [1].

Lignite, as an energy source, still holds a significant share in the energy mix of many countries, both in Europe and worldwide. Sustainable lignite production requires cost reduction, increased production, and improved efficiency. To achieve this, production optimization is necessary, which can only be realized through modernization, revitalization, and maintenance of mining equipment [2].

In Europe, the traditional technology used for lignite extraction and overburden removal in open-pit mining is based on bucket wheel excavators. However, in recent years, the geological and rock environment in many European open-pit lignite mines has been deteriorating continuously.

Among the challenges are the values of the hauling force and energy requirements for waste rock or coal, their variability, and the dynamic effects that occur during excavation, as well as the resulting failures [3, 4].

Several studies have been conducted to investigate the phenomena described above, which can provide considerations for optimizing the sizing of steel structures in mining equipment [2, 5, 6, 7].

The research topic of this paper is the dynamic analysis of the boom structure of a bucket wheel excavator using the finite element method, which will be presented in detail within the framework of the paper.

2. Model geometry and loads of the boom

To investigate the behavior of the boom structure of a bucket wheel excavator under operational loads, a finite element model was developed using the FEM Design finite element software [8, 9, 10]. The model was based on the geometric characteristics of the bucket wheel excavator and incorporated the following assumptions:

* Corresponding author: University of Miskolc, Faculty of Earth and Environmental Sciences and Engineering, Institute of Mining and Energy, H-3515, Miskolc-Egyetemváros, Hungary, alex.juhasz@uni-miskolc.hu; Tel.: +36-46-565-111/1808

Material properties: The steel used for the boom structure was assumed to be linear elastic with a Young's modulus of 210 GPa and a Poisson's ratio of 0.3.

Boundary conditions: The boom structure was assumed to be fixed at the connection point to the main structure of the excavator.

Loads: The operational loads acting on the boom structure were considered to include the weight of the boom itself, the weight of the bucket wheel and its associated equipment, the weight of the excavated material, and the dynamic loads generated by the bucket wheel rotation.

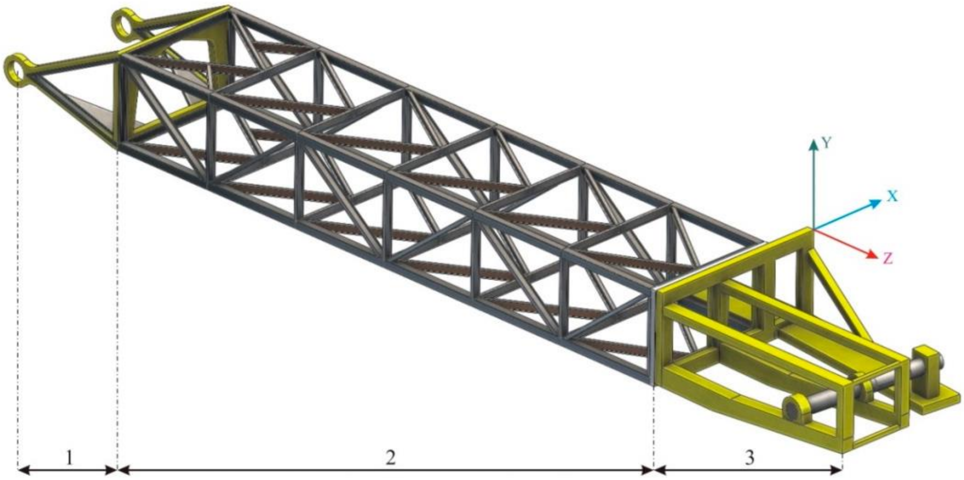


Fig. 1 Section of the BWE's boom [2]

The boom structure of the bucket wheel excavator can be modeled as a spatial truss structure, which can be further divided into three main structural units:

- Section 1: The hinged connection between the rest of the structure and the boom, which provides vertical lifting motion and allows for horizontal swinging motion.
- Section 2: The intermediate section, where the conveyor belt for discharging the excavated material is mounted.
- Section 3: The part that supports the bucket wheel, which carries not only the bucket wheel and its assemblies but also the elements of the bucket wheel drive and the attachment points for the boom lifting cables.

The intermediate section (Section 2), which is defined as a spatial truss structure, can be further decomposed into planar truss elements based on mechanical considerations. These truss elements consist of interconnected rods at the nodes of the trusses [9]. In addition to bending stresses, shear forces, axial normal forces, and torsional forces act on the structure under investigation.

The discretization used in the construction of the 3D finite element model is as follows:

- Sections 1 and 2: The elements were assembled from rod elements in accordance with the actual geometric arrangement and dimensions.
- Section 3: This section, which is the main functional part of the excavation process, was modeled as a rigid body since it is not examined in detail in this study.

In the linear material model assigned to the elements in the model, an elastic modulus of $E = 210000$ MPa, a Poisson's ratio of $v = 0.3$, and a density of $\rho = 7.85$ g/cm3 were specified for structural steel. Thus, the model follows the properties of the real structure in both material and mass.

The supports of the boom structure were taken up on the one hand by the hinged connection at the beginning of Section 1 with the degrees of freedom according to the actual structural behavior, and on the other hand by the connection points of the lifting ropes at the junction of Sections 2 and 3.

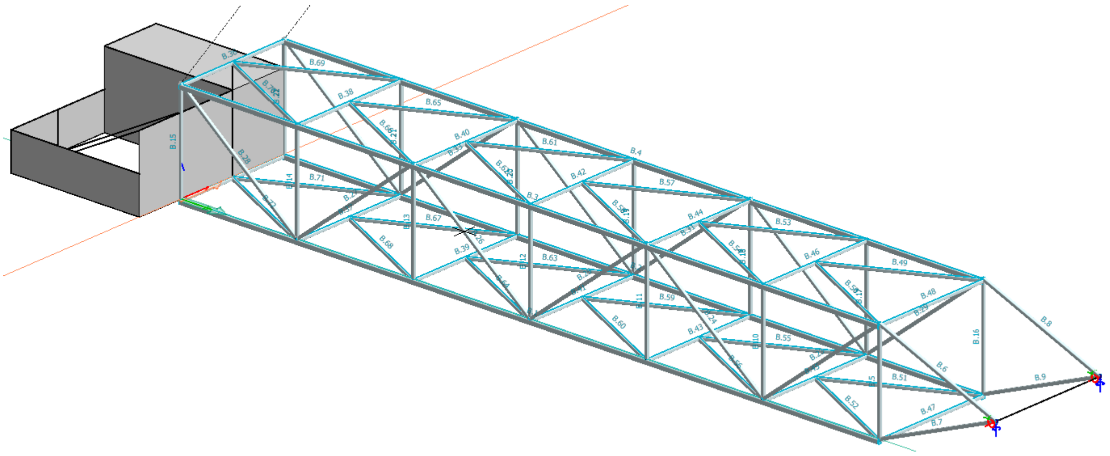


Fig. 2 FE model of the boom

The lifting rope pair used as support consists of 40 mm diameter galvanized steel wire ropes with WS40-6x36 construction. These were modeled as springs, each with an equivalent spring constant of 35000 kN/m, using a point-to-point connection element [8].

The following loads and effects act on the investigated part of the boom structure:

- The operating self-weight of the boom structure: This is automatically generated by FEM Design based on the properties of the specified material model.
- The load of the conveyor belt mounted inside the structure: These can be taken up according to technical specifications and standards.
- The loads of the bucket wheel drive system: These were taken into account using the following formulas: (cutting force; forward force; side force; force exerted by the mass of the excavated material)

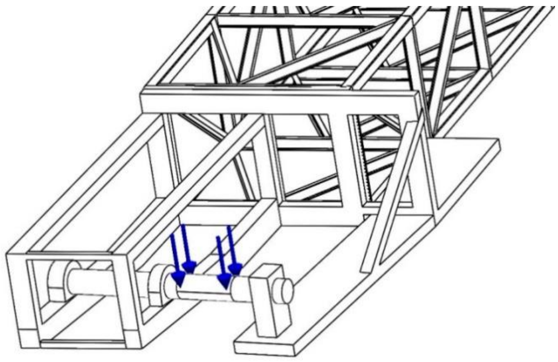


Fig. 3 Applying the force to the bucket wheel's shaft – Section 3 [9]

The self-weight of the structure is automatically generated by FEM Design based on the properties of the specified material model. The additional loads and effects described above were taken into account based on previous studies [6, 11, 12] and are detailed in Table 1.

Table 1. Loads on the stuctures

No.	Loads	Magnitude [kN]	Type
1	Structure's Self-Weight	FEM Design Generated	Constant
2	Conveyor Belt	250	Reduced
3	Drive System	295	Distributed
4	Bucket wheel	396	Point Load

3. FEA analysis of the boom

After the 3D finite element model of the structure was assembled in FEM Design and the loads and effects acting on the structure were defined, dynamic analyses were performed. The analyses determined the natural frequencies, vibration modes, and nodal displacements associated with each vibration mode. The software-based analysis provided the opportunity to determine the natural frequencies and vibration modes that can be calculated under the influence of static loads per unit modal mass, which may be important for subsequent analyses.

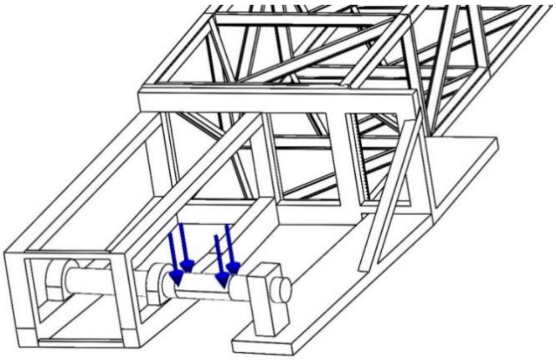


Fig. 4 Boom deformation in Mode Shape 2 (1.775 Hz)

The calculations were carried out for the case where the lifting force of the lifting rope pair was taken into account. As a result of the modal analysis, natural frequencies and associated vibration patterns were determined. The eigenvalue problem was solved using FEM Design software, where the individual vibration patterns can also be displayed graphically (Figure 4). The calculated natural frequencies and periods are summarized in Table 2.

Table 2. Natural frequencies and periods of the boom considering the lifting effect of cable pairs

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
f [Hz]	0.260	1.775	2.319	4.468	5.067	5.455	6.701	7.822	7.961	7.990
t [s]	3.853	0.563	0.431	0.224	0.197	0.183	0.149	0.128	0.126	0.125

Based on the results, it can be concluded that the model we developed can be run to simulate the behavior of real structures. It clearly demonstrates the behavior of the lifting rope pair used as a support as a spring model, as well as the allowable vertical displacement and horizontal swinging of the hinged support at the beginning of Section 1.

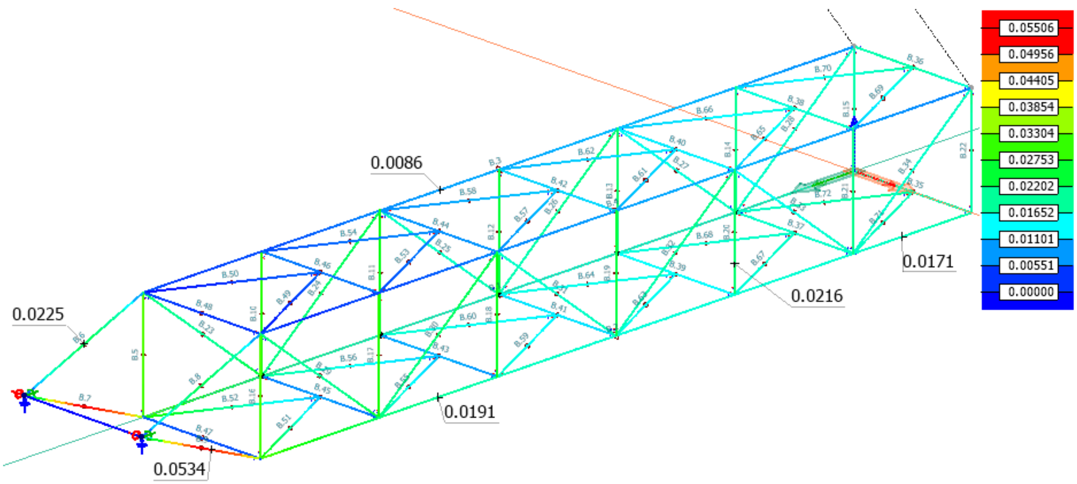


Fig. 5 Boom Deformation in Mode Shape 2 (1.775 Hz) [Rad]

4. Conclusions

The analysis of steel structures in mining machinery has become more complex due to the availability of advanced design tools. In this study, we developed a finite element model of Sections 1 and 2 of the boom structure of a bucket wheel excavator using the FEM Design finite element software for dynamic analysis of the structure under operational loads.

The vibration analysis performed on the excavator's supporting structure provided a comprehensive overview of the evolution of the boom's natural frequencies in the modeled environment. This information can also be useful for analyzing similar space truss structures.

In addition to the analyses conducted so far, it is important to consider that the loads of the bucket wheel and dipper can vary abruptly during excavation due to hard-to-excavate inclusions and the variable geological environment. The stresses can act in a highly repetitive manner. In the following stages of the research, we intend to address additional dynamic effects, their modeling and analysis, and simulation studies. As part of this, we incorporate non-linear material properties into the model and simulate different types of failures for which the experience gained in this study can be particularly beneficial.

References

[1] **Kovács, F., Faur, Gy.**, 1985
Surface mining I. (Winning, loading) (in Hungarian). Tankönyvkiadó, Budapest, Hungary.

[2] **Popescu, F. D., Radu, S. M., Kotwica, K., Andras, A., Kertesz, I.**, 2019
Simulation of the Time Response of the ERc 1400-30/7 Bucket Wheel Excavator's Boom during the Excavation Process, Sustainability, 2019, 11 (16), 4357. https://doi.org/10.3390/su11164357

[3] **Bošnjak, S., Zrnić, N., Oguamanam, D.**, 2006
On the dynamic modelling of bucket wheel excavators, FME Transactions, 34 (4) pp. 221-226.

[4] **András, J., Kovács, J.**, 2018
The operating of bucket wheel excavators when occure inclusions with excessive mining resistance, Műszaki Tudományos Közlemények, 8, pp. 15–20. https://doi.org/10.33894/mtk-2018.08.01

[5] **Popescu F. D., Radu S. M., Andraş A., Kertesz Brînaş I.**, 2019
Simulation of the frequency response of the ERC 1400 Bucket Wheel Excavator boom, during the excavation process, New Trends in Production Engineering, 2 (1), pp. 153-167. https://doi.org/10.2478/ntpe-2019-0016

[6] **Andras, A., Radu, S. M., Brînas, I., Popescu, F. D., Budilica, D. I., Biro Korozsi, E.**, 2021
Prediction of Material Failure Time for a Bucket Wheel Excavator Boom Using Computer Simulation, Materials, 14 (24), 7897. https://doi.org/10.3390/ma14247897

[7] **Brînaş, I., Andraş, A., Radu, S. M., Popescu, F. D., Andraş, I., Marc, B. I., Cioclu, A. R.**, 2021
Determination of the Bucket Wheel Drive Power by Computer Modeling Based on Specific Energy Consumption and Cutting Geometry, Energies, 14 (13), 3892. https://doi.org/10.3390/en14133892

[8] **Popescu, F. D., Radu, S. M., Andras, A., Brînas, I., Marita, M. O., Rebedea, N. I.**, 2020
The modal analysis, using simulation and modelling, of the boom of the ERC-1400 Bucket Wheel Excavator during operation, Acta Technica Napocensis - Series: Applied Mathematics, Mechanics, and Engineering, 63 (4), pp. 353-362.

[9] **Juhász, A., Virág, Z.**, 2023
Static analysis of the boom structure of a BWE using the finite element method (in Hungarian), 55. Bányagépészeti és Bányavillamossági Konferencia, pp. 95-100., Balatongyörök, Hungary, 28-29 September 2023., ISBN: 9786156524010

[10] **Juhász, A., Virág, Z.**, 2023
Dynamic investigation of the boom structure of a BWE using the finite element method (in Hungarian), Új eredmények a műszaki föld- és környezettudományba, A Műszaki Föld- és Környezettudományi Kar konferencia kiadványa, Miskolc, Hungary, 24 November 2023. ISBN: 978-963-358-310-4

[11] **Popescu, F. D., Radu, S. M., Kotwica, K., Andraş, A., Kertesz (Brînaş), I, Dinescu, S.**, 2019
Vibration analysis of a bucket wheel excavator boom using Rayleigh's damping model, New Trends in Production Engineering, 2 (1), pp. 233-241. https://doi.org/10.2478/ntpe-2019-0024

[12] **Radu, S. M., Popescu, F. D., Andras, A., Andras, I., Brinas, I., Valceanu, F.**, 2021
Numerical analysis of fatigue for the assessment of remaining service life of the ERC 1400-30/7 bucket wheel excavator, Proceedings of the Romanian Academy, Series A: Mathematics, Physics, Technical Sciences, Information Science, 22 (2), pp. 143-152.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 56-63

DETERMINING THE POSITION OF THE CENTER OF GRAVITY BY TENSIOMETRIC MEASUREMENTS FOR THE MACHINES WITH BUCKET WHEELS USED TO REMOVE COAL FROM DEPOSITS

Răzvan Bogdan ITU[1], Florin VÎLCEANU[2], Gheorghe Bogdan URDEA[3]*

[1]University of Petrosani, Romania, razvanitu@upet.ro
[2]University of Petrosani, Romania
[3]University of Petrosani, Romania

DOI: 10.2478/minrv-2024-0040

Abstract: *The machines with bucket wheels used to remove and to put coal in deposits are intended to dump and remove coal from quarries and power station deposits. The paper presents how to determine the gravity center of a machine with bucket wheels used to remove coal from deposits, by tensiometric measurements, in various positions of the arm of the bucket rotor (wheel). The machine with bucket wheel used for taking out from deposits is within Arcelor Mittal Galați. The measurements have been made in limit positions of the arm of the bucket wheel, horizontally and vertically, respectively, and have been made because of determining an additional weight that should be added in the ballast box of the equilibrium arm, if appropriate.*

Keywords: *removal and depositing machine, center of gravity*

1. Introduction

Machines with bucket wheels for removing and depositing are part of the technological machinery used in quarries, machinery used for transport and dumping, from the simplest (bucket excavators, truck hauling) to the most up-to-date and sophisticated ones (rotor excavators, heavy transporters, depositing machines, reloading bridges, direct dumping bridges). Removal and dumping machines belong to the category of depositing machinery. They are intended to dump and remove coal from the quarry, power station, or iron-and-steel works deposits. Coal deposits, either from the power station precincts, or from mines, are manipulated with the help of depositing machines, removal machines, or mixed, because of consumption, or loading coal in means of conveyance. Similarly, there may be machinery in the deposits that homogenize coal, for a certain requirement of the consumer (specifically power stations) [1].

Fig. 1. Removal machine from deposits with bucket wheels

In a way, the dumping machines in deposits can be assimilated to the dumping machines in wastes, as a principle of forming piles, and the removal machines to bucketwheel excavators.

The bucket wheel machine, meant to remove coal, which is the object of this paper, operates in the Iron-and-steel Works Galati, (officially Liberty Galati, previously Arcelor Mittal Galati and Sidex Galati, which is the largest Iron-and Steel Works in Romania. (Fig. 1).

* Corresponding author: Itu Răzvan Bogdan, assoc.prof. Ph.D. eng., University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Mechanical, Industrial and Transport EngineeringPetrosani, Romania, Contact details: University of Petrosani, 20 University Street, razvanitu@upet.ro

The removal (and depositing) machine with bucket wheel, is part of the heavy machinery for the exploitation and manipulation of coal at the surface, as with the rotor excavator and the dumping machines, have a relatively small support base, and the constructive parts, over which great forces act, extend much towards the exterior.

For such structures, stability is a critical issue, since the resultant of all the forces acting, should not reach or exceed the outline of the support surface, because that might lead to flipping the support structure over.

The problem is more difficult since the center of gravity of the machinery's own mass is much above the support structure and so is the point in which exterior forces act on the machinery.

2. Removal and dumping machine in deposits

Machines that remove and dump from and in deposits, with bucket wheels on track, are part of the family of the machinery of coal households, intended to dump and take over coal to and from the coal deposits of quarries, power stations, or iron-and steel works.

The load-bearing structure of the machinery has the following sub-units (Fig. 2):

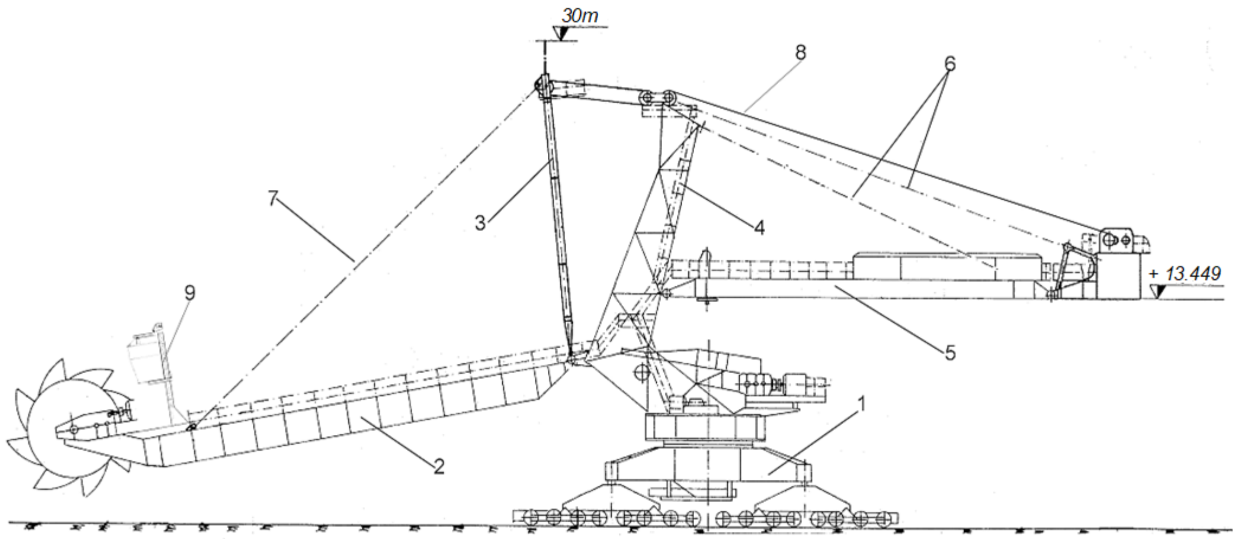


Fig. 2. Construction sub-units

1–tripod and rotating platform (travel mechanism); 2 - boom (arm of the bucket wheel); 3–articulated mast; 4–fixed tower; 5– balance arm; 6–balance anchor arm tie-bars (secondary); 7- boom anchor tie-bars (principal); 8–boom lifting-lowering cables; 9–control cabin

A tripod (lower load-bearing structure or basic chassis) is a triangular metal construction, placed above three pairs of balances of the marching mechanism, which travels by the running wheels on a railway track.

On the basic chassis, the lower ring (running track) of the rotating bearing is mounted, with a toothed crown, interlocked with threaded screws to the basic chassis. Above the bearing, the pivoting load-bearing metal construction is assembled, made up of the rotating platform, the tower, the balancing arm and the wheel arm with buckets (boom) with articulated pillar.

The rotating platform is found above the basic chassis and can rotate through the support bearing and the toothed crown, the movement being given by the rotation mechanism (motor – brake- reduction gear – attack pinion).

The arm of the wheel with buckets-boom is a special metal construction, rigidized for torsion, that works in the console. It is made up of two longitudinal sections, and a third lateral section, in console. At the end of the console, the bucket wheel is found and its driving mechanism. The second end of the bucket wheel arm is articulated to the tower through two axes (boom rotation center). Each of the two axes is applied by bearings at one end by a set of annular fixing wedges. On the arm of the bucket wheel, the conveyer belt is mounted (reversible), which conveys the excavated material to the receiving funnel that is found above the rotating platform, and/or the material coming from the conveyer belt (for depositing regime of the machine).

The mast rests on the bucket wheel arm and attaches with the help of the tie-bar the arm part in the console. The arm of the bucket wheel, the part up to the console articulated to the tower, the mast, and the principal tie-bars (front) make up special triangles, which cannot be distorted, that take over the special forces from the chipping and conveying process.

The tower is the principal part of the fixed metal construction, which rests directly on the rotating platform, and in the upper part there is the block with the cable guiding rollers of the lifting mechanism of the bucket wheel arm. Of the metal construction of the tower, which is a spatial lattice girder, the balancing arm is rigidly fixed, ending with the ballast box.

The balancing arm (counterweight arm) is a spatial rigidized metal construction, on which the cabin with control and monitoring apparatus is found, as well as the electrical transformer. At the end of the balancing arm, the tiltable ballast box is found. On the ballast box the lifting mechanism of the arm–wheel–tie–bar–mast unit is mounted.

The anchor tie-bars of the balancing arm connect the balancing arm and the tower. Their role is to support the balancing arm. They are part of the safety and load-bearing elements of the machinery.

Anchor tie-bars are principal elements helping in lifting and lowering the bucket-holder arm vertically.

Boom lifting – lowering cables – using the pulley battery, they lift and lower the bucket-holder arm.

Control cabin is on the bucket wheel arm, being the machinery control point.

The machinery can function in a *depositing regime* – takes over the coal of the conveyer belt (the rotating mechanism of the superstructure and of the arm lifting ensures homogeneity, plus the matching mechanism ensures depositing along the entire length of the deposit); *take over regime*–from the deposit piles; *direct regime*–the machine is in functioning – stationary regime [2].

3. Determining the center of gravity

Determining the center of gravity of the machinery can be done by weighing or by tensiometric measurements.The classic method of determining the center of gravity by 'weighing', lies in lifting the superstructure on hydraulic cricks with static determinations for certain distinct situations.

For this, the machinery must be on horizontal ground, with good and safe carrying capacity in time. The difference between the levels of the three resting points is maximum 15 mm (we use a theodolite). Again, the machinery's conveyer line is empty of material. The arm of the bucket wheel and the bucket wheel are cleaned (in the inside too). The stairs, catwalks, metal constructions, mechanisms, etc. are cleaned, the possible tools, parts that by falling could lead to accidents are removed.

The electric supply is cut off. Measures are taken to avoid accidental turning on the voltage.

The machinery structure is rotated as to the basic structure, so that the points on the chassis and on the rotating platform, marked for mounting the hydraulic presses (cricks), would match. These points should overlap as exactly as possible. The bucket wheel is left at 0,5 m above the floor.

The points of application of the hydraulic presses are specified in the documentation regarding the distances between them and to the rotation center of the upper platform (superstructure). Groups of presses by two are used. In mounting the groups of presses in view of even distribution of lifting forces, both in the upper part, and in the lower part of the presses, one metal beam will be interspersed between the lifting points and the group of presses, for each. The presses will be symmetrically positioned to the lifting points marked on the base chassis close to one another. Each group of presses is hydraulically coupled between them, for evenly lifting from all the marked points, for even distribution of the forces of the presses in the groups, to be able to measure the lifting force on each of the points of application of the marked presses, to measure the lifting height in the marked points.

For the verification of the lifting forces, whence conclusions are drawn regarding the position of the center of gravity of the excavator superstructure, for each group of presses, a manometer, previously checked metrologically before use, is mounted.

From a constructive point of view, the machinery is supported by three travel mechanisms. The weight of the machinery is supported by the group of the three mechanisms loaded by means of spherical bearings, which form in the horizontal plane, an equilateral triangle *ABC*, the center of the circle circumscribed in, and inscribed outside, being situated on the vertical rotation axis in the horizontal plane of the superstructure (Fig. 3).

Through these bearings, pressures are transmitted to the travel mechanisms, and further to the ground.

The R_A, R_B and R_C reaction values being known, measured in *A*, *B*, and *C* supports, the weight of the superior rotative platform and the position of the superior platform's center of gravity projection, in *ABC* triangle plane, can be determined.

We consider two systems of reference, a mobile *Oxyz* reference system, attached to the upper platform with *Ox* axis along the arm of the bucket wheel and with the positive sense towards the wheel, and a fixed reference system $O_1x_1y_1z_1$ with O_1x_1 axis, passing through point *A* and perpendicular on *BC*, with the positive sense of the axis towards point *A*. Axes *Oz* and O_1z_1 of the two reference systems coincide, and the origins *O* and O_1 of the two reference systems coincide among them and coincide with the rotation center as well, situated in the ABC triangle plane, on the vertical rotation axis.

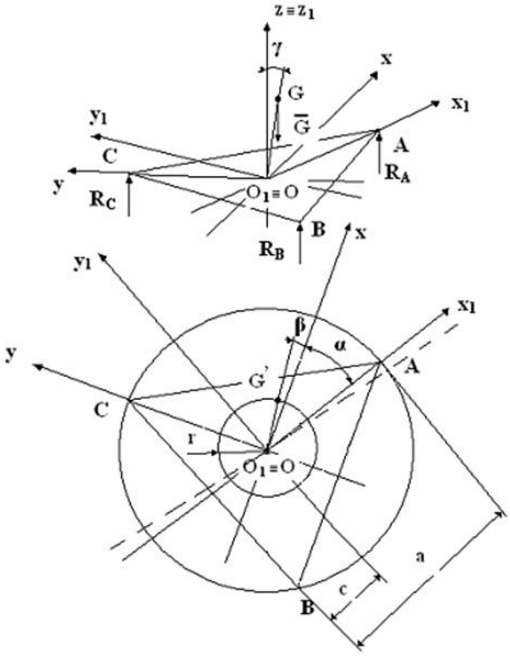


Fig. 3. Scheme of the machinery support

If we reduce the applied forces, and all the connection forces related to point *O* (sum of the resultants and sum of the resultant momentums), we obtain the elements of the reduction torsor. From the necessary and sufficient equilibrium conditions, known from mechanics, these elements equal zero.

Projecting the vectorial relationships on the axes of the coordinate system (reference system), equilibrium equations are obtained for the rigid body actuated by a particular system of forces, as in the case considered, parallel forces in space, and, respectively, 3 scalar equations, an equation of projections from the resultant (on *Oz* axis), and two projection equations from the resultant moment on *Ox* and *Oy* axis). It results that the support on the three spherical bearings is statically determined.

Solving the system of equations leads to obtaining expressions of R_A, R_B and R_C reactions from bearings, function of αandβ angles, and reactions that have two components each, one constant and one variable. Variable components are a function of the α position angle of the arm and are harmonic, de-phased between them with 120°.

Since these components are harmonic forms, the corresponding signal of a sensor placed at one of the bearings, will have a proportional form of variable signal [3].

3.1. Location of the measuring point

In order to determine the variation of the position of the gravity center of the upper rotating platform (mass unbalance of the excavator), it is sufficient to process the signal of a single sensor placed in the vicinity of the bearing on the connecting beam.

Resistive transducers have been applied in the middle of the translation mechanism on the principal beam, as per Fig. 4

Fig. 4. Positioning of transducers on the beam

Fig. 5. Beam calibration

One can notice that one of the transducers is longitudinally applied on the beam, and the second is transversally applied on the beam.

In view of measurements, the following stages have been applied:

1. The beam has been calibrated to determine the position of the initial center of gravity. The calibration has been made with a hydraulic crick of 200.000 N, and with a tensiometric transducer of 100.000 N, as per Fig. 5

2. In order to determine the position of the center of gravity, in horizontal position the arm rotated from left to right, from 0 degree to 180 degrees, Fig. 6. Angle Φ represents the position of the arm and is in the range of 0 – 180 degrees, and β represents the center of gravity as to the machine arm, OC_g represents the radius at which the center of gravity is.

3. To determine the position of the center of gravity in the case in which the arm moves in extreme positions, namely, *-9°...9°*, the beam has been brought to *0°* position, that is, on the bearing where the transducers are placed.

The measurement apparatus is a SPDER 8 tensiometric amplifier with 8 channels, Hottinger Baldwin Messtechnik made. To record the value of distortions in dynamic regime, the amplifier is connected to a PC using an analogous -digital convertor. Electroresistive transducers have the following characteristics:

3/120 LP 21 type- Hottinger Baldwin Messtechnik made;

Ohmic resistance R=120Ω;

TER factor k=2,01;

Manufacturer series V-13202/21 Lot Nr: Y-5.

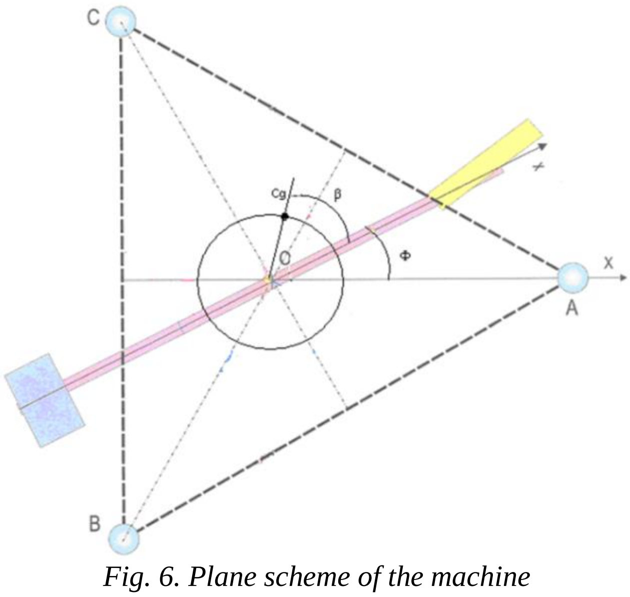


Fig. 6. Plane scheme of the machine

Transducers have been applied with X60 type adhesive, lac protector de tip PU120 type protective lacquer, made by Hottinger Baldwin Messtechnik.

The measurement apparatus is heated under voltage for 30 minutes, after which all the measurement points are balanced and recordings are made in a dynamic regime [4].

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 56-63

3.2. Measurement results and their interpretation

As a result of calibration, force diagrams have been recorded (given force captor) – distortion (given by eletroresistive transducers), Fig. 7. Following the calibration, the constant resulted. The recorded values have been analyzed by collinearity correlation and c=51965 constant resulted, with which specific distortion, mass conversion will be done, Fig. 8.

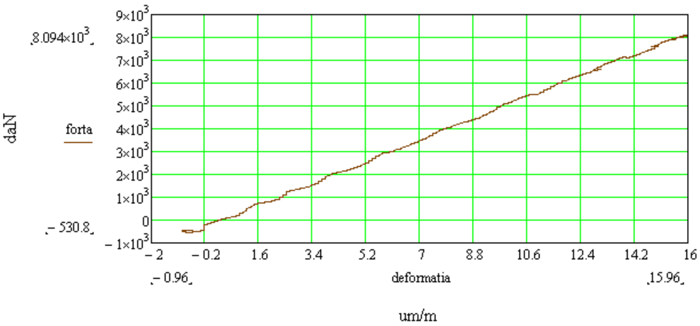


Fig. 7. Force–distortion diagram

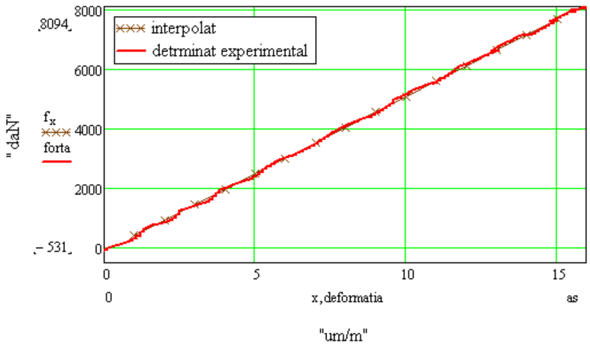


Fig. 8. Results interpolation

The results of the center of gravity position calculated based on the measurements undertaken are shown in Table 1, and the diagrams from below, OC_g and β as per Fig. 6.

Table 1. Measurement results

Rotation	**OC_g [mm]**	**β [degrees]**
Rotation 1	488	5,9
Rotation 2	482	4,8
Rotation 3	485	5,64
Rotation 4	493	9

Fig. 9 shows the signals recorded in the case of rotation of the arm in trigonometric sense, from bearing A (see Fig. 6), zero point, to a 180-degree domain, Fig. 6. The signals presented are: recorded signal and filtered signal to avoid possible perturbations. The diagrams presented are in specific distortion, *μm/m*, function of the rotation angle of the arm.

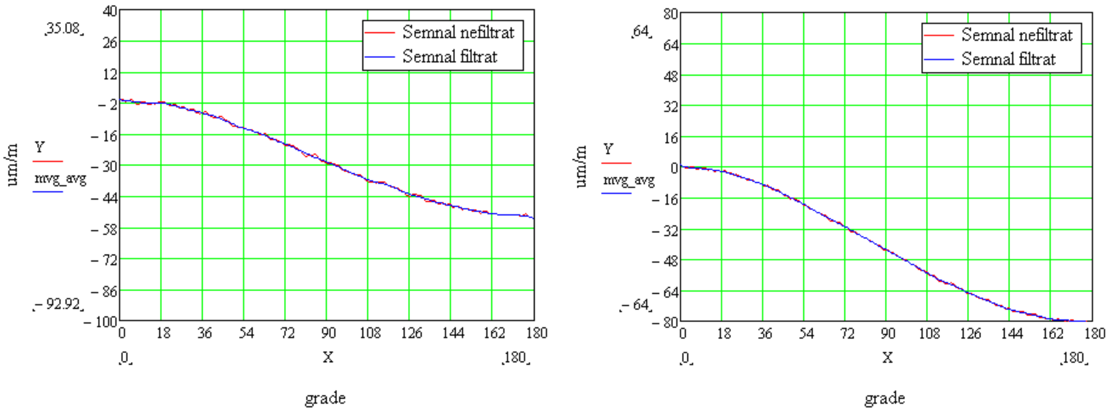


Fig. 9. Recorded signals [unfiltered signal, filtered signal]

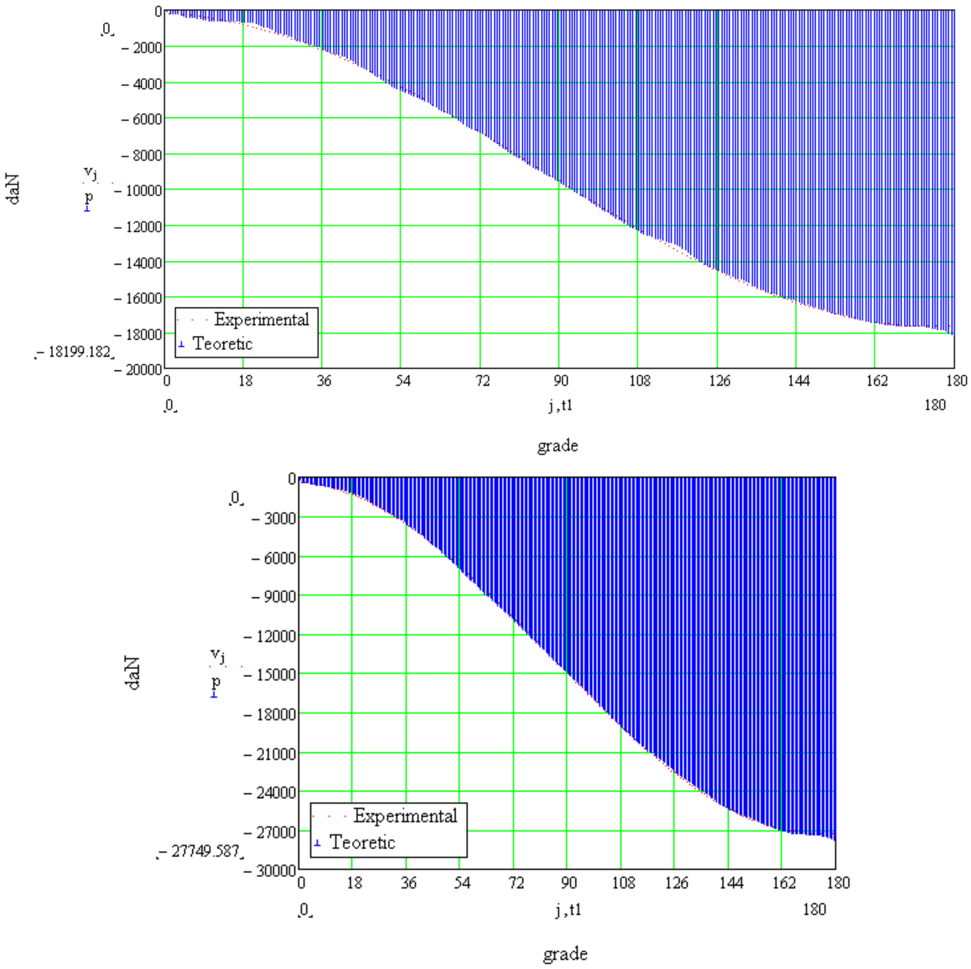


Fig. 10. Force variation on A bearing, function of the rotation angle of the arm

Fig. 10 shows the force variation, function of the rotation angle. Diagrams are determined on theoretical and experimental principles.

Fig. 11 shows the variation of specific distortion on bearing *A*, function of the vertical position of the arm, -9° ... 9°. Analyzing the diagram, a 178 mm oscillation resulted, compared to OC_g eccentricity.

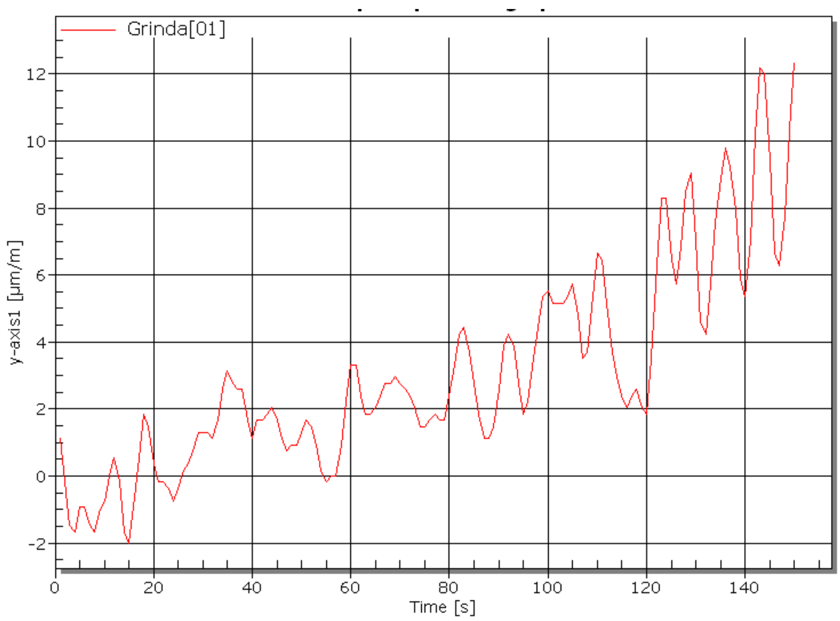


Fig. 11. Force variation on A bearing, function of the descending angle of the arm

4. Determining the additional mass

With the following data:

l = 17800 mm, the distance between the ballast box and the rotation center;

m = 197081 kg, superstructure mass;

OC_g=485 mm, eccentricity value, Table 1

additional mass is determined:

$$m_a = \frac{mr}{l} = \frac{197081 \cdot 485}{17800} = 5370$$

5. Conclusions

Following the system calibration, 519,65 constant resulted.

Following the arm rotation in a horizontal position, the following eccentricities resulted 488 mm, 482 mm, 485 mm and 493 mm. All these eccentricities are towards the rotor, angle *β< 90* grade.

In the case of lifting the arm from -9 to 9 degrees, the position of the center of gravity has a deviation of 178 mm.

In the case of the machine at which the ballast box is at l= 1780 mm to the rotation center, and the superstructure mass is m= 197081 kg it resulted that 5370 kg should be added to the ballast box [5].

References

[1] **Radu S.M., Dinescu S., Vîlceanu F.**, 2023
Comparative analysis of dynamic coefficients in lignite cutting and of the excavation machines in the Oltenia's open pits. Volume 66, Issue 4, Page 465-472, Acta Technica Napocensis series-applied mathematics mechanics and engineering, Nov. 2023, https://www.webofscience.com/wos/woscc/full-record/WOS:001236162800010.

[2] **Läpple V.**
Einführung in die Festigkeitslehre. Lehr- und Übungsbuch 3., verbesserte und erweiterte Auflage Mit 413 Abbildungen und 49 Tabellen, Studium, ISBN 978-3-8348-1605-4.

[3] **Hoffmann K.**, 1989
An Introduction to Measurements using Strain Gages, Publisher: Hottinger Baldwin Messtechnik GmbH, Darmstadt,

[4] **William M., William R.**, 1992
The Bonded Electrical Resistance Strain Gage, New York Oxford, Oxford University Press

[5] **Mihut N.**, 2016
Method in calculating own vibration frequencies of open sections bars with thin walls, ModTech International Conference - Modern Technologies in Industrial Engineering IV IOP Publishing, IOP Conf. Series: Materials Science and Engineering 145 (2016) 042029 DOI:10.1088/1757-899X/145/4/042029, WOS:000396437600081.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 64-69

DETERMINATION BY STANDARDIZED TEST METHODS OF THE DRUM FRICTION RESISTANCE PERFORMANCE OF CONVEYOR BELTS USE IN THE UNDERGROUND AND AT SURFACE

Florin Adrian PĂUN[1], Adrian JURCA[2], Anca TĂZLĂUANU[3], Ana Petrina PĂUN[4]*

[1]INCD – INSEMEX Petroşani, Romania, florin.paun@insemex.ro
[2]INCD – INSEMEX Petroşani, Romania
[3]INCD – INSEMEX Petroşani, Romania
[4]University of Petroșani, Petroșani, Romania, anapaun@upet.ro

DOI: 10.2478/minrv-2024-0041

Abstract: *The field of use of conveyor belts is varied, they can be found both in the composition of installations operating in normal environments as well as in environments with the danger of potentially explosive atmospheres. The use of conveyor belts in environments with the risk of potentially explosive atmospheres requires the fulfilment of those safety requirements aimed at preventing sources of initiation of explosive atmospheres. In order to ensure the highest level of security, in these spaces with the danger of potentially explosive atmospheres, the conveyor belts used must have adequate protection properties against sources of ignition that may appear during their operation. At the same time, in this context, the application of test methods that allow determining the specific performance of conveyor belts, such as, for example resistance to friction on the drum, resistance to flame propagation, electrical resistance, is also important. The paper essentially aims to deal with the issues related to the application of standardized test methods, developed in the laboratory, necessary to determine the performances regarding the friction resistance on the drum of the conveyor belts used in the underground and at surface.*
Keywords: *explosion hazard, conveyor belts, drum friction, laboratory tests, environments Ex.*

1. Introduction

Conveyor belts are widely used for the transport of solid materials, which are a component of transport facilities and systems. At the same time, the field of use of conveyor belts is vast, conveyor belts can be found both on the surface and underground. The wide field of use of conveyor belts means that they can be encountered both in normal environments, where the presence of potentially explosive atmospheres is not possible, and in environments with the danger of potentially explosive atmospheres [1].

In the case of potentially explosive atmospheres, unlike normal environments, the danger of explosions/fires occurs as a result of the initiation of potentially explosive atmospheres generated either by the transported material or by other external sources. Potentially explosive atmospheres of gases, vapors, mists or dusts and air are generated by combustible/flammable substances processed, transported, stored in industrial premises, even under normal working conditions, due to processes or accidental releases occurring at a given time.

The presence of potentially explosive atmospheres in these industrial spaces leads to the occurrence of the risk of explosion. To reduce the risk of explosions in industrial premises with potentially explosive atmospheres, both equipment and their components must be used in explosion-proof construction, which are not capable of producing sources of ignition that could initiate an explosion.

Therefore, conveyor belts that are used in environments with potentially explosive atmospheres must meet the essential safety requirements related to the risk of explosions.

[*] Corresponding author: Florin Adrian Păun, National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani; Contact details: 32-34 G-ral Vasile Milea Street, Postcode: 332047, Petroşani, Hunedoara County, Romania, Tel.: +40-720-01-76-38, florin.paun@insemex.ro

These requirements aim on the one hand to prevent the formation of a potentially explosive atmosphere around the conveyor belts, and on the other hand to prevent sources of ignition of the explosive atmosphere such as, for example, electrostatic discharges, hot surfaces and incandescent particles resulting from friction between the belt conveyors and the metal elements of the transport facility [2].

Working conditions, inadequate maintenance, non-existence or inefficiency of systems that allow the detection and monitoring of possible friction, make possible the occurrence of such a situation, during the operation of conveyor belts, within various industrial activities.

Therefore, an important role to ensure protection against the sources of ignition, mentioned previously, belongs to the materials used to make the conveyor belts, which must have a series of properties that do not allow the generation of such sources of ignition.

The determination of the properties referred to can be done after testing the conveyor belts through laboratory tests. Such a laboratory test refers to the determination of the resistance of the conveyor belts to the friction on the drum, by means of the test method simulating at the same time a real situation that may occur in practice [3].

The test method by which the resistance of conveyor belts to drum friction can be determined is a standardized method given in the EN ISO 20238:2019 standard. The results obtained following the application of this test method later allow the characterization of the materials in the composition of the conveyor belts from the point of view of the risk of generating sources of ignition as a result of friction, respectively the establishment of the properties that ensure protection against these sources of ignition.

2. Test method for determining the drum friction resistance of conveyor belts

2.1 The principle of the test method

The sample taken from the conveyor belt, which is to be tested, is wrapped around half the circumference of a rotating steel drum, being fixed rigidly at one end and tensioned at the other end with the help of weights.

The test is carried out at certain stresses and for a given period of time or until the specimen breaks. During the test, the presence or absence of flame or smoldering is observed, and the maximum temperature of the drive drum is reported and recorded. The test is carried out in still air and in a draft.

2.2 Description of the stand for determining the drum friction resistance of conveyor belts

Principle diagram of the stand for the determination of frictional resistance on the drum for the purpose of laboratory testing of conveyor belts, intended for use in environments with a risk of explosion, as a component of transport installations, in order to assess compliance with the essential safety requirements applicable according to the Directive 2014/34/EU - ATEx, is presented in figure 1 [4].

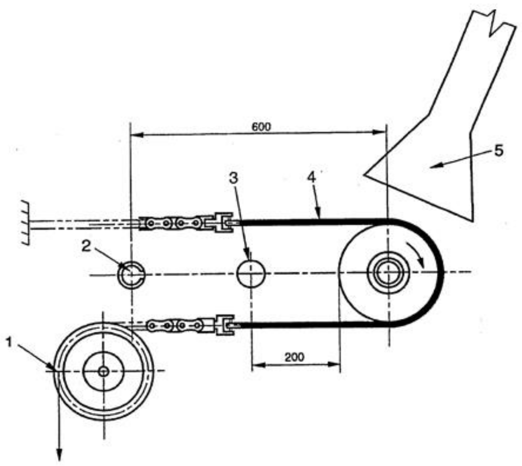


Fig. 1. Principle diagram of the test stand for determining the frictional resistance of conveyor belts on the drum
1 - guide roller; 2 - perforated pipe for air supply; 3 - anemometer; 4 - test sample; 5 - exhauster.

A device for recording the temperature of the steel drum (thermocouple wrapped in a stainless-steel casing, insulated with mineral material with an outer diameter of 2 mm, connected to a data acquisition board) is added to the components of the test stand mentioned before AGILENT 34970A, a tensioning system, emergency stop devices and a timer [5].

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 64-69

3. Laboratory testing of drum friction resistance of conveyor belts

Friction between the conveyor belt and one of the metal elements in the conveyor (drums, rollers) that may occur during operation due to local conditions and malfunctions such as a roller blocking, improper tensioning of the conveyor belt, etc., may be a source of ignition for potentially explosive atmospheres due to the high temperatures generated, the presence of flame and incandescent particles.

Since in practice the probability that such a situation will occur exists and all the more so as the protection systems are missing, it is very important to know the behavior of such a conveyor belt subjected to the friction process on the drum, roller or other metal element in the composition the conveyer.

Therefore, in this case, the laboratory testing of the conveyor belts to be used in environments with the risk of potentially explosive atmosphere is called for, using standardized test methods, such as the test method for determining the friction resistance on the drum, given in the EN ISO 20238:2019 standard, a test method that was developed within the INSEMEX - GLI laboratory, a laboratory accredited according to the requirements of the EN ISO/CEI 17025:2018 standard [6].

The test method for determining the friction resistance on the drum of conveyor belts applied in an accredited testing laboratory according to the requirements of the EN ISO/CEI 17025:2018 standard, allows the measurement of the maximum temperature of the drum during the period of friction between it and the respective conveyor belt specimen recording the presence/absence of flame or incandescent particles resulting from the friction process.

In order to determine the behavior of conveyor belts with friction on the drum, laboratory tests were carried out on conveyor belts compliant with the requirements of the EN 14973:2016 and EN 12882:2016 standards [7, 8].

The laboratory tests were performed according to the requirements of the EN ISO 20238:2019 standard, on several conveyor belt samples from the same belt roll.

Table 1. Obtained results

Sample	Temperature and relative humidity	No. test sample	Obtained results
1000, EP1000/4, 5+3K, class C1, roll 863/2020	22 ºC and 42 %	1	a) Method B (in air current): thin strip face: Method B2 - no flame or incandescent points appeared until the test piece broke (the break did not occur after 1 h and 50 min. at a tension of 1715 N); - maximum drum temperature: 222,3 °C
		2	a) Method B (in air current): thin strip face: Method B2 - no flame or incandescent points appeared until the test piece broke (the break did not occur after 1 h and 50 min. at a tension of 1715 N); - maximum drum temperature: 265,3 °C
		3	a) Method B (in air current): thick face tape: Method B2 - no flame or incandescent points appeared until the test piece broke (the break did not occur after 1 h and 50 min. at a tension of 1715 N); - maximum drum temperature: 256,3 °C
		4	a) Method B (in air current): thick face tape: Method B2 - no flame or incandescent points appeared until the test piece broke (the break did not occur after 1 h and 50 min. at a tension of 1715 N); - maximum drum temperature: 237,9 °C

In table 1 are given the results obtained after carrying out the tests, and in figure 2 these results are exemplified.

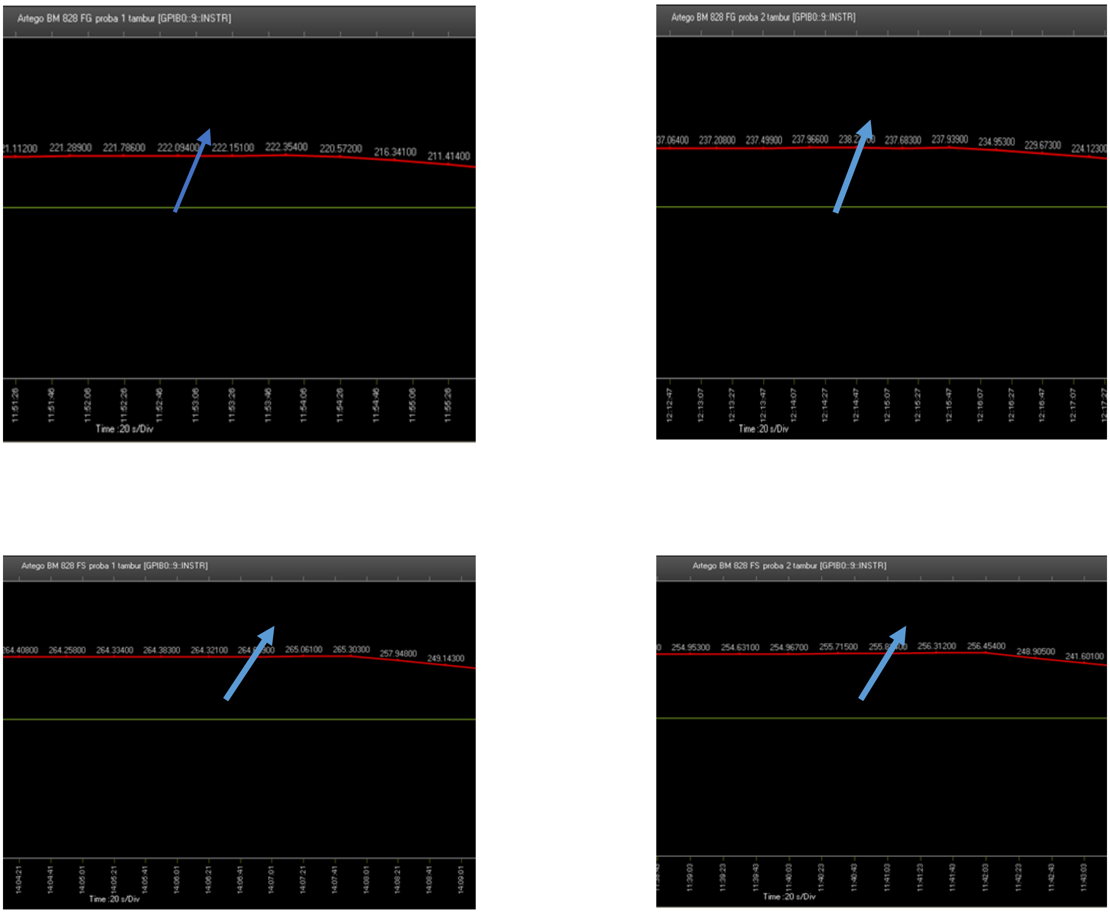


Fig. 2. Maximum drum temperature in degrees Celsius

The results obtained from the tests provide information on the behavior of the conveyor belts to be used in environments with the risk of potentially explosive atmospheres when they are exposed to the friction process on the drum or another metallic element of the conveyor.

At the same time, it was found that the drum temperature values are not influenced by the temperature and relative humidity, both of the test atmosphere and of the conditioning atmosphere; the tests being carried out under the same conditions of temperature and relative humidity as those of conditioning.

Instead, from the records made, differences can be observed between the drum temperature values for the four conveyor belt samples, tested according to the requirements of the SR EN ISO 20238:2019 standard.

Based on the results obtained, it can be appreciated that the differences recorded are mainly due to the performance of the materials used to make the conveyor belts, in terms of protection against the development of high temperatures during the friction between the conveyor belt and the drum, as well as due to the inhomogeneity of the material of the conveyor belt roll, from which the samples subjected to subsequent testing are taken.

4. Quality assurance of the results test, requirement regarding product conformity assessment in relation to applicable requirements

In order to assess the conformity of the products in relation to the applicable essential safety and health requirements, it is necessary to ensure the quality of the test results. Ensuring the quality of the test results requires compliance, both in the stage preceding the performance of the tests and during their performance, of all the requirements and conditions that may negatively influence the results obtained.

Several factors contribute to the correctness of the tests carried out in a laboratory, namely the environmental conditions, the conditioning of the samples, the test methods, the measuring equipment used, the handling of the samples, the traceability of the measurements and last but not least the human factor.

Among the previously mentioned factors that can influence the quality of the results obtained after carrying out the tests, the physical and chemical properties of the tested samples are also identified.

The quality of the test results can also be influenced by whether or not the samples to be tested have been pre-conditioned. Standards containing test methods specify that where conditioning is applied, the samples must be conditioned and then tested under the same conditions of temperature and relative humidity.

The measuring and recording equipment used to perform the tests can influence the quality of the test results if it is not periodically subjected to a program of metrological checks (calibration/calibration).

An important role in the case of use and implicitly in ensuring the quality of the results is also played by the human factor, who must have the necessary competence both for the proper use of these equipment and apparatus, as well as for the correct application and performance of the test methods and the tests themselves.

At the same time, the purpose being the same, the test methods applied to determine the protective performance of the tested products must allow and ensure the reproducibility and repeatability of the results obtained given their importance for the assessment of compliance with the applicable essential safety and health requirements.

In the sense of the previously mentioned, ensuring the quality of the results also implies the existence of necessary control procedures in the process of monitoring the validity of these results. The results obtained must be recorded so that trends are detectable and when possible statistical analysis of the results can be applied.

Ensuring the quality of test results can include, but is not limited to, the conditions in figure 3.

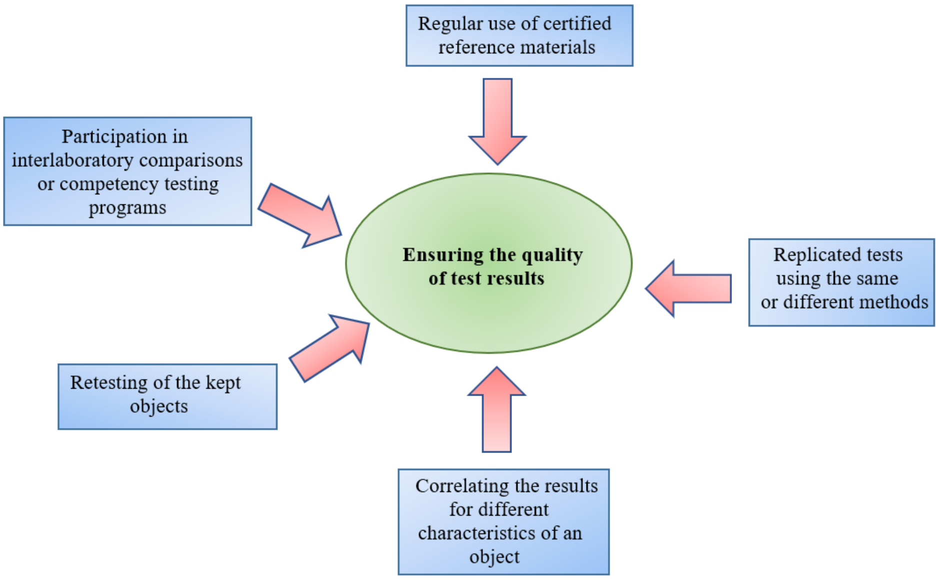


Fig. 3. Elements that contribute to ensuring the quality of test results

5. Conclusions

When using conveyor belts, in various applications, depending on their field of use, friction may occur between the conveyor belt and one of the metal elements of the conveyor (drums, rollers) due to local conditions and malfunctions such as the blocking of a roller, improper tensioning of the conveyor belt.

The friction between the conveyor belt and one of the metal elements in the conveyor (drums, rollers) can be a source of ignition for potentially explosive atmospheres as a result of the high temperatures that are generated, the presence of flame and incandescent particles.

Since there is a risk of the initiation of potentially explosive atmospheres by the sources of ignition generated by the friction between the conveyor belt and the metallic elements of the conveyor, laboratory testing is required as a necessity, using appropriate, standardized test methods of their performances to ensure protection against these ignition sources.

The results obtained from laboratory testing allow the subsequent assessment of the conformity of the conveyor belts with the essential safety and health requirements regulated by the applicable standards and norms, thus ensuring a high level of safety in environments with the risk of potentially explosive atmospheres.

For the evaluation of the conformity of the products with the applicable essential safety and health requirements, the quality of the test results is of particular importance, and this presupposes compliance with all those requirements and conditions that may negatively influence the results obtained from the tests performed.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 64-69

References

[1] **Păun F., Părăian M., Ghicioi E., Vătavu N., Lupu L., Jurca A.**, 2012
Development of the test methods of the conveyor belts used in environments endangered by explosion hazards - The 5th Symposium „Durability and reliability of mechanical systems - SYMECH 2012" – Târgu Jiu, 18-19 may 2012, ISSN 1844-640x

[2] **Părăian M., Ghicioi E., Lupu L., Păun F., Vătavu N., Jurca A.**, 2011
New test methods for conformity assessment of conveyor belts with the safety requirements. The 5th International conference on manufacturing science and education, MSE 2011, Sibiu, ISSN 1843-2522

[3] **Lupu L.**, 2010
Study – NUCLEU Program - Development of assessment methods for belt conveyors intended for use in underground mines - group I non-electrical equipment (2010 - 2011)

[4] **Directive 2014/34/EU**, 2014

[5] **Standard SR EN ISO 20238**, 2019

[6] **Standard SR EN ISO/IEC 17025**, 2018

[7] **Standard SR EN 14973**, 2016

[8] **Standard SR EN 12882**, 2016

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 70-77

DESIGN AND EXECUTION OF DRILLING AND BLASTING WORKS USING MODERN SCANNING TECHNIQUES

Edward GHEORGHIOSU [1], Silviu BECUȚ[2]*

[1] National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani Department of Safety Explosives and Pyrotechnic Aticles, 32-34 G-ral Vasile Milea St., 332047 - Petroşani, Hunedoara County, Romania
[2] SSE Explo Romania, Cluj Napoca, Cluj County, Romania

DOI: 10.2478/minrv-2024-0042

Abstract: *The basic principles for the design of the parameters of the shooting techniques are: the exact definition of the technical and economic objectives and especially those related to the granulometry of the demolished material, knowledge of the characteristics of the rock massif (degree of cracking and local fracturing, compressive and tensile strength of the rocks, the degree of homogeneity and their compactness), knowing in detail the possibility of executing the firing holes for loading and crushing the demolished material, knowing the explosive used and its behavior in the concrete conditions of the quarry, specifying the restrictions imposed by the protection of the environment (distances from the surrounding objectives, the maximum accepted levels of vibrations, noises, dust). In order for all these principles to be fulfilled, there are methods of designing and executing the drilling and shooting works so that the results of the shooting works are those expected in conjunction with a rational exploitation in safe conditions. The paper presents a case study where the design and execution of drilling and blasting parameters was successfully applied using modern equipment.*

Keywords: *explosives, blasting parameters, quarry, blasthole*

1. Introduction

In order to have the desired results when carrying out quarry blasting work, special attention must be paid to the design of the blasting technique used. [1]

All technical aspects that can influence the outcome of a shot job carried out in a quarry must be taken into account. All the necessary information must be analyzed, an action that leads to the achievement of the previously established objectives of carrying out the demolition works with the help of civil explosives. [2]

When designing the shot, all the geometrical and placement parameters of the shot holes are determined, the type of explosive that will be used and how to load it into the shot holes, the delay scheme, etc. [3]

The necessary parameters to be determined when designing a shot are (Figure 1): the height and inclination of the slope of the step, the diameter and inclination of the hole, the line of resistance to the hearth (anticipatory), the length and depth of the drilled hole, the distance between the holes of the same row and between the rows of holes, explosive construction / distribution of the explosive in the hole, the length of the blast and the firing sequences of the charges. [4]

In order to obtain the most accurate data from the field regarding the main characteristics of the working bench (bench height, angle of inclination of the bench, geology of the area, etc.), various methods of scanning the surface of the working bench have been developed in the last 20 years using 2D or 3D laser, GNSS, Boretrack, drone.

These scanning equipment together with various specialized software have led to a very high accuracy of the data collected from the field, their processing and the correct design of the perforation scheme. [5]

This paper presents the way of designing and evaluating the drilling and shooting works in order to optimize the shooting parameters with a direct impact on the results obtained.

[*] Corresponding author: National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani Department of Safety Explosives and Pyrotechnic Aticles, 32-34 G-ral Vasile Milea St., 332047 - Petroşani, Hunedoara County, Romania, edward.gheorghiosu@insemex.ro

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 70-77

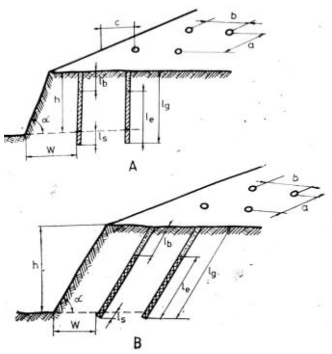


Fig. 1 Blasting technique parameters

For these actions, modern means of scanning, design and processing were used, which made it possible to obtain exceptional results.

Thus, the design-evaluation method was applied in the Hoghiz Quarry, mainly having the following execution stages:

- scanning the work front can do using measuring equipment such as Laser 2D, 3D, Drone, GNSS;
- the use of a specialized software for determining drilling parameters (hole length, hole inclination, hole azimuth, drilling network);
- the transposition of the projected data on the drilling scheme, which includes for each shooting hole, the length, the drilling angle and the azimuth of the hole and which is transmitted to the operator on the drilling;
- marking in the field the position of the shooting holes according to the designed drilling scheme;
- drilling shot holes, checking them using Boretrack scanning equipment, inclinometer, compass, flashlight or laser device;
- establishing the explosive charge for each hole and designing the delay scheme;
- carrying out the shooting work and filming it with a video camera or drone;
- verification of shooting results by visual control immediately after the shooting operation and photographic analysis of the shooting

2. Methods of evaluation

2.1. Scanning the work front using Drona-type measuring equipment

For the initial scanning, a Drona-type equipment (Mavick 3 was used, with the help of which the blasting front was photographed. (Figure 2)

The obtained information was downloaded and processed with a specialized software design (QarryX), with the help of which the blasting holes were designed.

Fig. 2 Scanned front

2.2. Design of blasting holes

The operator is required to know the actual depth, inclination, azimuth and lead for each borehole before charging it with explosive. For the front row, the information from the drill monograph is used in conjunction with the face profiling data to calculate the correct anticipation both upslope and around each borehole along the front row.

For an optimal design of the drilling monograph, the specialized software QuarryX was used, with the help of which the design of each blasting hole in the first row was analyzed, in relation to the real surface of the front slope.

With the help of the QX software - Profile mode, the holes are designed - (distance from the ridge, length of the hole, angle of inclination, azimuth) so that all the holes, depending on the calculated theoretical anticipation, touch as many points as possible in the real profile of the working step. (Figure 3).

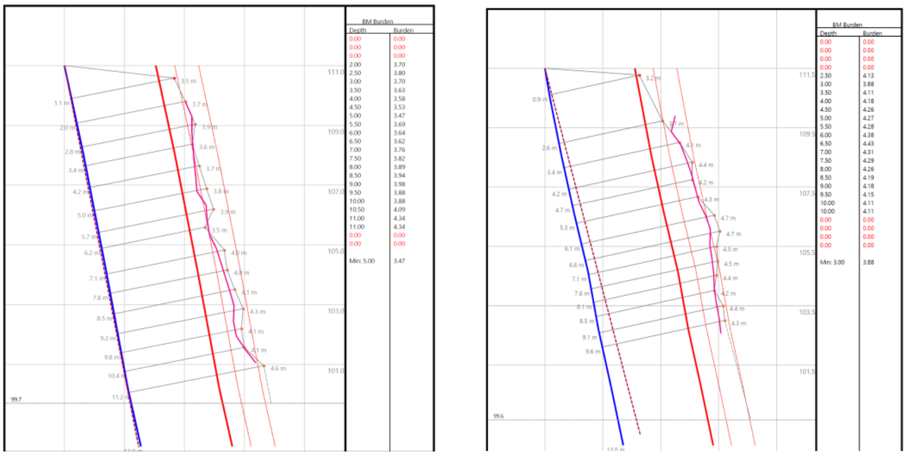


Fig. 3 Design blasting holes

Taking as a reference the design of the first row of blasting holes, the distribution of blasting holes for the entire shot front was generated. (Figure 4)

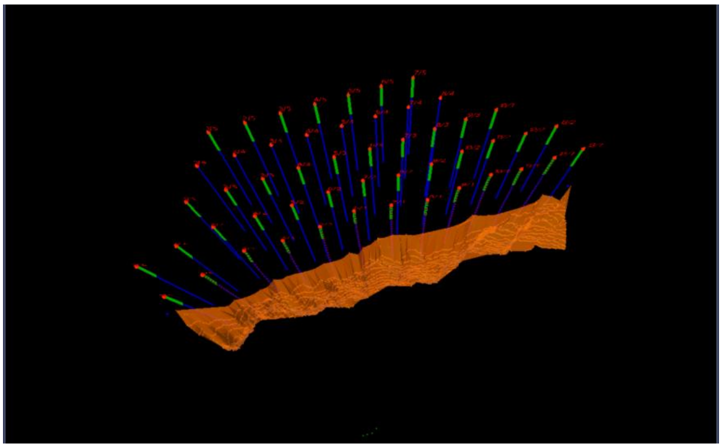


Fig. 4 The distribution of blasting holes

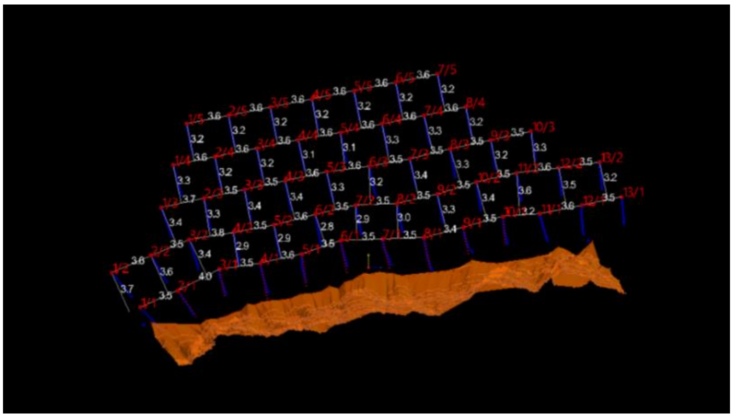


Fig. 5 Drilling monograph

The distribution of the holes in the front and their coordinates, respectively the drilling monograph (Figure 5), was sent to the drilling operator.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 70-77

2.3. Design of blasting holes

If the holes are straight, then in most cases the depth of the hole is easy to measure. Inclination and azimuth can be checked by optical survey, i.e. flashlight, compass and inclinometer.

A modern method of checking the execution of blasting holes is electronic measuring tools (MDL – Cabled Boretrak System) should be used (Figure 6).

Fig. 6 MDL – Cabled Boretrak System

Boretracking is a method of measuring "as drilled" holes. A probe is lowered into the drilled hole that meaures the pitch and role of the probe sensor at pre-set intervals. [6]

This information can be added to specialized softwere 3D model of the bench. This allows the software to calculate actual burdens of the holes at different locations and measure hole separations for optimized loading.

With the help of the specialized software (QuarryX), the accuracy of the execution of the holes in Figure 7 was verified, the results being presented in the table 3. [7]

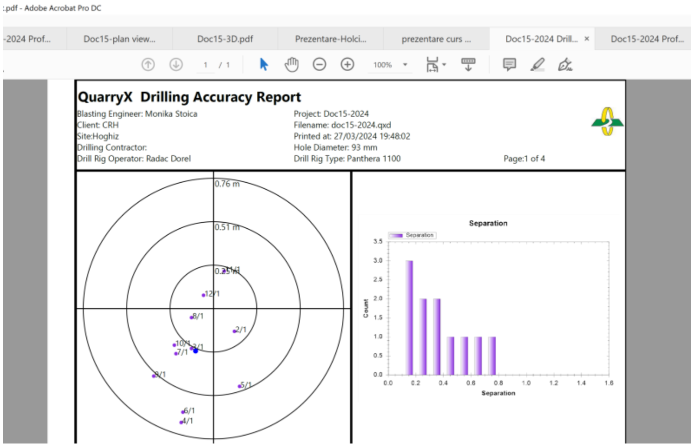


Fig. 7 Drilling accuracy

It can be compared to a shot plan designed in QuarryX on the bench to measure drilling deviations.

3. Results and discussions

The following parameters are highlighted for each hole [8]:
geolocation of the hole (lat, & long.), z-elevation, azimuth of the hole, angle of inclination, length of the hole, drilling diameter, sub-sinking, anticipation, bore, hearth level). (Tabel 1 and Tabel 2)

Table 1. Parameters for blasthole no. 1÷5

Parammeters	**BLASTHOLE**				
	1	2	3	4	5
East	982.01	985.55	989.02	992.51	995.78
North	1025.57	1027.35	1027.87	1028.66	1029.78
Elevation	112.1	111.7	111.5	111.69	111.56
Drill Azimuth (°)	146.9*	165.9*	165.3*	170.9*	164.9*
Search Azimuth (°)	146.9	165.9	165.3	170.9	164.9
Drill Angle (°)	11.5*	10.0*	11.8*	11.0*	10.3*

Hole length	13.0m*	13.0m*	13.0m*	13.0m*	13.0m*
Subdrill	0.4m	0.7m	0.8m	0.7m	1.0m
Diameter	93mm	93mm	93mm	93mm	93mm
Offset	-2.2m	-3.4m	-3.3m	-3.4m	-3.9m
Horizontal Offset	0.8m	0.0m	0.1m	0.3m	0.3m
Vert.Face Height	11.6m	11.8m	11.6m	11.7m	11.3m
Profile Area	41.1m²	49.4m²	50.7m²	51.0m²	51.7m²
Planned Burden	4.0m	4.0m	4.0m	4.0m	4.0m
Tolerance	10.0%	10.0%	10.0%	10.0%	10.0%
Floorlevel	99.8	99.6	99.6	99.6	99.8
Critical Burden	3.0 m	3.0 m	3.0 m	3.0 m	3.0 m
Stemming	2.7m	2.7m	2.7m	2.7m	2.7m
BurdenMaster Settings: Search Width BM Grid (H x V) Burden To Report Excessive Burden	 4.0m 0.5mx 0.5m 3.3m 6.0m				

Table 2. Parameters for blasthole no. 6÷11

Parammeters	**BLASTHOLE**					
	6	7	8	9	10	11
East	999.32	1002.81	1006.14	1009.49	1012.64	1016.15
North	1029.91	1030.02	1030.9	1031.83	1032.04	1032.75
Elevation	111.42	111.28	111	111.01	110.88	111
Drill Azimuth (°)	161.1*	165.7*	160.5*	170.0*	164.9*	176.9*
Search Azimuth (°)	161.1	165.7	160.5	170.0	164.9	176.9
Drill Angle (°)	11.1*	13.3*	11.8*	11.2*	11.2*	11.5*
Hole length	13.0m*	13.0m*	13.0m*	13.0m*	13.0m*	13.0m*
Subdrill	1.1m	1.2m	0.8m	1.5m	1.7m	1.4m
Diameter	93mm	93mm	93mm	93mm	93mm	93mm
Offset	-3.4m	-2.9m	-3.3m	-3.3m	-3.1m	-2.8m
Horizontal Offset	0.4m	0.4m	0.1m	1.2m	1.1m	1.8m
Vert.Face Height	11.2m	10.9m	11.6m	10.7m	10.6m	10.9m
Profile Area	49.5m²	46.4m²	50.7m²	46.1m²	41.7m²	44.8m²
Planned Burden	4.0m	4.0m	4.0m	4.0m	4.0m	4.0m
Tolerance	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Floorlevel	99.8	99.8	99.6	99.8	99.8	99.7
Critical Burden	3.0 m	3.0 m	3.0 m	3.0 m	3.0 m	3.0 m
Stemming	2.7m	2.7m	2.7m	2.7m	2.7m	2.7m
BurdenMaster Settings: Search Width BM Grid (H x V) Burden To Report Excessive Burden	 4.0m 0.5m x 0.5m 3.3m 6.0m					

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 70-77

Table 3. Drilling accuracy

Hole	MaxX	MaxY	Separation
1	0.12	-0.13	0.17
2	-0.13	-0.23	0.27
3	-0.19	-0.66	0.72
4	0.15	-0.45	0.48
5	-0.18	-0.60	0.65
6	-0.22	-0.26	0.35
7	-0.13	-0.05	0.14
8	-0.35	-0.39	0.53
9	-0.23	-0.21	0.32
10	0.06	0.22	0.23
11	-0.06	0.08	0.10
Min	0,06	0,50	0,10
Max.	0,35	0,66	0,72
Avr.	0,17	0,30	0,72

After measuring the holes located on row 1 with the help of the Boretrack equipment and the graphical overlay of the measured hole with the designed hole, minor deviations of the drilled holes on both the x and y axis can be observed, which do not exceed 0.3 m and do not influence the maximum anticipation taken into account.

After completing all the design-verification stages, the final conditions for carrying out the shooting work were established.

The main purpose of checking compliance with the drilling monograph is to highlight a possible risk situation that consists of shot holes drilled too close / too far from the free surface or shot holes that, in depth, reach too close / too far from each other.

These situations mean that in respective areas of the firing front, the quantities of explosives are oversized / undersized, as the case may be.

If they are not identified and resolved, such situations lead to the amplification of the effects of the shooting works (throwing rocks, scattering rocks, producing high-intensity vibrations) as well as cracks in the massif, obtaining an irregular shape of the front after shooting, unnecessary consumption of explosive.[9]

In the following, the geometric and quantitative parameters established considering the results obtained during the design-verification stages of the drilling monograph are presented.

- avg. step height: 11,8 m;
- inclination of the holes: 76 ÷ 78°;
- number of holes: 51;
- number of rows: 5;
- diameter of the holes: 92 mm;
- planned burden (w); 4 m;
- critical burden: 3 m
- distance from the edge of the beam to the first row of holes (c): 3,2 m;
- the distance between the holes on the same row (a): 3.6 m;
- distance between rows (b): 3.3 m;
- length under the recess (Lsub.): 0.7 m;
- hole length (Lg): 13 m;
- length of the explosive column: 9.3 m;
- civil explosives used:
• basic explosive charge, Blendex emulsion type explosive;
• explosive initiation charge; Dynamite
- means of initiation: non-electrical initiation system;
- amount of explosive / hole: 4386 Kg E TNT (Trotil equivalent), consisting of Blendex emulsion type explosive and explosives dynamite;
- quantity of explosive / delay stage: 86 kg. E TNT (1 shot hole / delay stage).

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 70-77

Sequential rock detachment from the massif will be accomplished using network of delayed surface connectors to initiate staple shock tubes that transmit the detonation into the shot holes.

The initiation of the deployment of the firing front will be done from one of the flanks (left/right) or from the front depending on the conditions in the work stage.

The delay scheme presented in Figure 8 was also established

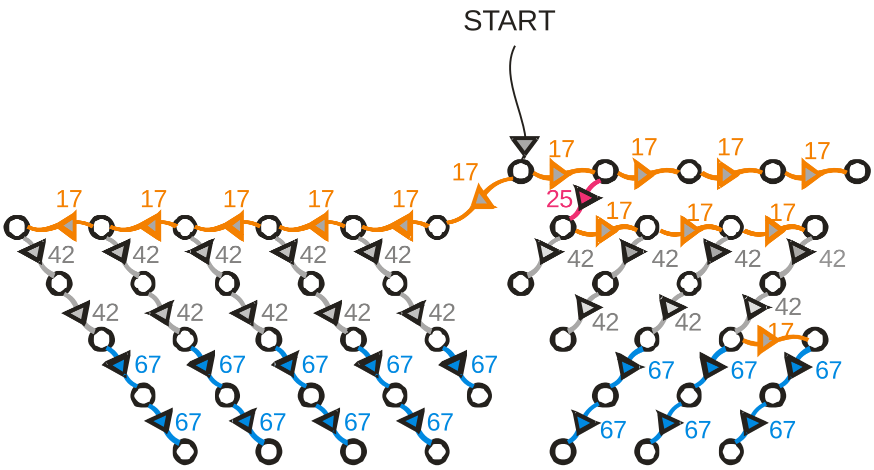


Fig. 8 Design delay blasting

The blasting results were very good, this can be seen in Figure 9.

The presence of oversizes rock was not found, the fragmentation of the rock was adequate, the material was good grouped and the shape of the step left after blast allows the preparation of the next front, without the need for additional work (contouring etc).


Fig. 9 Rezults of blasting

4. Conclusions

Application of the design-verification procedure led to very good blasting results.

The design-verification system of the blasting holes which consists of modern high-performance infrastructure (specialized software QuaryX, boretrack) allowed a detailed analysis of the execution of the blasting holes and the adaptation of the blasting conditions to the concrete situation in the field.

Even if the results presented were obtained, to be certain of obtaining consistently positive results it is still recommended to check each shot hole.

Every economic operator should use such a design-check system.

The use and implementation of such a design-verification procedure maintains adequate control of the blasting works in terms of their effects (fly rock, seismic effect), thus increasing the degree of safety when performing the blasting works.

References

[1] **R. Landmal**, 2023
Comparison of accuracy of Quarry-Face-modelling between Drone and 3D-Laser-data, 4th Technical Conference, Wroclaw.

[2] **M. Kolesar**, 2023
Use of tools supporting D&B and work efficiency management to increase customer satisfaction, 4th Technical Conference, Wroclaw.

[3] **C. Thomas**, 2023
Face profiling in open pits by using a Robotic Total Station, 4th Technical Conference, Wroclaw.

[4] **J. Kutschera**, 2023
Geo-konzept solutions, 4th Technical Conference, Wroclaw.

[5] **U. Gyllande**, 2023
HNS and future. A SmartROC drill rig option for safe, easy drilling and improved productivity, 4th Technical Conference, Wroclaw.

[6] *MDL Cabled Boretrak system – manual system*

[7] *QuarryX – Manual user.*

[8] **Becut, S.; Stoica M**, 2023
*Drilling & blasting technology improvement program applied in the Hoghiz quarry belonging to CRH – ROMCIM Romania,*4th Technical Conference, Wroclaw.

[9] **E. Gheorghiosu, G. A. Găman, E. Ghicioi, A. Kovacs, G.D Vasilescu**, 2019
Guide for evaluating the seismic effect generated by blasting works in quarry, (INSEMEX 2019).

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 78-86

THE INFLUENCE OF BLAST HOLES STEMMING ON THE BREAKING YIELD OF ROCKS FRAGMENTED WITH EXPLOSIVES

Cristian RĂDEANU[1], Bogdan GARALIU-BUȘOI[2], Ladislau RADERMACHER[3]*

[1,2] National Institute for Research and Development in Mine Safety and Protection to Explosion - INSEMEX Petrosani, Department of Safety of Explosion and Pyrotechnic Articles, 332047, Petrosani, Romania
[3] 2University of Petrosani, Department of mining engineering, topography and construction, 332006, Petrosani, Romania

DOI: 10.2478/minrv-2024-0043

Abstract: *Stemming of blast holes is an essential operation for controlled explosions, serving the purpose of filling the voids left after loading with explosives. This process prevents the escape of gases produced during the explosion, which have a pressure of around 10,000 daN/cm², and enhances the breaking effect while reducing dust and noise. Efficient use of stemming can significantly reduce the consumption of explosives and, consequently, the costs of rock fragmentation through drilling and blasting operations, allowing a reduction in explosive consumption by 20-25%. Furthermore, improper stemming of blast holes results in low breaking efficiency, large material granulation, misfires, and, in other words, increased costs for drilling, blasting, and crushing operations, as well as potential accident hazards due to misfires. In this article, we will explore the materials used for stemming, the technologies employed, and improvement proposals to maximize the efficiency and safety of mining operations, leading to more efficient and safer use of explosives in rock fragmentation operations, enhancing breaking efficiency while reducing associated costs and risks.*
Keywords: *civil explosives, stemming, drill-blast works, firing parameters, burst yield, controlled explosions*

1. Introduction

The density of geological exploration drill holes is one of the primary bases for designing the loading structure of blast holes. The development of the mining industry is deeply interconnected with sustainability principles, and improving blasting efficiency is an essential factor in implementing sustainable mining practices. With the continuous increase in global demand for minerals, mining companies must not only boost production but also pay close attention to environmental sustainability. This entails rational control of vibrations and noise during operations to minimize negative environmental impacts. Nevertheless, the current efficiency of using explosives in rock fragmentation remains relatively low, with a significant portion of the explosion energy dissipating as vibrations or air shocks [1-4].

Therefore, there is an urgent need to improve the energy efficiency of explosives used in rock fragmentation and to mitigate secondary negative effects, thereby facilitating the sustainable development of the mining industry. Burdening plays a crucial role in optimizing the use of explosive energy. [5-8].

The length of the blast hole is a particularly important parameter in blast design, and its rational application to enhance the utilization of explosion energy has been demonstrated in various studies. [9-12].

During the propagation of detonation waves from the explosive charge to the stemming material, differences in properties between the explosion products (high-pressure and high-temperature gases) and the stemming material can influence the propagation of shock and stress waves, as well as the ejection of gas and stemming. Thus, investigating stemming materials becomes essential. Multiple research efforts have explored alternative stemming materials to improve rock fragmentation and reduce the generation of fly rock. These alternatives include gypsum stems, rubber-assisted stems (rubber plugs), crushed aggregates, and angular aggregates. Although these materials have shown potential benefits, they are often less common, can be relatively costly, and may have limited availability regarding raw material source [13-16].

[*] Corresponding author: National Institute for Research and Development in Mine Safety and Protection to Explosion - INSEMEX Petrosani, Department of Safety of Explosion and Pyrotechnic Articles, 332047, Petrosani, Romania, cristian.radeanu@insemex.ro; Tel.: +40-767-84-88-88

In comparison, clay and sand have the advantage of being widely available. Additionally, their use in underground mining provides multiple benefits, including ease of transport, lower costs, and non-toxicity. Water, a common substance, helps reduce explosive dust and can prevent the clogging of blast holes after blasting in deep holes. However, research on the use of clay, sand, or water as stemming materials is still incomplete and requires further investigation.

According to occupational safety regulations in the mining industry of Romania, specific requirements for stemming blast holes are as follow:

- short holes (0.4-0.6 m): must be stemmed at least 0.3 m;
- medium holes (up to 1.5 m): must be stemmed at least half their length;
- long holes (longer than 3 m): must be stemmed one-third of their length [17,18].

Blasting unstammed holes is prohibited, and the length of stemming is determined by the blasting order in day-to-day mining operations.

2. Methodological considerations on the mechanics of explosion and the role of stemming material

The stemming material plays a crucial role in confining the gases produced by the explosion within the blast hole, thereby increasing the pressure and ensuring efficient rock fragmentation. The efficiency of this process depends on the density and compressibility of the stemming material (Equation 1).

$$P_{explosion} = \frac{F_{gases}}{A} \tag{1}$$

where:
$P_{explosion}$ – explosion pressure,
F_{gases} – force exerted by the produced gases,
A – area of the stemmed surface.

Stemming materials vary in their ability to absorb and disperse the energy produced by the explosion. An inadequate stemming material may allow gas escape and reduce the detonation efficiency (Equation 2).

$$E_{absobed} = \frac{1}{2} \cdot m_{stemming} \cdot v_{gases}^2 \tag{2}$$

where:
E_{absorbed} – energy absorbed by the stemming material,
m_{stemming} – mass of the stemming material,
v_{gases} – velocity of the gases produced by the explosion.

2.1. The influence of stemming on blasting parameters

In the process of rock fragmentation through controlled explosions, blasting parameters are essential to ensure the efficiency and safety of blasting operations. These parameters include the charge diameter (influences the breaking energy and shock wave propagation); charge length (determines the distribution of explosive energy along the blast hole); stemming (prevents the escape of explosive gases, enhancing the breaking effect and reducing dust and noise); the distance between the explosive and the blast hole wall—coupling (affects how energy is transferred to the rock); initiation type and initiation point (determines the detonation method and shock wave propagation).

Stemming has a major influence on improving the quality of blasting operations because it favours:

a. Increasing gas pressure - Stemming prevents the escape of gases produced by the explosion, which increases internal pressure and, consequently, the efficiency of rock fragmentation. Gas pressure can reach values of around 10,000 daN/cm², leading to efficient material displacement.

b. Uniform energy distribution - The inert material used in stemming ensures uniform distribution of explosive energy, preventing local stress concentrations that could lead to uncontrolled fractures. This contributes to more controlled and efficient rock fragmentation.

c. Reduction of dust and noise - Stemming reduces the release of dust and noise, improving working conditions and reducing environmental impact. More complete combustion of the explosive due to effective stemming leads to reduced emission of toxic gases.

d. Economy of explosives - Proper stemming can reduce the required amount of explosives by 20-25%, resulting in significant operational cost savings. Increased explosion efficiency allows for the use of smaller quantities of explosives to achieve the same breaking effect.

e. Control of explosion direction - By controlling how explosive energy is released and distributed, stemming allows for more precise direction of shock waves. This is essential for executing a blasting plan that minimizes the risk of damage to adjacent structures or equipment.

Stemming offers numerous advantages including: increased efficiency of explosives; enhanced safety by reducing the risk of accidental or incomplete detonations; cost reduction through more efficient use of explosives; the decrease of dust and noise during detonation.

Despite its advantages, stemming also has certain disadvantages: namely the need for specialized, expensive equipment that requires regular maintenance; dependence on the experience and qualifications of the operator handling the equipment during stemming operations; and the potential negative environmental impact of the stemming and detonation process.

2.2. Physicochemical phenomena that may occur during stemming and influence the explosion power in blast holes

The most important physicochemical phenomena that may occur during the stemming operations of blast holes are:

a. Friction and heating - Friction between the stemming material and the walls of the hole can generate heat. This can influence the chemical stability of explosives and may lead to premature reactions if the temperature becomes sufficiently high.

b. Uncontrolled chemical reactions - Chemical reactions between the stemming material and the explosive or between the stemming material and the walls of the hole can affect the stability of the explosion. Certain materials may catalyse undesirable reactions or react with the explosives, leading to reduced efficiency or even safety risks.

c. Moisture absorption - The absorption of moisture by stemming materials can affect the physical and chemical properties of explosives. Hygroscopic materials, such as certain clays, can absorb water and thus alter the chemical composition and reactivity of the explosives.

d. Thermal conductivity - The thermal conductivity of the stemming material influences how heat is dissipated during detonation. Materials with high thermal conductivity can disperse heat more rapidly, which can affect the local temperature and the efficiency of the detonation.

e. Pressure and compaction - The pressure exerted by the stemming material on the explosive can affect the detonation velocity and explosion power. An overly compressible or insufficiently compacted stemming material can allow the escape of explosive gases, thereby reducing the efficiency of the detonation.

f. Change of material state - Phase changes of the stemming material (e.g., from solid to liquid) can influence the behaviour of the explosion. If a stemming material melts at high temperatures, it can affect the distribution of explosive force.

g. Ionization and plasma generation - In the case of very intense explosions, the ionization of the stemming material or the explosive itself can create plasma, which can alter the dynamics of the explosion and its effect on the surrounding rock.

h. Gases produced by chemical reactions - Gases produced by chemical reactions of the explosives and the stemming material influence the internal pressure and the efficiency of rock fragmentation. The chemical composition of the gases and the rate at which they expand are crucial for the final effect of the explosion.

i. Catalyst effect - Certain stemming materials can act as catalysts, accelerating or altering the chemical reactions of the explosives. This can affect the detonation velocity and the total energy released.

j. Gas desorption - The desorption of gases adsorbed on the surface of the stemming material can influence the pressure and temperature within the blast hole during detonation. Porous materials can retain and release gases, thus modifying the dynamics of the explosion.

3. Materials used for stemming blast holes

The materials used for stemming blast holes are diverse and have specific characteristics that make them suitable for different mining applications. Among these materials are:

- Inert dust, resulting from rock grinding, is used for stemming holes with both high and low inclinations, with filling done either gravitationally or mechanically;
- Detritus, consisting of rock fragments from drilling, is primarily used for stemming drill holes with high inclinations;
- Sand is used due to its fine granulation and controlled moisture content, making it suitable for air-compressed stemming. It has granules up to 4 mm and a moisture content of 4÷5%;
- Clay can be used alone or mixed with sand, ensuring the sealing and stability of the stemming;
- Sand-clay mix is a combination used to improve the quality of the stemming;

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 78-86

- Cement mortar cartridges are prefabricated from a mixture of cement and sand (1:6), offering high compressive strength;
- Plastic plugs are used to seal and stabilize the stemming;
- Water is used in downward-inclined holes, often in polyethylene vials or other plastic containers.

The materials that can be used for stemming boreholes in mining, along with their characteristics and specific uses, are presented in the following table:

Table 1. Materials used for stemming

Material	Specific Use	Characteristics
Inert Dust	High and low inclination holes	Fine granulation, gravitational or mechanical filling
Debris	High inclination drill holes	Free-falling rock fragments
Sand	Air-compressed holes, all mines	Granules < 4 mm, 4-5% moisture
Clay	Sealing and stability	Used alone or mixed with sand
Sand-Clay Mix	Improving stemming quality	Combination for sealing and stability
Cement Cartridges	Prefabricated, high inclination holes	Cement/sand mix (1:6), compressive strength
Plastic Plugs	Sealing and stabilizing	Various diameters
Water	Downward-inclined holes, water-resistant explosives	Polyethylene vials or direct pouring

Debris and inert dust are particularly used for stemming high inclination drill holes, with filling achieved through the free fall of the material into sections not filled with explosives. Inert dust and sand are used for both high and low inclination drill holes, with mechanical filling done using a compressed air gun.

Stemming with clay involves preparing clay cartridges that are inserted into the holes using a stemming rod. The quality of the stemming can be improved by mixing clay with sand in a 3:1 ratio, reducing the consumption of explosives by 10-15% and increasing the fragmentation coefficient of the holes.

Cement mortar cartridges are made from a mixture of cement and sand in a 1:6 ratio, offering a compressive strength of about 11 daN/cm². Stemming is done by inserting a clay cartridge following the explosive, followed by cement cartridges, with the last cartridge being clay to ensure sealing.

Water stemming is suitable for downward-inclined holes, where water is poured over the explosives until the hole is filled. This method is effective only when using water-resistant explosives. Water stemming can also be achieved using polyethylene vials, which are inserted into the holes and filled with water. For these vials, the last cartridge in the stemmed hole is clay to ensure sealing.

4. Proposals for improving stemming

Stemming plays an essential role in maintaining explosion gas pressure within the mine hole and reducing noise. Improper stemming can lead to suboptimal outcomes such as low fragmentation efficiency, large particle sizes of resulting material, and misfires in the work front.

Explosive materials constitute a significant portion of mining operational costs, making their conservation crucial. Efficient stemming can considerably reduce explosive consumption and thus operational costs.

Given that drilling, like the explosives themselves or initiation materials, plays a well-defined role in achieving maximum explosive utilization efficiency, the following proposals can be considered to enhance stemming practices:

- there is a need for a well-defined and standardized technological regime for stemming, applicable across all Ministry of Mines units;

- centralizing stemming production in a specialized mining unit capable of manufacturing and delivering the required stemming materials to mining operations. This unit should be equipped with machinery for producing stemming materials from a mixture of clay and sand at a predetermined moisture level, in the form of cartridges of various diameters and lengths;
- proper packaging of stemming materials to maintain constant moisture content for an extended period is crucial. Such stemming materials should be distributed to work fronts alongside explosives based on precise calculations performed by technical personnel;
- implementing a technological regime for the production and use of stemming materials that educates the entire mining workforce about its role and importance, leading to positive outcomes in terms of efficiency and safety of explosions.

Implementing these proposals would lead to more efficient and safer use of explosives in mining operations, improving fragmentation efficiency and reducing associated costs and risks. Therefore, stemming should be recognized for its importance and treated as an essential aspect of controlled explosions.

4.1. Methodology for optimizing stemming materials

To select the optimal stemming material, a rigorous evaluation of several criteria is necessary:

a. Density and compressibility

Density (ρ) and compressibility (Cc) are critical for ensuring proper confinement of explosion gases. Stemming materials with high density and optimal compressibility retain the produced gases, thereby increasing internal pressure (Equations 3 and 4).

$$\rho = \frac{m}{V} \tag{3}$$

$$C_c = \frac{\Delta V}{V_o} = \frac{V_o - V_f}{V_0} \tag{4}$$

where:
m – material mass,
V – the volume of the material,
V_0 – initial volume,
V_f – final volume.

b. Coefficient of friction

The coefficient of friction (μ) measures the resistance of the stemming material against the walls of the mine hole. A suitable coefficient of friction prevents gas leakage and maintains the necessary pressure for efficient fragmentation (Equation 5).

$$F_f = \mu \cdot N \tag{5}$$

where:
F_f – friction force,
N – the normal force exerted on the stemming material.

c. Chemical and mechanical stability

The stability of stemming material is crucial to prevent undesirable chemical reactions and disintegration during explosions. This is quantified by chemical stability factor (S_c) and mechanical stability factor (S_m) (Equation 6).

$$S_{total} = S_c \cdot S_m \tag{6}$$

where:
S_c – chemical stability factor,
S_m – the mechanical stability factor.

d. Environmental and health impact

The impact of stemming materials on the environment and health is assessed by the amount and toxicity of the produced dust (Equation 7).

$$I = \frac{M_{dust}}{M_{Total}} \tag{7}$$

where:
I – the impact,
M_{dust} – mass of dust produced,
M_{Total} – mass of dust produced.

e. Costs

Costs are evaluated based on the unit price of stemming material (Equation 8).

$$C = P \cdot M \tag{8}$$

where:
C – the total cost,
P – price per mass unit,
m – mass of the material.

Calculating the total score

The total score for each stemming material is computed as a weighted sum of scores obtained for each criterion (Equation 9):

$$S_{Total} = w_1 \cdot \left(\frac{\rho}{\rho_{\max}}\right) + w_2 \cdot \left(\frac{C_{cmax}-C_c}{C_{cmax}-C_{cmin}}\right) + w_3 \cdot \left(\frac{\mu}{\mu_{\max}}\right) + w_4 \cdot \left(\frac{S_{total}}{S_{total,max}}\right) + w_5 \cdot \left(\frac{I_{min}}{I}\right) + w_6 \cdot \left(\frac{C_{min}}{C}\right) \tag{9}$$

where:
$w_1, w_2, w_3, w_4, w_5, w_6$ – the weights of each criterion
ρ_{max}, C_{cmax}, C_{cmin}, μ_{max}, $S_{total,max}$, I_{min}, C_{min} – reference values for normalization

Table 2. Evaluation table

Criterion	Sand	Clay	Cement Mortar	Gravel	Water (Ampoules)
ρ (g/cm³)	1.6	2.0	2.4	2.2	1.0
C_c	0.15	0.25	0.20	0.10	0.05
M	0.6	0.5	0.7	0.6	0.1
S_{total}	0.8	0.9	0.95	0.85	0.99
I	0.05	0.03	0.02	0.04	0.01
C (Euro/kg)	5	6	8	4	10

Equal weights assumption: w1=w2=w3=w4=w5=w6=1.
Reference values for normalization: $\rho_{max} = 2.4$; $C_{cmax} = 0.25$; $C_{cmin} = 0.05$; $\mu_{max} = 0.7$; $S_{total,max} = 0.99$; $I_{min} = 0.01$; $C_{min} = 4$.

4.2. Assessment of the Impact of stemming materials on explosive efficiency

To assess the efficiency of stemming materials used in blasting operations aimed at increasing rock fragmentation with explosives, the following calculations can be performed:

a. Internal pressure and fragmentation

Stemming materials influence the internal pressure within the blast hole, thereby affecting rock fragmentation. Optimal internal pressure is achieved when the stemming material retains the gases produced long enough to ensure complete fragmentation (Equation 10).

$$P_{intern} = P_{initial} \cdot e^{-\alpha t} \tag{10}$$

where:
P_{intern} - internal pressure in the blast hole,
$P_{initial}$ - initial explosion pressure,

α - attenuation coefficient,
t – time.

b. Detonation velocity and explosive efficiency

Explosives have a specific detonation velocity that determines their efficiency. Stemming materials that provide optimal confinement enable explosives to achieve their maximum detonation velocity (Equation 11).

$$v_{detonation} = \sqrt{\frac{2 \cdot E}{m}} \tag{11}$$

where:
$v_{\text{detonation}}$ - detonation velocity,
E - energy released by the explosive,
m - mass of the explosive.

Let's consider an example with ANFO (Ammonium Nitrate Fuel Oil) as the explosive and compare the effect of different drilling materials on detonation efficiency.

- Parameters for ANFO explosive:
  ρ = 0.85 g/cm³; $v_{\text{detonation}}$ = 3200 m/s; E = 3.9 MJ/kg.
- Drilling materials and parameters:
  - Sand: ρ = 1.6 g/cm³, μ = 0.6;
  - Clay: ρ = 2.0 g/cm³, μ = 0.5;
  - Cement Mortar: ρ = 2.4 g/cm³, μ = 0.7.
- Attenuation coefficients: α_{sand} = 0.1; α_{clay} = 0.08; $\alpha_{\text{cemen t}}$= 0.06
- P_{initial} = 1000 kPa; t = 0.01 s.

The internal pressure created by the explosive considering the stemming materials can be calculated as follows (Equations 12):

$$\begin{aligned} P_{internal,\ sand} &= P_{initial} \cdot e^{-\alpha_{sand} \cdot t} \approx 990kPa \\ P_{internal,\ clay} &= P_{initial} \cdot e^{-\alpha_{clay} \cdot t} \approx 992kPa \\ P_{internal,\ cement} &= P_{initial} \cdot e^{-\alpha_{cement} \cdot t} \approx 994kPa \end{aligned} \tag{12}$$

In this example, stemming materials significantly affect internal pressure and detonation efficiency.

4.3. Case study: Evaluation of stemming materials for civilian explosives

The optimal stemming material must confine gases for a sufficient duration to ensure complete and efficient detonation (Table 3).

Table 3. Recommended stemming materials for civilian explosives

Explosive Name	Manufacturer	Application Location	Detonation Velocity (m/s)	Brisance	Recommended Stemming Material	Reason
ANFO	Orica	Surface mines, quarries	2500-3000	Medium	Cement Mortar Sand, Clay	Low cost, good compressibility
Emulex 1	Dyno Nobel	Underground mines, quarries	5400	High	Cement Mortar	Excellent stability, water-resistant
Magnafrac	Austin Powder	Surface mines, quarries	5700	High	Cement Mortar, Water (Phials)	High performance, water resistance
Powergel	Orica	Underground mines, quarries	6000	High	Water (Phials), Cement Mortar	Gel explosive, requires water resistance
Pentolite	Ensign-Bickford	Demolitions, mines	7800	Very High	Cement Mortar, Clay	High sensitivity, requires stability
Tovex	DuPont	Underground mines, quarries	5500	High	Water (Phials), Clay	Good performance in wet conditions

Explosive Name	Manufacturer	Application Location	Detonation Velocity (m/s)	Brisance	Recommended Stemming Material	Reason
Ammonal	Dyno Nobel	Surface mines, quarries	3200-4500	Medium	Sand, Clay	Easy to prepare, low cost
Gelignite	Nitro Nobel	Underground mines, quarries	6000	High	Cement Mortar, Water (Phials)	Good performance in wet conditions
C4	Chemring	Military use, demolitions	8000	Very High	Cement Mortar, Clay	Stability and shock resistance
Slurry Explosives	Various Manufacturers	Surface mines, quarries	4000-5000	Medium-High	Sand, Clay	Good water resistance, medium sensitivity

Among the materials analysed, cement mortar provides the best confinement, followed by clay and sand.

5. Conclusions

The methodology for optimizing stemming materials involves a detailed evaluation of essential criteria to ensure maximum efficiency and safety of blasting operations.

By selecting appropriate stemming materials for each type of explosive and specific usage conditions, significant cost savings and performance improvements can be achieved in mining operations.

To improve the breaking yield of rocks fragmented through drilling and blasting operations, continuous investments in research and development are necessary to identify and implement new stemming technologies and materials. These efforts aim to enhance the quality of stemming, making it more efficient and environmentally friendly. Collaboration with academic and research institutions can accelerate progress in this field.

Acknowledgements

This work was developed within the" Nucleu" Program within the National Plan for Research, Development, and Innovation 2022-2027, with the support of the Romanian Ministry of Research, Innovation and Digitalisation, project no. 23 32 02 03, title: "Development of monitoring methods to reduce environmental impact from the use of explosive materials, pyrotechnic articles, and application of blasting technologies", Phase 2/2024.

References

[1] **Shi, X.; Zhang, Z.; Qiu, X.; Luo, Z.**, 2023
Experiment Study of Stemming Length and Stemming Material Impact on Rock Fragmentation and Dynamic Strain. Sustainability 2023, 15, 13024. https://doi.org/10.3390/su151713024.

[2] **Peng, J.; Zhang, F.; Du, C.; Yang, X.**, 2020
Effects of Confining Pressure on Crater Blasting in Rock-like Materials under Electric Explosion Load. Int. J. Impact Eng. 2020, 139, 103534.

[3] **Sanchidrian, J.A.; Segarra, P.; López, L.M.**, 2007
Energy Components in Rock Blasting. Int. J. Rock Min. Sci. 2007, 44, 130–147.

[4] **Ouchterlony, F.; Nyberg, U.; Olsson, M.; Bergqvist, I.; Granlund, L.; Grind, H.**, 2004
Where Does the Explosive Energy in Rock Blasting Rounds Go? Sci. Technol. Energ. 2004, 65, 53–64.

[5] **Oates, T.E.; Spiteri, W.**, 2021
Stemming and Best Practice in the Mining Industry: A Literature Review. J. S. Afr. Inst. Min. Metall. 2021, 121, 1–11.

[6] **Zhang, Z.**, 2016
Rock Fracture and Blasting: Theory and Applications; Butterworth-Heinemann: Oxford, UK; Elsevier: Oxford, UK, 2016; ISBN 978-0-12-802688-5.

[7] **Ur Rehman, A.; Emad, M.Z.; Khan, M.U.**, 2021
Improving the Environmental and Economic Aspects of Blasting in Surface Mining by Using Stemming Plugs. J. S. Afr. Inst. Min. Metall. 2021, 121, 369–377.

[8] **Boshoff, D.; Webber-Youngman, R.C.W.**, 2011
Testing Stemming Performance, Possible or Not? J. South. Afr. Inst. Min. Metall. 2011, 111, 871–874.

[9] **Zhang, Z.; Hou, D.; Guo, Z.; He, Z.**, 2020
Laboratory Experiment of Stemming Impact on Rock Fragmentation by a High Explosive. Tunn. Undergr. Space Technol. 2020, 97, 103257.

[10] **Fourney, W.L.; Barker, D.B.; Holloway, D.C.**, 1981
Model Studies of Explosive Well Stimulation Techniques. Int. J. Rock Mech. Min. Sci. Geomech. Abstr. 1981, 18, 113–127.

[11] **Choudhary, B.S.; Rai, P.**, 2013
Stemming Plug and Its Effect on Fragmentation and Muckpile Shape Parameters. Int. J. Min. Miner. Eng. 2013, 4, 296–311.

[12] **Choudhary, B.S.; Agrawal, A.**, 2022
Minimization of Blast-Induced Hazards and Efficient Utilization of Blast Energy by Implementing a Novel Stemming Plug System for Eco-Friendly Blasting in Open Pit Mines. Nat. Resour. Res. 2022, 31, 3393–3410.

[13] **Sharma, S.K.; Rai, P.**, 2001
Investigation of Crushed Aggregate as Stemming Material in Bench Blasting: A Case Study. Geotech. Geol. Eng. 2015, 33, 1449–1463.

[14] **Cevizci, H.**, 2012
A Newly Developed Plaster Stemming Method for Blasting. J. S. Afr. Inst. Min. Metall. 2012, 112, 8.

[15] **Cevizci, H.**, 2019
Comparison of the Efficiency of Plaster Stemming and Drill Cuttings Stemming by Numerical Simulation. J. S. Afr. Inst. Min. Metall. 2019, 119, 465–470.

[16] **Cevizci, H.**, 2009
Fragmentation, Cost and Environmental Effects of Plaster Stemming Method for Blasting at A Basalt Quarry. Arch. Min. Sci. 2014, 59, 835–846.

[17] **OATES, T.E.; SPITERI, W.**, 2021
Stemming and best practice in the mining industry: A literature review. J. S. Afr. Inst. Min. Metall. [online]. 2021, vol.121, n.8 [cited 2024-06-22], pp.415-426.Availablefrom: http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S2225-62532021000800009&lng=en&nrm=iso. ISSN 2411-717. http://dx.doi.org/10.17159/2411-9717/1606/2021.

[18] **Ggg Chen, Y., Chen, J., Wang, P. et al.**, 2021
Design method of blasthole charge structure based on lithology distribution. Sci Rep 11, 24247 (2021). https://doi.org/10.1038/s41598-021-03758-y

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 87-91

THE STUDY OF THE GAS DYNAMIC REGIME OF A NEW OPEN SALT MINE TURDA, VALEA SĂRATĂ

Emeric CHIUZAN[1], Corneliu BOANTĂ[2], Adrian MATEI[3], Răzvan DRĂGOESCU[4], Alexandru CĂMĂRĂȘESCU[5]*

[1]INCD INSEMEX Petroșani, Romania, emeric.chiuzan@insemex.ro
[2]INCD INSEMEX Petroșani, Romania
[3]INCD INSEMEX Petroșani, Romania
[4]INCD INSEMEX Petroșani, Romania
[5]INCD INSEMEX Petroșani, Romania

DOI: 10.2478/minrv-2024-0044

Abstract: *The opening of any underground mining work requires a check and the establishment of the regime of explosive and toxic gas emissions (methane and carbon dioxide). Establishing the regime of gas emissions is necessary to clearly establish the correct choice of specific machinery in construction Ex. or not, as well as the correct sizing of the vent. The purpose of this paper is to determine the rate of methane (explosive gas) and of carbon dioxide (axphysants gas) in the mine workings of Valea Sărată salt mine newly opened salt mine. For the preparation of the documentation, the following elements were taken into account:*
-The geological conditions of the salt deposit in the Valea Sărată mining perimeter;
-Existing records and documentation regarding previous occurrences of gas and their manifestation;
The results of quantitative and qualitative measurements in underground mining works, regarding:
-circulated air flows;
-gas concentrations: methane, its counterparts and carbon dioxide;
Establishing the release of gases in the underground atmosphere of the mining works. Based on the measurements and observations made, as well as the analysis of the previously mentioned elements, the underground mining works were included.
Keywords: *salt mine, methane, carbon dioxide release, gas emission*

1. Introduction

In Romania there are six salt mines which exploit the salt through underground mine workings: Praid salt mine, Tg. Ocna salt mine, Slanic Prahova salt mine, Ocnele Mari salt mine, Cacica salt mine, and Dej salt mine. these six salt pans belong to the Romanian state. At the same time, in Romania there are two private salt mines, one in Turda and the other in Dej-Nyires.

The purpose of this work is to verify the regime of methane releases (explosive gas) and carbon dioxide releases (asphyxiating gas), in the mining works within the Valea Sărată I Turda Saltworks, in order to maintain its classification.

The classification of underground mining works and the monitoring of the gas dynamic regime was carried out within two years, namely 2022 - 2023.

Based on the measurements and observations made, the analysis of the geological and mining elements taken into study, as well as the existing records and documentation regarding the previous occurrences of gas, the proposal was made to categorize the Valea Sărătă I Turda Saltworks from the point of view of gas emissions. [1]

2. Geological and mining data

From an administrative point of view, the Valea Sărată I Turda perimeter is located in the outskirts of the Turda locality, Cluj county (Fig. 1).

[*] Corresponding author: Chiuzan Emeric, Ph.D. eng., INCD INSEMEX, Petrosani, Romania, Contact details: INCD INSEMEX, Petrosani, emeric.chiuzan@insemex.ro

Access to the perimeter is via the European road E 60 and E 81 or the A3 highway up to the Turda municipality, then on the road network of the Turda municipality, up to the Turda Agricultural Research and Development Station, then on the road that connects Durgău lake and the commune Ploscoș. Also, access can be made on the railway line 300 Turda - Câmpia Turzii - Apahida - Cluj Napoca - Oradea.

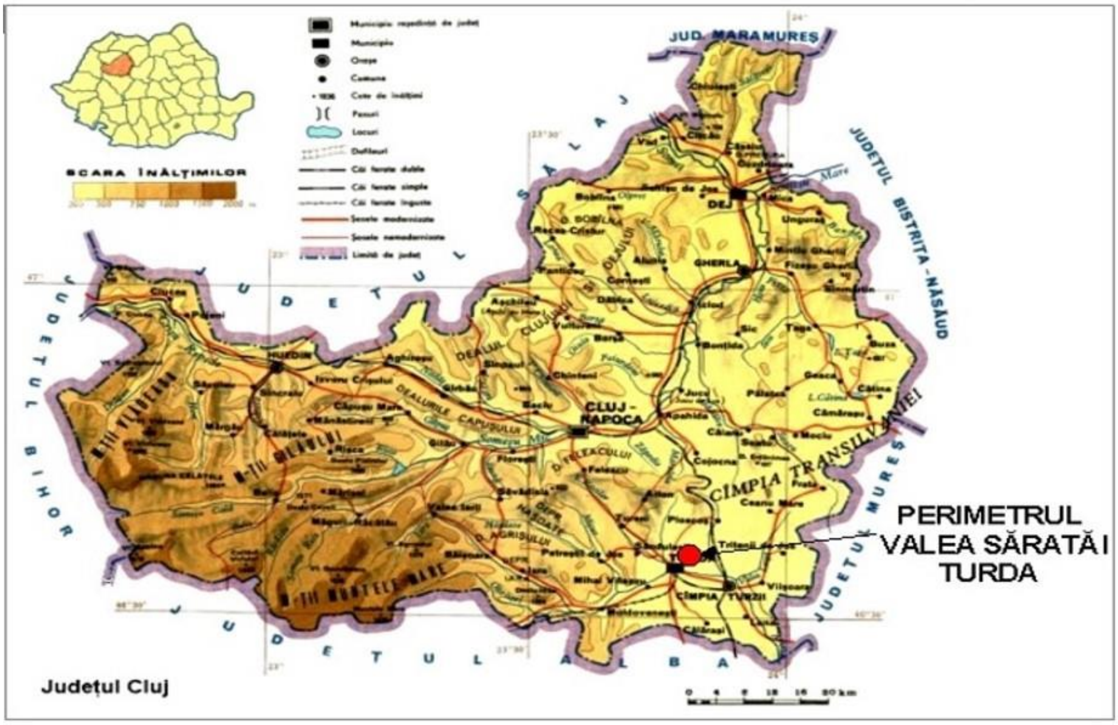


Fig. 1. Location of Valea Sărată I Turda perimeter

The Turda Băi-Valea Sărată sector is, from a geological point of view, part of the area of the diapir folds in the western part of the Transylvania basin. Deposits belonging to the Neogene and the Quaternary take part in the geological composition of this sector.

The Badenian, represented by the Dej tuff at the base and limited to the upper part by the Apahida tuff. On the Salt Valley, the Badenian appears only with its upper part. The lower Badenian, represented by the Dej tuff and the white marls with globigerine, does not appear up to date.

The Upper Badenian is made up of formations with salt and gypsum - the halogen facies, over which is arranged the pelitic facies consisting of an argillaceous suite, the horizon of radiolarian schists with tuffaceous intercalations, over which follows a marl suite - the marl horizon with Spirialis. The succession of Badenian deposits reaches a thickness of over 1,000 m in the accumulation areas of the salt formation. The salt formation appears today in the Valea Sărătă depression, and is covered on the flanks with clayey-marly deposits belonging to the pelitic facies of the Badenian, over which the Sarmatian is superimposed.

The Volhynian is present through two characteristic horizons, a lower horizon of approx. 350 m thick, bounded by the Apahida-Turda tuff at the base, the Ghiriş tuff at the top. This horizon appears well exposed during the day on the left side of the Aries river from the west of Turda, to the Valea Florilor and is present in a marly-clay facies with rare sandy-pebble intercalations. In the suite of this horizon, five layers of dacitic tuffs with variable thicknesses are found along the directives. The Flădăreni tuff with thicknesses of up to 12 m, located in succession at approx. 200 m below the Ghiriş tuff.

The Bessarabian was deposited over the Volhynian, on the left side of the Aries River; Downstream from the confluence of the Turda valley with the Aries river, a suite of deposits was separated consisting of packages of gray marls with intercalations of poorly cemented sandstones, microconglomerate sandstones with trovantes and layers of dacitic tuffs. On the left side of the Aries river it appears with thicknesses of approx. 250 m.

3. The current mining works executed at Valea Sărată

For the research of the rock salt deposit Valea Sărată I, after the execution of the research drillings, we moved on to the realization of some mining works consisting of - research well and access and research gallery.

The research well was made by mechanical digging, with the help of the pickon mounted on the mini-excavator. Along with the completion of the digging works or execution of the well equipping works by creating three compartments as follows: the personal circulation compartment equipped with ladders, the material transport compartment and the technical compartment for the installation of electrical networks, aeration columns and compressed air supply.

At the base of the well, also with the hydraulic picon, a technical room was created in which the components of the point attack combination were brought, which after assembly or executed digging works.

Until now, all the works performed in the research well and the research gallery and contour have used non-destructive technology - dig with a combine.

The access and research gallery carried out from the surface was also executed using non-destructive technologies - 130 m, sterile excavation with combined support TH + shotcrete - in rock salt, excavation with combined point attack.

After the completion of the research works, these works will become the main works for ventilation, access and circulation.

4. The ventilation systems

The partial aeration of the Valea Sărată I Turda Saltworks is carried out in a reflow system with flexible aeration pipes with a diameter of 500mm.

The inclined plane is ventilated with the help of a centrifugal ventilation installation type MVR-A 800/4KB- being located on the surface, with the following technical characteristics,

- flow rate: 505 m3/min
- depression: 1800 Pa

being driven by an electric motor with the following parameters:

- power: PM = 18.5 kw
- speed: nM = 1420 rpm
- supply voltage: U = 380 V

The well was aerated with the help of a HPCHPO350 type centrifugal ventilation installation, being located on the surface, with the following technical characteristics,

- flow rate: 150 m3/min

being driven by an electric motor with the following parameters:

- power: PM = 7.5 kw
- speed: nM = 2935 rpm
- supply voltage: U = 380 V

The works related to the opening of the exploitation horizon were ventilated with the help of an installation equipped with an axial fan type AXC 1120-5/210-4 being located on the surface, with the following technical characteristics,

- flow rate: 850 m^3/min

being driven by an electric motor with the following parameters:

- power: PM = 18.5 kw
- speed: nM = 1470 rpm
- supply voltage: U = 380 V

5. Specialized measurements carried out in underground mining works

In order to establish the regime of gas releases, respectively the classification category, depending on the presence of methane and carbon dioxide, during the months of October 2022 and October 2023, quantitative and qualitative measurements were carried out, both in the exhaust currents of the contaminated air from the mine, as well as in the active and inactive mining works in reserve.

The research of the presence of methane gas in the salt massif around the mining works was carried out by drilling test holes over 2 m long, in which a gas collection probe was inserted, which was sealed for 24 hours, as and stopping aeration in a 24-hour bag bottom job.

The results of the specific measurements performed are presented centrally in table 1 and 2. [1, 2, 3]

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 87-91

Table 1. Gas concentrations from the underground atmosphere of mining works

Nr. crt	No. station	Name of mining work	Composition of gases [% vol.]				Remarks
			O_2	CH_4	CO_2	CO*	
1	**A**	General outlet stale air on the coastal gallery	20.8	0.0	0.14	0.0012	Total air exit from the inclined plane in the trench
2	**B**	Car contour gallery plan where the test holes were drilled	20.8	0.0	0.019	0.0011	In the gallery (where the probes were located approx. 35m front)
3	**C**	In the digging front of the inclined plane	20.8	0.0	0.10	0.0	In front of the forward combine
4	**D**	Bottom of the bag					End of plan
5	**C**	In the digging front of the inclined plane	19.7	0.0	1.21	0.0020	Ventilation off 24 hours

* The presence of carbon monoxide is due to gases emitted by internal combustion engine

Table 2. Qualitative measurements in the salt massive

Nr. crt.	No. station	Name of mining work	Rock	No. hole	Composition of gases [% vol.] Before sealing			Composition of gases [% vol.] After sealing 24 hours			Remarks
					O_2	CH_4	CO_2	O_2	CH_4	CO_2	
1	**B**	Perimeter gallery I (right side)	Salt	Front	20.8	0.0	0.1				
				F1	19.8	0.0	0.96	19.8	0.0	0.97	About 35m from the interception
				F2	19.8	0.0	0.96	19.7	0.0	0.98	
				F3	19.8	0.0	0.8	19.7	0.0	0.9	
2	**B**	Perimeter gallery I (left side)	Salt	Front	20.8	0.0	0.07				
				F1	19.7	0.0	0.1	19.5	0.0	1.1	About 35m from the interception
				F2	19.9	0.0	0.91	19.8	0.0	0.98	
				F3	19.8	0.0	0.80	19.80	0.0	0.88	

* the measurements were made at the level of the wells during the extraction, both at the ceiling of the work and at their base, recording the highest value.

6. Conclusions and proposals

The results of the measurements performed

The measurements and determinations carried out in the underground atmosphere highlighted the following:

A. lack of methane gas on the route of the mining works to exhaust the stale air from the salt pan, in the mining works under the depression of the main ventilation station, in the contouring works of the new panels, in the active, inactive and reserve work fronts;

B. the presence of carbon dioxide in the mining works that serve to evacuate the stale air in concentrations up to 0.1% vol.

The measurements and determinations carried out in the event of the partial aeration installations at the well being stopped and the contour and research galleries for the opening of the first exploitation horizon, highlighted:

- lack of methane gas in front of the gallery;
- the presence of carbon dioxide in concentrations between 0.04 and 0.1% by volume in the main ventilation currents;
- the presence of carbon dioxide in a concentration of 1.1% in the case of a 24-hour stoppage of the aeration installation in a work in the bottom of the bag.

The measurements and determinations made in the salt massif around the mining works highlighted:

- the lack of methane gas in the work fronts or during the demolition operation with the help of the salt advance combine, respectively in the research drillings executed in the salt massif in the inclined plane - car return niche and horizon I.

The results obtained from the measurements and determinations made in the underground atmosphere (Table 1) and in the salt massif (Table 2) around the mining works, also highlighted:

♣ lack of sulphide hydrogen;

♣ the presence of carbon monoxide in the atmosphere of the mining works and in the salt massif in concentrations of 0.0 - 0.0040 % vol.

♣ lack of gas pressure in the test holes executed in the salt massif;

♣ no blowouts or other phenomena of gas manifestation were reported.

At the same time in drawing No. 1 shows the orientation scheme of the aeration network and the places where measurements were made in the Valea Sărată I Turda Saltworks.

Based on the specific measurements carried out and the existing records regarding gas emissions, it is proposed to place the Valea Sărată I Turda salt mine in the:

- "**NON-FIREDAMP REGIME**" from the point of view of methane emissions;
- "**CATEGORY I**" from the point of view of carbon dioxide emissions. [3]

Acknowledgements

This paper was developed within the Program PN EXH2 and IOSIN PCDIEX Program, carried out with the support of MCID

References

[1] **INCD INSEMEX Petroșani**
Test procedure for the determination of gas emissions in underground works

[2] **Chiuzan E., Matei A., Dragoescu R., Camarasescu A.**, 2023
Establishing the regime of gas emanations - methane and carbon dioxide - in order to classify the inclusion category of the Valea Sarata Turda Saltworks, studies – INCD INSEMEX Petrosani 2022-2023

[3] **INCD INSEMEX Petroșani**
Evaluation procedure regarding the approval of mine classification documentation from the point of view of gas emissions

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 92-97

RESEARCH ON USE OF METHANE GAS FROM THE DEGASSING OF COAL SEAMS AND THE COGENERATION PRODUCTION OF ELECTRICITY AND THERMAL ENERGY

Cosmin COLDA[1], Sorin BURIAN[2], Dănuț GRECEA[3], Gheorghe MARC[4]*

[1]INCD INSEMEX Petroșani, Romania, cosmin.colda@insemex.ro
[2]INCD INSEMEX Petroșani, Romania
[3]INCD INSEMEX Petroșani, Romania
[4]Marc Instal SRL, Romania

DOI: 10.2478/minrv-2024-0045

Abstract: *The present work aims to analyze possibilities of using the methane gas resulting from degassing of coal seams under conditions of increased efficiency. Degassing is absolutely necessary for the safe exploitation of coal seams, the result being accumulation of substantial amounts of methane gas that we propose to use in the cogeneration system of electricity and heat.*
Keywords: *energy, methane cogeneration, safe in operation, explosion protection*

1. Importance of degassing in coal mines

In the context of mining operations, mines can be classified as gassy or non-gassy depending on the minerals / materials extracted and whether methane can appear in the mining works. In practice, all coal mines are considered gassy. In other types of mines, methane accumulations can also occur, for example, if minerals/materials are extracted near oil-bearing seams or unexploited coal formations disturbed by the extraction process, or mines with emissions of flammable gases.

In mines where flammable minerals / materials are extracted, there is a risk of explosion because small particles of the extracted product can become in suspension and can generate dust/air mixtures that can sustain rapid combustion [1]. Flammable dust can represent an explosion risk on its own (when in the form of an explosive dust/air mixture) or it can settle in layers on access paths and explode in the event of a methane explosion. Therefore, over time, the concept of explosion protection and explosive atmosphere has been developed, defining the mechanism of gas, vapor, or flammable mist/air explosions [2].

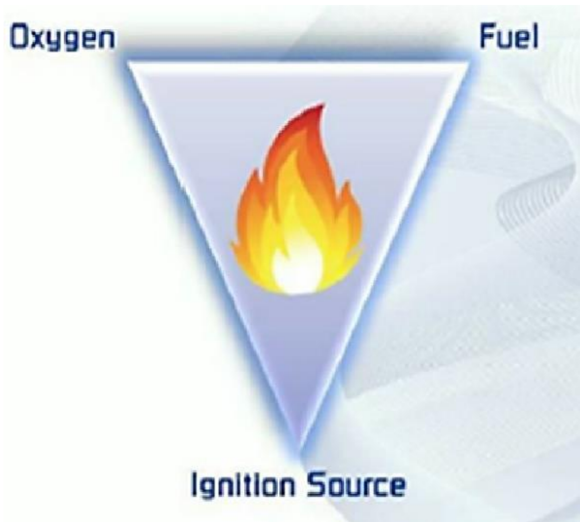


Fig.1. The mechanism of gas, vapor, or flammable mist / air explosions

* Corresponding author: Colda Cosmin, Ph.D. eng., INCD INSEMEX, Petrosani, Romania, Contact details: INCD INSEMEX, Petrosani, cosmin.colda@insemex.ro

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 92-97

Flammable gases such as methane, in combination with coal dust resulting from the technological process of coal extraction, can accumulate in coal mines.

If these gases reach hazardous concentrations and come into contact with an ignition source, they can cause devastating explosions.

Degassing is the technological process through which the risk of explosion, as well as intoxication or asphyxiation for staff, is reduced. Gases such as carbon monoxide (CO) and carbon dioxide (CO_2) are dangerous at certain concentrations.

Removing gases from the mine helps maintain a fresh air flow and control underground temperature and humidity.

2. Degassing methods

- *Ventilation:* Using an efficient ventilation system to evacuate gases from the mine. This system involves fans and ventilation ducts that bring in fresh air and remove hazardous gases.
- *Drilling Gas Wells:* Before exploiting a deposit, wells can be drilled to release gases from the coal seam. These wells can be located either on the surface or underground.
- *Water Injection:* Injecting water into coal seams can help release gases. Water reduces surface tension and facilitates gas release from the coal.
- *Monitoring Systems:* Using sensors and monitoring systems to detect gas concentrations in real-time. These systems can trigger alarms and automatic ventilation actions if necessary.

Equipment used:

- *Fans:* To ensure the circulation of fresh air and gas evacuation.
- Gas Sensors: For monitoring methane, carbon monoxide, and other dangerous gas concentrations.
- *Degassing Wells:* Specialized structures for releasing gases accumulated in coal seams.
- *Automated Control Systems:* For managing and optimizing the ventilation and degassing process.

Compliance with safety regulations and standards is essential for protecting workers and the environment.

In conclusion, degassing in coal mines is essential for preventing accidents and maintaining a safe working environment [1]. Using appropriate techniques and equipment, combined with constant monitoring, can significantly reduce the risks associated with the accumulation of dangerous gases.

Degassing in coal mines is a critical process for the safety of miners and the efficiency of mining operations.

3. Methane gas storage facilities

Underground Storage:

Salt Caverns: Created by dissolving salt in an underground deposit. These caverns are airtight and allow rapid injection and extraction cycles.

Depleted Gas Reservoirs: These are former natural gas deposits that have been depleted. The geological structure of these deposits is ideal for gas storage because it has already proven capable of naturally retaining gases.

Aquifers: These are underground water layers that can be used for gas storage. The gas is injected into the porous rock layers, and the water helps maintain pressure.

Surface Installations:

LNG (Liquefied Natural Gas) Tanks: Methane gas is cooled to -162°C to liquefy it, reducing its volume by approximately 600 times. These tanks are well insulated and used for long-term transport and storage of gas.

Compressed Gas Tanks: Gas is stored at high pressures in cylindrical or spherical tanks. These are generally used for short-term storage and transport.

The presented work focuses on the efficient utilization of methane gas resulting from coal seam degassing by compressing and storing it in surface tanks.

In conclusion, methane gas storage facilities are vital for the efficient management of energy resources, ensuring the continuity of operation of installations and equipment for utilizing recovered methane gas from the degassing process. Implementing advanced technologies and rigorous safety and environmental measures is essential for operating these facilities.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 92-97

4. Main composition of gas resulting from degassing

– *Methane (CH_4)*: 70-90%

Methane is the main and most important component energetically. It is a colorless and odorless gas in its pure state and is highly flammable.

– *Carbon Dioxide (CO_2)*: 0-15%

Carbon dioxide is an inert gas and, although not flammable, can be dangerous in high concentrations as it reduces the oxygen level in the air.

– *Nitrogen (N_2)*: 0-5%

Nitrogen is an inert gas and is present in the atmosphere at 78%. In mine gas, it does not significantly contribute to the energy value but dilutes the methane concentration.

– *Oxygen (O_2)*: 0-2%

The presence of oxygen in mine gas is an indicator of ventilation and can affect the risk of forming explosive mixtures.

– *Hydrogen (H_2)*: 0-1%

Hydrogen is a light and flammable gas. Its concentrations are usually small but can contribute to the reactivity of the gas mixture.

In all coal mining operations, specific installations are used for degassing and utilization of the extracted gas, known in the specialized literature as **„Coal bed methane" (CBM).**

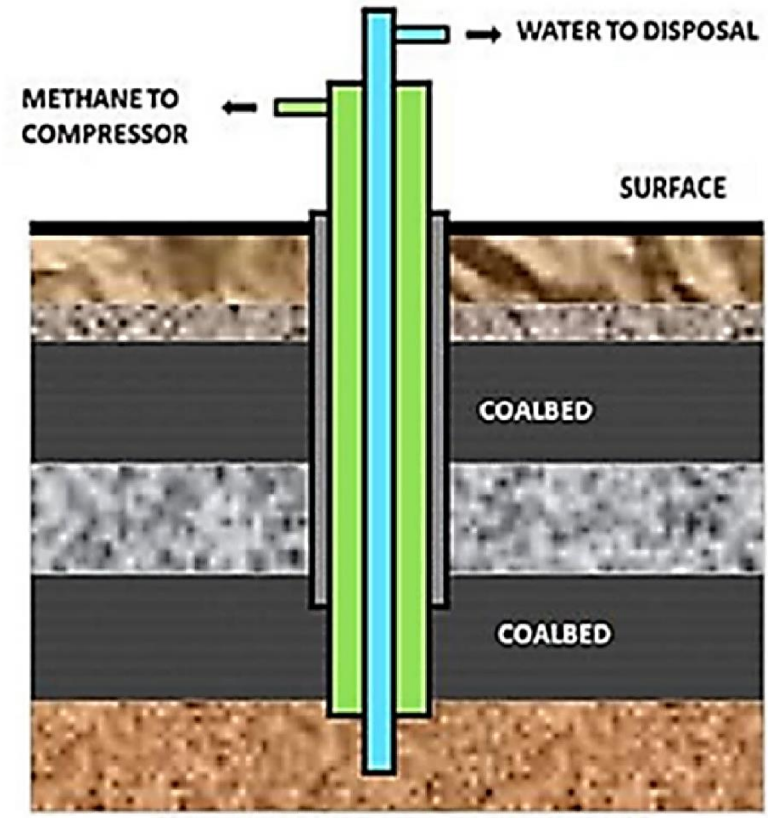


Fig. 2. Schematic presentation of degassing

The presented work proposes the use of methane gas resulting from degassing in high-efficiency cogeneration installations [3].

Combined heat and power (CHP) is an efficient and clean approach for generating electrical and thermal energy from a single fuel source.

CHP places energy production at or near the end-user location, so the heat released from energy production can be used to meet the user's thermal requirements while the generated energy meets all or part of the site's electricity needs [4].

CHP benefits:

– Increased energy efficiency;
– Reduction of specific energy costs and increased economic competitiveness;
– Increased reliability and reduced risk of energy supply interruptions;

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 92-97

Cogeneration installations rely on internal combustion engines (ICE) that are competitive in several aspects [5]:

- Cogeneration or trigeneration of energy;
- A very wide range of unit powers: 1 kWh – 18 MWh;
- MODULAR execution – flexibility, easy capacity increase, etc.;
- Operation on all types of gaseous and liquid fuels;
- Operation based on the load curve or standby reserve;
- Rapid start (from 10 seconds);
- Energy autonomy;
- Intelligent energy generation.

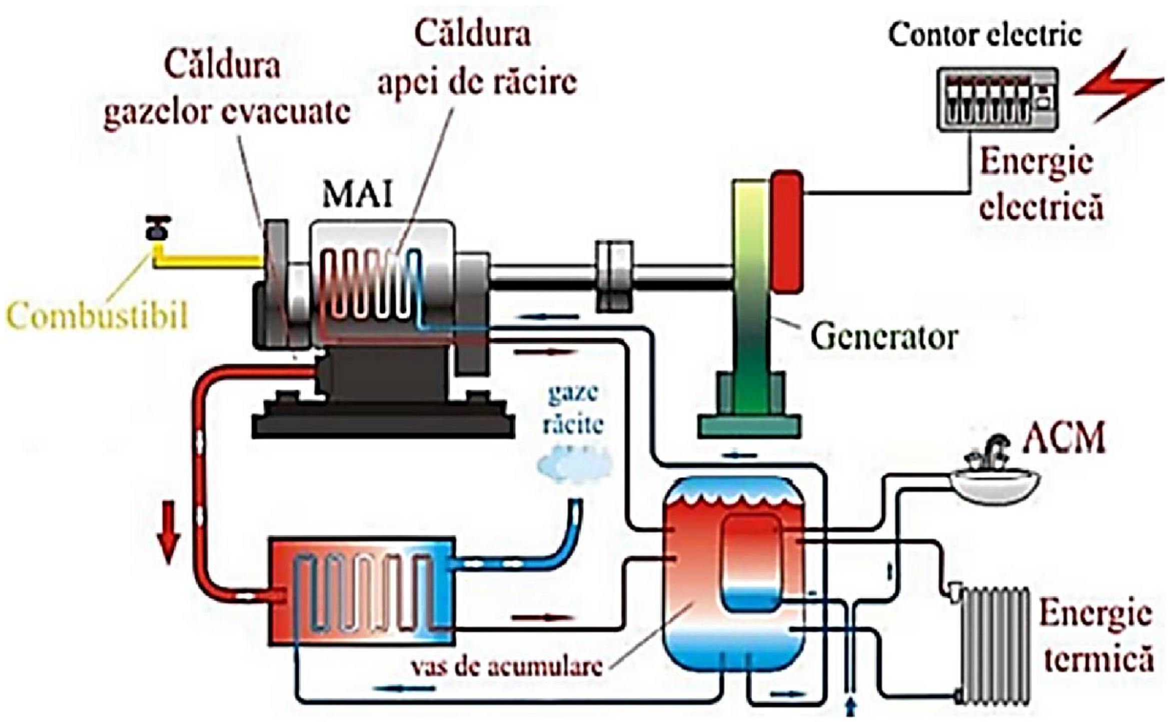


Fig. 3. Operation principle of a cogeneration installation

- The heat from exhaust gases (at 500°C) can be recovered up to ~70%
- The heat from cooling water and lubricating oil (at about 100°C) can be fully recovered.
- Recovered heat results from:
  - Cooling the equipment: 10-20%
  - Exhaust gases: 30-50%
- Heat recovery improves the total efficiency of the system to over 90% if all the recovered heat is used in a heating circuit with a supply temperature of about 100°C.

The following table presents the amount of gases resulting from degassing during the years 2015-2018 as well as graphically in table 1.

Table 1. Evolution of methane gas resulting from degassing [m^3]

Year	Methane gas from degassing	Methane gas released into the atmosphere	Methane gas used in own installations
2015	7996194	7310782	685412
2016	7362585	6592851	769734
2017	5502617	4806764	695853
2018	6037725	5270161	767564

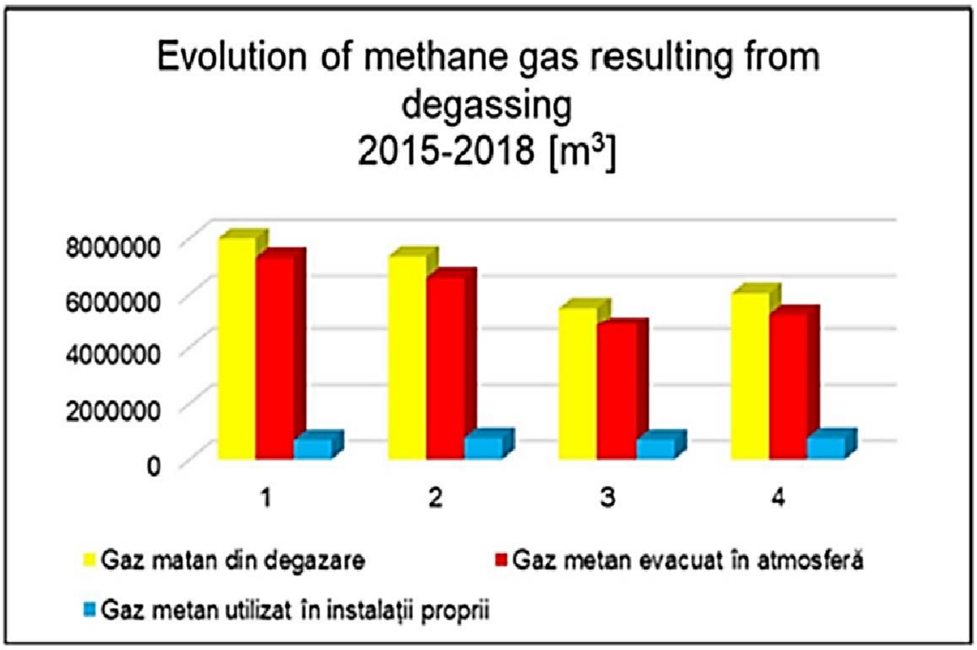


Fig. 4. Evolution of methane gas resulting from degassing 2015-2018 [m^3]

The widespread use of CHP (Combined Heat and Power) with ICEs (Internal Combustion Engines) is explained by numerous advantages [6]:

- relatively low specific investment;
- comparatively small dimensions;
- easy and rapid construction and installation;
- proximity to thermal energy consumers, which in turn eliminates losses during the transport and distribution of energy;
- elimination of the need to build costly and dangerous high-voltage power lines;
- ability to provide system services for stabilizing the electrical energy system;
- uninterrupted supply to the consumer;
- supply of high-quality electrical energy, maintaining specified voltage and frequency values.

4. Conclusions

Explosion First of all, it should be noted that this solution for using gas resulting from the degassing of coal seams in the Jiu Valley is mentioned in the „Strategy for the Transition from Coal in the Jiu Valley”.

The „Strategy for the Transition from Coal in the Jiu Valley” project was developed with funding from the European Union through the Structural Reform Support Program and in cooperation with the European Commission's Directorate-General for Structural Reform Support.

Extract from „Strategy for the transition from coal of the Jiu Valley”:

Consideration will be given to initiating pilot projects to harness the energy potential of the area (e.g., harnessing methane gas from the degassing of operational coal deposits using cogeneration plants for the production of electricity and heat, extracting and harnessing methane gas from coal deposits that are no longer in operation using surface drilling, underground pumped storage hydroelectric plant, etc.) to identify viable solutions and projects in the field of energy production, distribution, and storage (e.g., implementing a pilot project to supply energy using 'zero carbon' fuel, green hydrogen produced by electrolysis with solar energy converted to electricity through photovoltaic panels), followed by scaling these pilot projects based on demonstrated technical-economic potential.

The use of cogeneration installations in industry is already widely implemented and has exponential development prospects due to the presented advantages and achieved efficiencies of over 92%.

The technical conditions for implementing such installations are largely met at mining units, having the infrastructure for power supply and distribution.

The realization of such an installation has multiple benefits, on the one hand producing the necessary electricity and heat for own consumption, and on the other hand, the possibility of injecting surplus energy into the grid.

Not least, the implementation of this solution creates the prospects for fully utilizing the resulting gas, which has a major impact on reducing environmental pollution.

Acknowledgments

This work was carried out through the "Nucleu" program of the National Research, Development and Innovation Plan 2022-2027, supported by MCID, project no. PN23320102 and use equipment from IOSIN-PCDIEX.

References

[1] **Lupu C., Morar M., Tamas D., Chiuzan E.**, 2008
The utilization of methane gas from the coal mines in Valea Jiului - a direct way to reduce the ecological impact by reducing the greenhouse effect, Buletinul AGIR, no. 4/2008

[2] European Parliament and Council, 2014
Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on *the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres* (recast)

[3] **Romanian Ministry of Energy**, 2021
Study on the possibility of implementing advanced technologies in the exploitation and capitalization of coal: Final Report, Bucharest

[4] **SR CEN/TR 15316-6-7**
Energy performance of buildings - Method for calculation of system energy performance and system efficiencies

[5] I**onescu J., Darie M., Csaszar T., Andriş A.**, 2007
Requirements for Installations in Areas with Explosive Atmosphere, other than Mines, (in Romanian), INSEMEX – Petrosani Publishing House, Romania.

[6] **Fong K.F., Lee C.K.**, 2014
Performance analysis of internal-combustion-engine primed trigeneration system for use in high-rise buildings in Hong Kong, 12 December 2014.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 98-105

ASSESSMENT OF THE POLLUTION LEVEL AND DETERMINATION OF THE GEO-ACCUMULATION INDEX OF HEAVY METALS IN THE SOIL FROM THE OLD FUNICULAR DUMP AREA – URICANI

Madalina-Flavia IONIȚĂ[1], Sorin-Mihai RADU[2]*

[1]University of Petrosani, Doctoral School, Petrosani, Romania, madalina.ionita96@yahoo.com
[2] University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Mechanical, Industrial and Transport Engineering, Petrosani, Romania

DOI: 10.2478/minrv-2024-0046

Abstract: *As a result of the mining activities carried out in the Jiu Valley, tailings dumps resulted. Currently, some of these tailing dumps are greened, some are inactive, and some of them are still active within operational exploitation perimeters. In order to capture the negative effects of these deposits, in this work an assessment of the degree of contamination will be carried out and the level of geo-accumulation of heavy metals will be determined in the soil in the area of the Old Funicular dump, an inactive one for about 12 years. The dump was formed following the deposition of tailings resulting from coal mining in the Uricani mine. The main purpose is to identify the types and concentrations of heavy metals present in the soil and determine the level of accumulation of these metals in a certain area. The study involved the collection of soil samples from 17 sampling points, followed by detailed chemical analyses to determine the concentrations of heavy metals present in the soil at the tailings dump. The results indicated variable levels of heavy metal contamination, with concentrations exceeding the normal value of these heavy metals in soil in certain areas. The geo-accumulation index (I_{geo}) was calculated to assess the degree of accumulation of each heavy metal in soil. The I_{geo} values obtained varied from slightly polluted to moderately polluted, suggesting a significant influence of mining activities on the soil in this area. The conclusions of the study emphasize the need to implement phytoremediation measures and continuous monitoring to prevent ecological and human health risks.*
Keywords: *contamination, heavy metals, mining, Old Funicular, soil, tailings dump*

1. Introduction

At the European level, numerous organizations and governments have implemented strict regulations to control and reduce soil contamination caused by closed mining activities. These regulations include the Basel Convention, which deals with the transboundary transport of hazardous waste and its disposal; the Minamata Convention, which focuses on reducing mercury emissions globally; and the European Union Directives, respectively, the Waste Framework Directive and the Industrial Emissions Directive, which impose strict standards for mining waste management and pollution control [1, 2, 3, 4].

During approximately two centuries of mining activity in the Jiu Valley, there have been significant consequences for the environment and the economy, manifested by extensive pollution and the exclusion of considerable areas of land from the economic circuit [5].

Soil pollution with heavy metals is a major environmental problem with significant implications for human health and ecosystems. Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni) are known for their toxicity and ability to accumulate in living organisms. These can come from various sources, such as industrial activities, household and agricultural waste, vehicles, and emissions from fossil fuel combustion [6].

The effects of heavy metal exposure on human health include neurological problems, impaired kidney

* Corresponding author: Madalina-Flavia Ionita, University of Petrosani, Doctoral School, Contact details: University Str., no. 20, 332006, Petrosani, Romania, madalina.ionita96@yahoo.com; Tel: +40-785-18-88-82

function, cardiovascular disease, and other imbalances. For example, lead and mercury can cause learning and behavioral disorders in children, and arsenic and nickel can affect the central nervous system, causing tremors, insomnia, and personality changes [7, 8].

In terms of ecosystems, heavy metals can reduce biodiversity by affecting organisms at the bottom of the food chain, such as soil microorganisms, plants, and small animals. Soil contamination can lead to a decrease in its fertility, thus affecting agricultural productivity and, implicitly, food security.

Tailings dump from mining activity are important sources of heavy metals in soil [9]. This study focuses on determining the concentration of heavy metals in the soil, evaluating the level of pollution by comparing the determined concentrations with reference values, and determining the geo-accumulation index (I_{geo}) of heavy metals in the soil in the area of the Old Funicular tailings dump.

The main purpose is to identify the types and concentrations of heavy metals present in the soil and determine the level of accumulation of these metals in a certain area.

The tailings dump Old Funicular was formed following the deposition of the tailings resulting from the mining of coal in the Uricani mine. The Uricani mine is located in the western part of the Jiu Valley coal basin, and the tailings dump is located in the southern part of the mine, at a distance of approximately 1000 m from it, occupying an area of 5.17 ha and a volume of 31,169 thousand m^3. The existence of a body of water or a human settlement was not detected near this tailings dump.

The Old Funicular tailings dump has been an inactive dump for about 12 years. This tailings dump was not included in the greening process after the disposal of waste material on it was stopped. So, over time, herbaceous vegetation naturally settled on the surface of the two branches of the tailings dump, except for the plateau area, such as mulberry, rose hip, hornbeam, hawthorn, and medicinal plants horsetail, dandelion, and others. This process of natural vegetation colonization contributed to soil stabilization and reduced erosion. On the slopes of the tailings dump, tree species such as birch and acacia were identified, along with other native species. Figure 1 shows the Old Funicular tailings dump as well as its location in the area of the Jiu Valley coal basin [10] (Fig. 1.)

Fig. 1. Location tailings dump Old Funicular (Source: GoogleEarth)

2. Research methods and techniques

2.1 Taking soil samples

In order to take soil samples in the initial stage, the mapping of the Old Funicular tailings dump was carried out. 17 soil sampling points were established, according to Ministerial Order No. 184/1997, for the approval of the Environmental Assessment Procedure. (Fig. 2.)

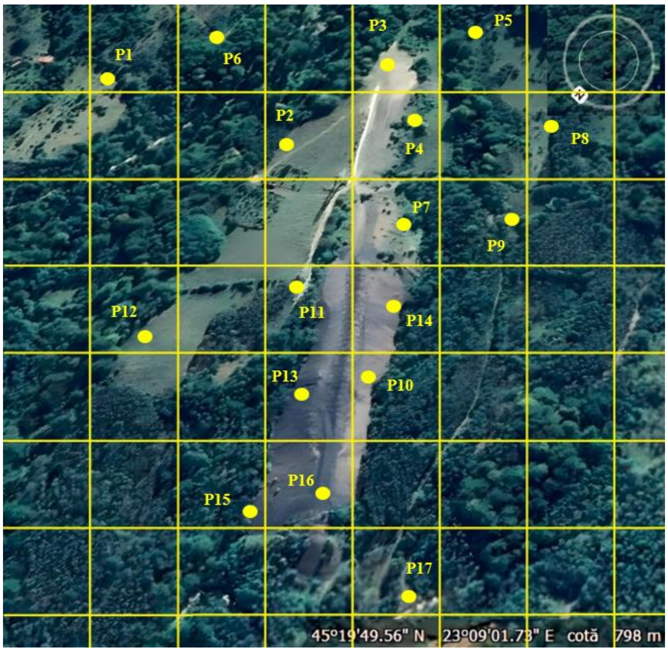


Fig. 2. Mapping of the Old Funicular tailings dump with the 17 sampling points

The actual collection of the samples was carried out at two depths of 0–20 and 20–40 cm, respectively, with the help of a shovel (Fig. 3). Before sampling, the soil was cleaned to remove organic remains (plants, roots, leaves, etc.). A container of approximately 100–200 ml was used, which I filled to the brim with shredded soil, according to the state standard (STAS) 7184/1:1984: Soil quality/collection of samples for pedological and agrochemical studies [11].

Fig. 3. Sampling and labeling of soil collected from the Old Funicular tailings dump

The soil sampled in this way was placed in 500-gram plastic bags labeled with the place of sampling, the depth, and the date on which the collection was carried out.

In order to better understand the properties and qualities of the soil in the study area, a soil sample unaffected by the mining activity was taken. This soil sample was taken from agricultural land in the yard of a local in the city of Uricani.

The soil samples were transported to the Environmental Laboratory of the University of Petrosani to undergo chemical analysis.

2.2 Determination of heavy metals

2.2.1 The utensils and equipment used

- grinding mill, which grinds all types of soil to sizes smaller than 150 µm without producing contamination with elements to be determined;
- sieve with a mesh size of 0.150 mm;
- desiccator with a nominal volume of 2 l;
- a reaction vessel with a nominal volume of 250 ml;

- refrigerant with ground glass conical coupling;
- absorption vessel without return;
- unpolished glass balls with a diameter between 2 and 3 mm;
- a temperature-controlled heating device capable of heating the contents of the reaction vessel to the reflux temperature;
-funnel, with a diameter of approximately 110 mm;
- rated flask with a nominal capacity of 100 ml;
- quantitative filter paper, without calcination residue, based on cellulose, with an average pore size of approximately 8 µm and a diameter of 150 mm.

Reagents used: They must meet the purity conditions for further analysis. The purity of these reagents was verified by analyzing the blank sample taken.

- the water used must correspond to the quality according to ISO 3696.
- hydrochloric acid c (HCl) = 12.0 M, ρ = 1.19 g/ml;
- nitric acid c (HNO_3) = 16.3 M, ρ = 1.42 g/ml;
- nitric acid c (HNO_3) = 0.5 M dilute 32 ml of nitric acid (ρ = 1.42 g/ml) with water to 1.

2.2.2 Mode of Work

According to the Romanian standard SR ISO 11047/1999, the microelement content was determined [12].

Thus, approximately 3 g of soil was weighed to the nearest 0.001 g in a 250-ml reaction vessel. Then the soil was moistened with about 0.5-1 ml of water, and with stirring, 21 ml of hydrochloric acid was added, followed by 7 ml of nitric acid. The absorption vessel and refrigerant were attached to the reaction vessel, and the mixture was left for 16 hours at room temperature to allow the organic matter in the soil to slowly oxidize.

The temperature of the reaction mixture was slowly raised until reflux conditions were reached, and this temperature was maintained for 2 hours, making sure that the condensation zone did not exceed 1/3 of the height of the refrigerant. After this interval, the mixture was allowed to cool.

The contents of the absorption vessel were added to the reaction vessel through the refrigerant, flushing both the absorption vessel and the refrigerant with an additional 10 ml of nitric acid. The insoluble residue in the reaction vessel was allowed to settle, and the decanted supernatant, relatively free of sediment, was passed through filter paper, thus collecting the filtrate in a 100-ml volumetric flask. The entire initial extract from the reaction vessel was passed through the filter paper, and then the insoluble residue on the filter paper was washed with a minimal amount of nitric acid, collecting this last filtrate together with the first.

2.3 Calculation of the geo-accumulation index of heavy metals in the soil

The geo-accumulation index (Igeo) was used to evaluate the level of soil contamination with heavy metals. Originally developed by Müller in 1969, this method allows us to evaluate the level of heavy metal pollution in the soil and determine the level of accumulation of these metals in a certain area. When calculating this index, the concentrations of heavy metals determined in the soil samples taken were taken into account, and the values obtained were compared with the values of the natural background [13, 14]. The geo-accumulation index was calculated using the formula:

$$I_{geo} = log_2\left(\frac{C_n}{1{,}5\ x\, B_n}\right) \tag{1}$$

where:

- C_n is the concentration of the metal in the analyzed sample (mg/kg su);
- B_n represents the reference (background) concentration of the metal in the soil (mg/kg su);
- 1.5 represents the correction factor due to lithogen* (*is a sedimentary rock that is predominantly composed of particles resulting from the process of erosion, transport and sedimentation of other rocks or organic materials. These particles can include rock fragments, sand, clay, as well as organic materials such as shells and plant debris).

After all this processing, the analysis and interpretation of the results obtained following the determination of the heavy metal content of the soil samples taken from the Old Funicular tailings dump and the calculation of their geo-accumulation index were carried out.

3. Data analysis and interpretation

By analyzing and interpreting data, it contributes to the development of critical and analytical skills needed in the scientific field.

In order to identify the presence of heavy metals in the soil taken from the Old Funicular tailings dump, the reference values for traces of chemical elements in the soil were taken into account, according to Order 756/1997 [15] (Table 1).

Table 1. Reference values for trace chemical elements in soil (mg/kg d.s)

Trace elements	Normal values	Alert thresholds/types of use		Intervention thresholds/types of use	
		Sensitive	Less sensitive	Sensitive	Less sensitive
Total chromium (Cr).	30	100	300	300	600
Copper (Cu)	20	100	250	200	500
Nickel (Ni)	20	75	200	150	500

Following the chemical analyses, it was found that, in the soil samples taken from the Old Funicular tailings dump at some sampling points, the determined value for **Cr (total)** was exceeded by **1.12 times** compared to its normal value in the soil. The presence of **Cu** was **2.83 times** higher compared to the normal value, and the determined value of **Ni** exceeded **4.12 times** its normal value in the soil (Table 2 and Fig. 4.)

Table 2. Determined values of soil samples from the Old Funicular tailings dump (mg/kg d.s)

Sampling points	Analyzed indicators		
	Cr (Total)	Cu	Ni
P1	20.53	46.39	56.49
P2	32,32	49,48	67.95
P3	40.84	56.95	99.22
P4	31.00	54.90	70.39
P5	27.58	53.81	71.28
P6	22.01	51,51	55.79
P7	43.31	55.33	104.42
P8	22.17	50.35	55.99
P9	44.81	54.87	72.57
P10	46.34	71.27	100.05
P11	32.12	47.78	79.64
P12	30.02	72.53	86.48
P13	33.17	70.18	101.82
P14	45.78	55.74	106.18
P15	32.02	60.03	87.60
P16	38.69	57.12	105.66
P17	30.11	54.91	79.37

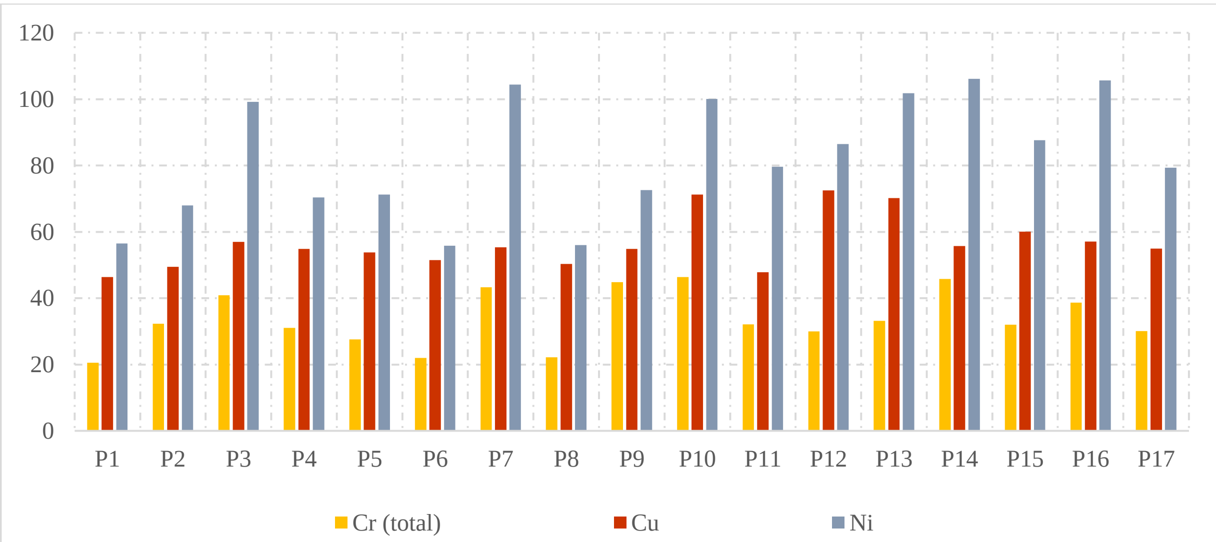


Fig. 4. The determined values of the soil samples

After determining the content of heavy metals in the control soil sample, taken from land not affected by mining activity, the following values resulted (Table 3):

Table 3. Determined values of the control sample (mg/kg d.s)

Analyzed indicators	Cr (Total)	Cu	Ni
Determined values	27.20	17.80	19.04

From Table 3, it can be seen that the heavy metals Cr (total), Cu, and Ni are also found in the control sample, but in lower concentrations than normal in the soil.

As a result of the calculations, the following values of I_{geo} emerged in the 17 sampling points of the soil collected from the Old Funicular tailings dump; they are presented in Table 4, respectively, in Figure 5.

Table 4. Determined values of the geo-accumulation index (I_{geo})

Sampling points	The values of the geo-accumulation index (I_{geo})		
	Cr (Total)	Cu	Ni
P1	0.13	0.46	0.56
P2	0.21	0.49	0.68
P3	0.27	0.56	0.99
P4	0.20	0.55	0.70
P5	0.18	0.53	0.71
P6	0.14	0.51	0.55
P7	0.28	0.55	1.04
P8	0.14	0.49	0.55
P9	0.29	0.54	0.72
P10	0.30	0.71	1.00
P11	0.21	0.47	0.79
P12	0.19	0.72	0.86
P13	0.21	0.70	1.02
P14	0.30	0.55	1.06
P15	0.21	0.60	0.87
P16	0.25	0.79	1.05
P17	0.19	0.55	0.79

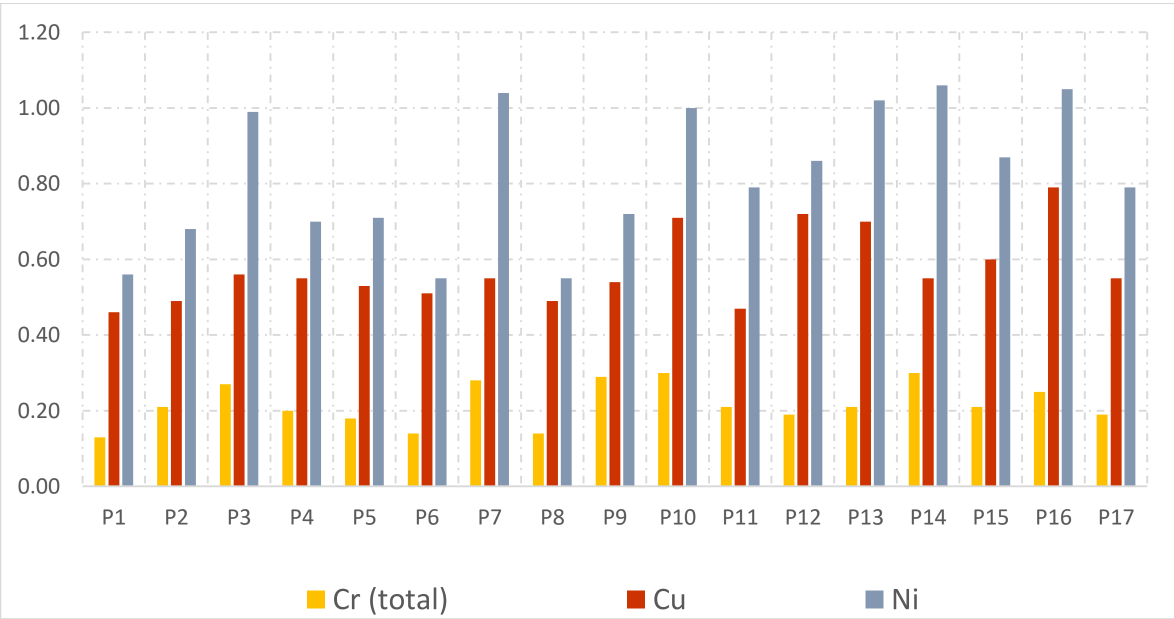


Fig. 5. Variation of the geo-accumulation Index (I_{geo})

To establish the rank of the geo-accumulation index of heavy metals present in the soil samples collected from the tailings dump, the following intervals were taken into account to identify the type of contamination present at the analyzed site (Table 5).

Table 5. Classification of the geo-accumulation index of heavy metals present in soil samples

Value I_{geo}	**Class vs. I_{geo}**	**Pollution level**
≤ 0	0	Unpolluted
0 - 1	1	Unpolluted to moderately polluted
1 - 2	2	Moderately polluted
2-3	3	Moderately to heavily polluted
3-4	4	Heavily polluted
4 - 5	5	Strong to very strong polluted
>6	6	Very heavily polluted

From the determination of the geo-accumulation index and based on its classification, it follows that the Old Funicular tailings dump falls into class 1 regarding the level of pollution with Cr (total) and Cu, which indicates a soil from unpolluted to moderately polluted, but in some sampling points from the dump, the geo-accumulation index of the heavy metal Ni falls into class 2, suggesting a moderately polluted soil with this metal. These aspects are directly proportional to the age of the dumped material, as the bio-geochemical reactions that take place in the dumps allow the release of the ions of these heavy metals.

4. Conclusions

The field and laboratory study carried out in the area of the Old Funicular tailings dump, located on the perimeter of the Uricani mining operation, reveals a significant contamination of the soil with heavy metals, namely chromium (total Cr), copper (Cu), and nickel (Ni).

The normal values allowed in the soil for the analyzed heavy metals (total Cr, Cu, and Ni) were exceeded in the studied area. In some sampling points, the normal value of Cr (total) was exceeded by 1.12 times, that of Cu by more than 2.83, and that of Ni exceeded by 4.12 times its normal value in the soil. This suggests a potential risk to the environment and, by implication, to human health.

Based on the I_{geo} index, the soil in this area is moderately polluted with nickel (I_{geo}=1.06), and the chromium (total Cr) and copper (Cu) contamination is classified as lightly contaminated, with I_{geo} values of 0.30 for Cr and 0.79 for Cu. This indicates a variability in the distribution of heavy metals in the soil, depending on the pollution sources and the physico-chemical properties of the soil.

The mining activity carried out in this area and the tailings storage have led to high concentrations of heavy metals in the soil, thus affecting the natural balance and causing the I geo index values to increase. The mobility of these metals in soil is a critical factor, influenced by soil physico-chemical properties such as pH, texture, organic matter content, and cation exchange capacity.

In order to reduce the impact of pollution and restore soil quality, it is recommended to implement some phytoremediation measures. This method, considered efficient and ecological, involves the use of plants with the ability to extract, stabilize, or degrade heavy metals from the soil. The application of phytoremediation on the Old Funicular tailings dump would significantly contribute to reducing heavy metal concentrations and improving the quality of the environment.

Proper management of tailings dump and continuous monitoring of soil quality are essential to protecting environmental quality and human health. The implementation of an active monitoring and remediation program is essential to maintaining an ecological balance in this area affected by mining activity.

References

[1] **Basel Convention**, 1989
https://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx

[2] **Minamata Convention**, 2013
https://www.mercuryconvention.org/en

[3] **Waste Framework Directive (2008/98/EC)**, 2008
https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=CELEX:32008L0098

[4] **Industrial Emissions Directive (2010/75/EU)**, 2010
https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=CELEX:32010L0075

[5] **Iliaș N., Radu S.M., Serafinceanu A.**, *Mining industry in Romania. "Past, present and scenarios for the future"*. AGIR Publishing House, Bucharest, 2020. https://www.edituraagir.ro

[6] **Alloway B.J.**, 2013
Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability (3rd ed.). Springer. https://link.springer.com/book/10.1007/978-94-007-4470-7

[7] **Clemens S., Ma J.F.**, 2016
Toxic Heavy Metal and Metalloid Accumulation in Crop Plants and Foods. Annual Review of Plant Biology, 67(1), pp. 489-512. https://doi.org/10.1146/annurev-arplant-043015-111648

[8] **Chen H.M., Zheng C.R., Tu C.**, 2016
Heavy Metal Pollution in Soils in China: Origin, Assessment, and Mitigation. Environmental Pollution, 222, pp. 605-614. https://doi.org/10.1016/j.envpol.2016.02.007

[9] **Meers E., Lamsal S., Vervaeke P., Hopgood M., Lust N., Tack F.M.G., Verloo M.G.**, 2005
Availability of Heavy Metals for Uptake by Salix viminalis on a Moderately Contaminated Dredged Sediment Disposal Site. Chemosphere, 61 (5), pp. 662-672. https://doi.org/10.1016/j.chemosphere.2005.03.066

[10] **Dunca E.C., Sârbu R.I., Radu S.M., Ciolea D.I.**, 2021
Stabilization process of heavy metals from the solid waste resulting from the purification process of acid mine waters. Patent a/00517/11.10.2021. https://osim.ro/publicatii-brevetelor

[11] **STAS 7184/1**, 1984
State standard for determining the content of heavy metals in soil.

[12] **SR ISO 11047**, 1999
Romanian Standardization Association (ASRO)

[13] **Müller G.**, 1969
Index of Geoaccumulation in Sediments of the Rhine River. GeoJournal, 2 (3), pp. 108-118. https://doi.org/10.1007/BF02826714

[14] **Hakanson L.**, 1980
An ecological risk index for aquatic pollution control: a sedimentological approach. Water Research, 14 (8), pp. 975-1001. https://doi.org/10.1016/0043-1354(80)90143-8

[15] **Minister's order no. 184**, 1997
Order for the approval of the Normative on determining the content of heavy metals in the soil. https://legislatie.just.ro/Public/DetaliiDocumentAfis/13327

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 106-113

LIVING LAB – A SYSTEMIC INNOVATION APPROACH TO RESTORING SOIL HEALTH ON UNPRODUCTIVE LAND IN THE JIU VALLEY

Emilia-Cornelia DUNCA[1], Sorin-Mihai RADU[2], Sabin IRIMIE[3], Lucia-Ana VARGA[4], Fabian PANAITE[5]*

[1, 4] University of Petroșani, Faculty of Mine, Department of Environmental Engineering and Geology, 332006 code, Petroșani City, Hunedoara Country
[2] University of Petroșani, Faculty of Mechanical and Electrical Engineering, Department of the Mechanical, Industrial and Transport Engineering, 332006 code, Petroșani City, Hunedoara Country
[3]University of Petroșani, Faculty of Mine, Department of Management and Industrial Engineering, 332006 code, Petroșani City, Hunedoara Country
[5]University of Petroșani, Faculty of Mechanical and Electrical Engineering, Department of Automation, Computers, Electrical and Energy Engineering, 332006 code, Petroșani City, Hunedoara Country

DOI: 10.2478/minrv-2024-0047

Abstract: *The Living Lab is an innovative and effective approach to restoring soil health on unproductive land. Through collaboration between different researchers and the use of adaptable and sustainable solutions, this method can transform degraded land into valuable resources, contributing to agricultural sustainability and the development of local communities. The establishment of a Living Lab on the non-productive lands of Jiu Valley as a systemic approach to innovation in which all interested parties are involved in the research and application of solutions to restore soil health is a challenge. The paper presents the methods used, the working hypotheses, the data analysis and the interpretation of the results obtained in the living lab created to study the cultivation of biomass, its energy utilization and the obtaining of biofertilizers. Multiple approaches regarding the obtained biofertilizers and their application to restore soil health are presented. The limits and conclusions of the innovative research carried out so far in the Living Lab are presented.*

Keywords: *Living Labs, unproductive land, biomass, innovative research, soil health*

1. Introduction

The development of human society has been realized over time with serious consequences on the environment and indirectly on the quality of life. The burning of fossil fuels, the practice of intensive agriculture, the unsustainable exploitation of natural resources, the development of infrastructure have led to air and water pollution, the destruction of the ozone layer, the loss of biodiversity, soil degradation. The long-term effects have resulted in the intensification and increase in scale of extreme weather events, heavy rainfall storms, floods and landslides, heat waves, fires and droughts resulting in loss of life and property. Climate change and environmental degradation threat en future generations, that's why the European Union adopted the European Green Pact to transform Europe into a climate-neutral and efficient economy from the point of view of resource use. One of the EU initiatives that is put into practice until 2050 is the EU Soil Strategy [1] which underlines the importance of soil for life considering the fact that It is estimated that approximately 60 to 70% of the Union's soils are not healthy [1]. It underlines the fact that the soil hosts more than 25% of the entire biodiversity on the planet and is at the base of the food chains that feed humanity and, on top of that, biodiversity [1] and aims that, by 2050, all soil ecosystems in the EU they will be healthy and therefore more resilient, but for this, very firm changes are needed during this decade [1]. The ambitious objective requires collaboration between different researchers and the use of adaptable and sustainable solutions and an integrated, innovative and effective approach to restore soil health on unproductive lands [2].

* Corresponding author:University of Petroșani, Faculty of Mine, Department of Environmental Engineering and Geology, 332006 code, Petroșani City, Hunedoara Country; duncaemilia@yahoo.com; Tel.: +40-751-01-04-39

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 106-113

The reduction of pollution to zero, the sustainable use of chemical substances, the transition to a green and circular bioeconomy, the mitigation and adaptation of climate change are EU initiatives in synergy with the EU Soil Strategy. The strategy provides for the creation of a „network of excellence of practitioners" and a network favorable to the inclusion of ambassadors of sustainable management of the academic soil and agricultural actors. For this purpose, the respective networks will be based on the activity of living laboratories [1]. These living labs (Living Labs) are constituted as a systemic approach to innovation in which all interested parties are involved in the research and application of solutions to restore soil health [3-7]. Such a living laboratory was created in the Jiu Valley with the aim of contributing to the restoration of the health of unproductive lands affected by mining activity and the transformation of these dumps into valuable resources that contribute to the development of local communities. Non-productive lands „comprise degraded lands with excessive degradation processes, which are practically devoid of vegetation. I belong to this category [8, 9]. Dumps belong to this category - land on which sterile material resulting from industrial activities and mining operations has been stored [10, 5].

2. Presentation of the working hypotheses - the choice of the experimental batches of the Living Lab

In order to choose the non-productive lands on which living labs was established, the tailings dumps in Jiu Valley were inventoried. These waste dumps do not fall into the category of dumps with problems from the point of view of stability [11] but the lands are unproductive, on them there are waste deposits resulting from mining activities, from the exploitation of coal. They represent 38% of all the degraded land in the Jiu Valley, i.e. approximately 299 ha [12].

The non-productive lands chosen for Living Labs were selected taking into account several criteria such as: the fact that no more excavation works have been carried out on them since 2015; some gradual subsidence of the base land is visible on the surfaces between the piling branches, as a result of the underground exploitation; they are not located in areas with many springs and water stagnations in the form of puddles and lakes between the dump branches; the surface is covered with grass, shrubs and small trees, without being affected by instability phenomena; the angles of the slopes vary between 14o and 35o; waste from Petrila Preparation was stored on these lands, which could lead to the presence of heavy metals and other specific pollutants; the administrator of the dump which is the Petrila City Hall, a local public administration interested in identifying solutions to restore the health of the soils within its radius. Petrila City Hall made the non-productive land selected for Living Labs available to the University of Petrosani, through a Lease Agreement (Figure 1).

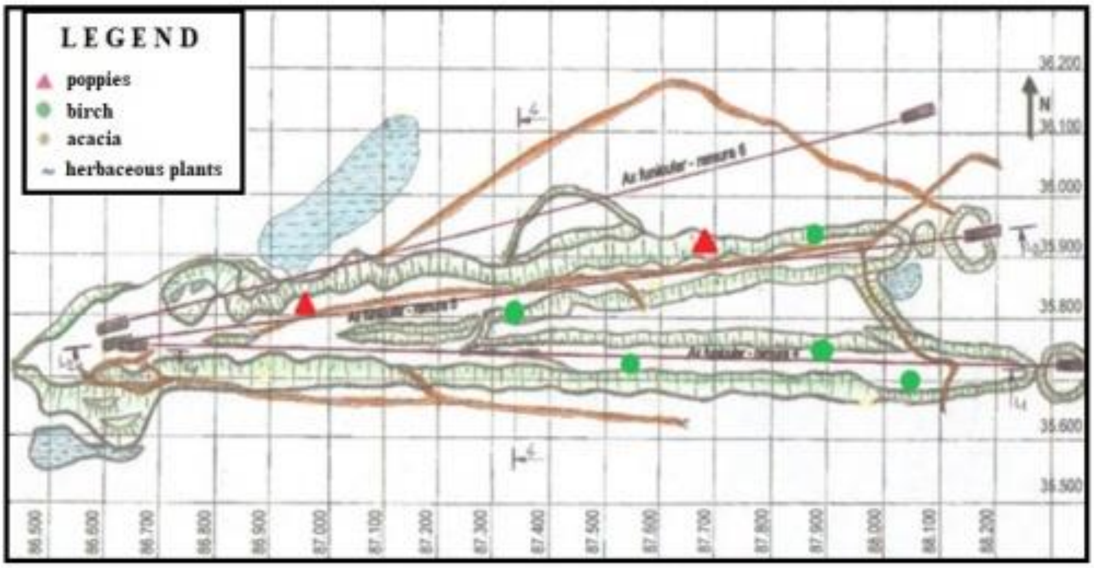


Fig.1 Petrila Preparation tailings dump – Branch 4 and 5 [12]

2.1. Layout of experimental plots for Living Labs

The plots for Living labs were made on the non-productive lands of the waste dump of the Petrila Preparation, where the experimental lots were set up for the cultivation of biomass. Vegetation has already been installed on the identified landfill area; the first necessary works are the removal of the already installed vegetation and the realization of land development works and the identification of the suitable area for planning the experimental plot and determining its size (Figure 2).

Fig.2 Arrangement of the experimental plots with the 3 types of crops on the Petrila tailings dump [4]

The plots were established at the size of 500 m2, arranged in 3 experimental lots for the three types of biomass. In each batch, 3 experimental plots were established, so in total 9 such plots, necessary for carrying out the research. Soil monitoring devices as well as other tools needed to collect crop performance data were also placed on the plots.

2.2. Layout of experimental plots for Living Labs

Physico-mechanical analyzes were performed on the soil samples from the unproductive lands, the soil samples from the 9 experimental plots were collected, after which they were prepared in the laboratory. The collection of soil samples was carried out from representative areas on non-productive lands. The 18 sampling points were chosen to obtain a more complete picture of the soil characteristics of the experimental area. Appropriate equipment, such as a corer or sampling tube, was used to obtain representative soil samples from various depths.

After collection, the preparation of the soil samples followed, by removing impurities and fragments of plants or stones from the soil samples. Samples were homogenized by mixing and drying in a controlled environment to remove excess moisture and prepare them for analysis. Analyzes were performed to determine the natural humidity and the apparent density. The natural humidity is influenced by the genesis, the lithological nature, the shape and size of the component particles and the porosity. Natural humidity varies within very wide limits, being influenced by the climate regime. Figure 1 shows the soil samples for determining natural humidity (Figure 3).

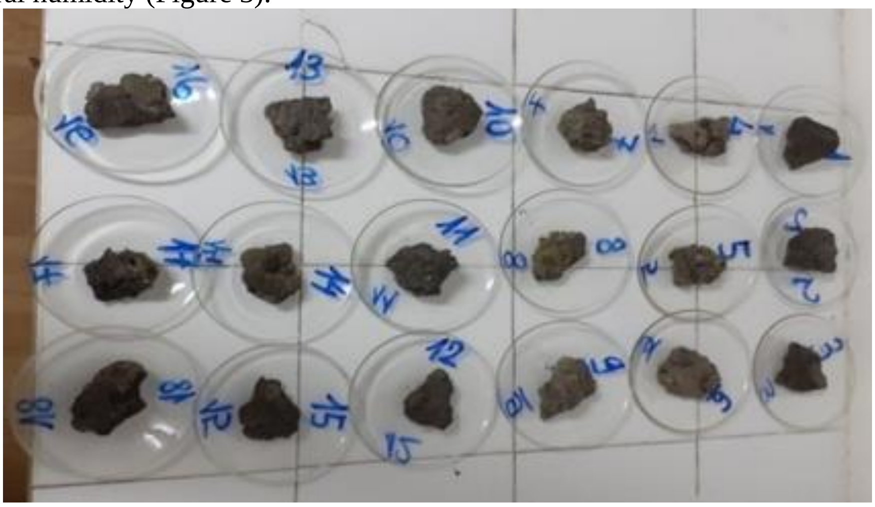


Fig.3 Soil samples for determining natural moisture

Knowing the natural humidity and the saturation humidity is of particular importance for the quantitative and qualitative description of soils; an increase in humidity leads to a decrease in the mechanical characteristics of the earth. Soil moisture is a crucial factor in the establishment and management of agricultural crops, including biomass crops. Understanding the relationship between natural soil moisture and saturation moisture is critical to optimizing production and improving soil health. Biomass crops, in addition to the production of renewable energy, have multiple benefits on soil quality and the environment.

Natural moisture and saturation moisture are interconnected through the physical properties of the soil. Fine-textured soils, such as clays, have a higher water-holding capacity and therefore have higher saturation moisture compared to sandy soils.

Table 1 shows the experimentally determined values - June 2023.

Table 1. Experimentally determined values - June 2023

Rock type: Dump material						
No. sample	**No. watchglass (container)**	**m_u [g]**	**m_d [g]**	**m_c [g]**	**Natural humidity w_n[%]**	
					Sample	**Average**
Sample 1	1	59.7701	55.1562	25.0993	15.3506	
Lot 1 Plot 1	2	72.1657	66.7781	33.5198	16.1993	**15.5123**
Maize	3	62.3999	58.1149	29.5236	14.9871	
Sample 1	4	64.7271	60.4898	34.6950	16.4270	
Lot 1 Plot 2	5	71.5865	66.4441	39.2191	18.8885	**19.6326**
Maize	6	78.8464	72.1175	43.5838	23.5823	
Sample 2	7	72.9764	67.7394	41.8349	20.2166	
Lot 2 Plot 3	8	55.3881	50.9443	32.4098	23.9758	**20.2062**
Soya	9	75.6176	70.3013	37.9365	16.4262	
Sample 3	10	86.2772	78.2285	42.5575	22.5637	
Lot 2 - Parcel 2	11	87.4001	79.6679	46.1371	23.0600	**23.0564**
Soya	12	71.0057	65.4405	41.8047	23.5456	
Sample 4	13	82.0977	75.8558	47.4321	21.9602	
Lot 3-Plot 1	14	61.1316	55.2751	31.9738	25.1338	**23.7779**
Sorghum	15	57.7677	53.0467	33.5704	24.2397	
Sample 5	16	61.3425	55.0778	30.1861	25.1678	
Lot 3-Plot 3	17	74.2008	68.0138	42.7326	24.4727	**24.9379**
Sorghum	18	87.2752	78.6247	44.2608	25.1732	

The specific density is determined in the laboratory by the pycnometer method. The method consists in determining the mass of the solid particles of the earth by weighing, determining their volume using the pycnometer and calculating the density. Figure 4 shows the soil samples for determining the apparent density by the hydrostatic weighing method - June 2023. Determination of soil bulk density is a crucial aspect in agronomy and ecology, having direct implications on the productivity of agricultural crops, including biomass crops. Bulk density provides essential information about soil structure, water holding capacity, aeration and nutrient availability. This information is fundamental to the establishment and effective management of biomass crops. The root systems of biomass plants can be sensitive to soil compaction. A high bulk density can restrict root growth, reducing the plant's ability to access water and nutrients.

Fig.4 Soil samples for determining the apparent density by the hydrostatic weighing method - June 2023

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 106-113

Bulk density affects soil porosity and, implicitly, its ability to retain water. Soils with high bulk density have small pores and low water infiltration and storage capacity, which can lead to water stress for biomass crops, especially during periods of drought. Soils with high bulk density have poor aeration, which affects root respiration and the activity of soil microorganisms. This can negatively influence the growth and development of biomass plants. Bulk density influences the mobility and availability of nutrients in the soil. Compacted soils can limit the diffusion of essential nutrients to plant roots, thus affecting the productivity of biomass crops. Figure 4. Soil samples for determining the apparent density by the hydrostatic weighing method - June 2023.

In table 2, experimentally determined values are centralized - apparent density. Determination of soil bulk density is essential for the establishment and effective management of biomass crops. This directly influences the soil's ability to retain water, aeration, nutrient availability and root system growth. By properly assessing and managing bulk density, farmers can optimize growing conditions for biomass crops, thereby ensuring maximum productivity and contributing to improved long-term soil health.

Table 2. Experimentally determined values - apparent density

Rock type: Dump material						
No. sample	**No. watchglass (container)**	**m_0 [g]**	**m_1 [g]**	**m_2 [g]**	**Apparent Density ρ_ax 10^3[kg/m^3]**	
					Pe probă	Media
Sample 1	1	28.3054	32.2779	10.6789	1.6379	1.6160
Lot 1 Plot 1	2	30.7418	35.1373	11.2549	1.6091	
Maize	3	31.1568	35.3772	11.3297	1.6011	
Sample 1	4	25.9732	28.4858	10.8437	1.7419	1.8176
Lot 1 Plot 2	5	18.5471	20.7587	8.2441	1.8344	
Maize	6	34.0947	37.3627	15.6417	1.8765	
Sample 2	7	24.0079	27.3302	7.743	1.5027	1.5091
Lot 2 Plot 3	8	17.3212	19.5201	4.9789	1.4255	
Soya	9	26.8156	30.0649	9.7644	1.5992	
Sample 3	10	30.6998	33.4367	11.3178	1.6036	1.5991
Lot 2 - Parcel 2	11	24.2688	26.3441	8.6076	1.5677	
Soya	12	34.4298	37.5616	12.9824	1.6260	
Sample 4	13	22.8019	24.6987	8.2576	1.5857	1.5521
Lot 3-Plot 1	14	18.9289	20.6014	6.5571	1.5482	
Sorghum	15	14.1612	15.8292	4.714	1.5224	
Sample 5	16	24.5198	26.8385	9.4726	1.6517	1.6090
Lot 3-Plot 3	17	33.1961	36.6264	12.7043	1.6439	
Sorghum	18	21.8268	23.9948	7.3868	1.5315	

The conclusion of the interpretation of the results of the performed analyzes led to the conclusion that on the experimental lots on the productive lands, soil mobilization works can be carried out for the establishment of biomass crops. These works were carried out in compliance with good agricultural practices to ensure maximum biomass production and protect the environment. The choice of biomass species for the establishment of crops was made according to their ecological characteristics and their potential to be transformed through anaerobic digestion and pyrolysis into biofuels and organic fertilizers (digestate and biochar). Research has highlighted the fact that corn, soybeans and sorghum are used in biomass crops, being drought-resistant species, due to their ability to produce large amounts of biomass per surface unit and due to its benefits for the soil and the environment. They are species that have the ability to fix nitrogen and help improve soil fertility. They use water efficiently, which makes them suitable for these unproductive lands with limited water availability. Corn, soybeans, and sorghum can be grown successfully on soils with a low pH and can even help reduce soil acidity by releasing basic compounds during its growth. Crops of corn, soybeans and sorghum for obtaining biomass can be affected by several limiting factors, among which are plant densities, water availability, deficiency of nutrients such as nitrogen, these can reduce biomass production. These plant species can be affected by a number of limiting factors that can influence yield and production quality. Soils that are too poor in nutrients or soils with inadequate pH can affect the yield and quality of production. Soils that are too clayey or too sandy can affect drainage and lead to moisture problems. Considering these aspects, corn, soybean and sorghum cultures were established on the experimental plots. Figure 3 shows a corn plot from experimental lot 1, June 2023. It can be seen that the water deficit and low soil fertility have affected the growth and development of corn, soybean and sorghum crops.

3. Results

Field evaluations concluded that maize crop development is uneven, with maize being less developed in areas where there is soil mixed with stones and in areas where moisture is in excess. Figure 5 shows the comparison of biomass crops in July 2023, two weeks after sowing.

Fig.5 Plot 1 with corn from experimental lot 1 - June 2023 [4]

Fig.6 Biomass crops – June 2023

Figure 6 shows the development of corn and soybean crops in experimental plots - June. On the experimental lots, the soil is not very fertile, no nutrients were applied, and therefore biomass production is reduced. Also, too high temperatures led to reduced soybean production.

Fig.7 Development of corn and soybean crops in experimental plots - June

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 106-113

Figure 8 shows the development of sorghum culture in experimental plots, June and the sorghum culture diminished by extreme soil conditions - June.

Fig.8 Development of sorghum culture in experimental plots, June and sorghum culture diminished by extreme soil conditions - June

Sorghum culture needs a sufficient amount of water to produce a large amount of biomass. Lack of water led to poor plant growth and low sorghum production in the experimental plots. As can be seen, the soils in the experimental plots have physical-mechanical characteristics that lead us to the conclusion of the need for work to improve these characteristics.

The lack of soil fertilization makes it possible to obtain reduced amounts of corn, soybeans and sorghum on the experimental plots. The application of biofertilizers will lead to the improvement of the quality of the soils on the experimental plots.

For the production of biofertilizers, research will be carried out in the living lab with a view to the anaerobic digestion and pyrolysis of the biomass grown on the experimental plots and obtaining digestate and biochar as biofertilizers.

4. Conclusions

Living Lab is an innovative approach that makes a significant contribution to restoring soil health on unproductive land. This methodology involves collaboration between various stakeholders, including researchers, farmers, authorities and local communities, to develop sustainable and effective solutions for restoring soil health and sustainable development of non-productive mining areas.

Acknowledgments

This „CeSoH" project received funding from the research and innovation program PNRR-III-C9-2022 – I5. Funded by the European Union – Next Generation EU, under grant no: 760005/30.12.2022, Project code 2. The authors would like to thank all partners of the CeSoH project for their support during fieldwork and sampling, as well as for providing biomass yield data for investigated case study sites.

References

[1] *EU soil strategy for 2030. Capitalizing on the benefits of healthy soils for human ends, food, nature and climate, European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=CELEX:52021DC0699*

[2] **Irimie, S.I., Petrilean, D.C.**, 2013
Environmental Impact Assessment for Dismantling an Energetic Complex Using Thermodynamic Concepts, 9th International Conference on Energy, Environment, Ecosystems and Sustainable Development" (EEESD '13), Lemesos, Cyprus, March 21-23, pp. 76-81. https://getinfo.de/app/subject-search?cluster=tib&action=search&term=Petrilean*&tib=zbwkat&tib=roempp&tib=blcp&tib=dkf&tib=sudoc&tib=tema&tib=ceaba&tib=zbmkm&tib=ntis&tib=rdat&tib=tibkat&tib=citeseerx&tib=blse&tib=kmo3d&tib=iud&tib=zbmql&tib=kmoav&tib=zmat&tib=etde&tib=temaext&tib=rswb&tib=insp&tib=dkfl&tib=prob&tib=epo.

[3] **Almirall, E., & Wareham, J.**, 2011
Living Labs: Arbiters of mid- and ground-level innovation. Technology Innovation Management Review, 1(2), 28-32

[4] **Leminen, S., Westerlund, M., & Nyström, A. G.**, 2012
Living Labs as open-innovation networks. Technology Innovation Management Review, 2(9), 6-11, https://www.timreview.ca/sites/default/files/article_PDF/Leminen_et_al_TIMReview_September2012.pdf

[5] **Schuurman, D., De Marez, L., & Ballon, P.**, 2016
The impact of living lab methodology on open innovation contributions and outcomes. Technology Innovation Management Review, 6(1), 7-16. https://sweet-lantern.ch/wp-content/uploads/2023/09/The_Impact_of_Living_Lab_Methodology_on_Open_Innov.pdf.

[6] **Nevens, F., Frantzeskaki, N., Gorissen, L., Loorbach D.**, 2013
Urban Transition Labs: co-creating transformative action for sustainable cities. Journal of Cleaner Production. Volume 50, Pages 111-122. https://www.sciencedirect.com/science/article/abs/pii/S0959652612006452#preview-section-abstract.

[7] **Engez, A.; Leminen, S.; Aarikka-Stenroos, L.**, 2021
Urban Living Lab as a Circular Economy Ecosystem: Advancing Environmental Sustainability through Economic Value, Material, and Knowledge Flows. Sustainability, 13, 2811. https://www.mdpi.com/2071-1050/13/5/2811.

[8] **Filip, L.O.**, 2020
Possibilities of transcalculation of coordinates between stereographic and central projection systems, RevistaMinelor, vol. 26, nr. 3, pag. 52-55, Petroșani, ISSN-L 1220- 2053/ISSN 2247-8590, https://issuu.com/revmin/docs/nr3ro2020.

[9] **Marin I.**, 2012
Waste dumps - artificial wastelands. Greenly Magazine. Waste. https://greenly.ro/deseuri/haldele-de-steril-un-pericol-pentru-mediu. 2012. http://greenly.ro/deseuri/haldele-de-steril-un-pericol-pentru-mediu

[10] *Technical Rules of October 1, 2001 for the introduction of the general cadastre, updated until December 7, 2010, Ministry of Public Administration, published in the Official Gazette no. 744 of November 21, 2001*

[11] *Dumping ponds report 12 September 2017.pdf,, https://oldeconomie.gov.ro/images/resurse-minerale/Raport%20Halde%20Iazuri%2012%20sept%202017.pdf*

[12] *Scientific report - ,,Restoration of soil health on unproductive lands through biomass crops for sustainable energy - Soil- Biomass - Sustainability - SOBIOSUS", PNRR, Establishment and operationalization of a Competence Center for Soil Health and Food Safety-CeSoH, contract no. 760005/30.12.2022. https://www.upet.ro/cesoh-p1-upet/.*

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 114-122

EVALUATION OF THE SUITABILITY OF NON-PRODUCTIVE LAND FOR BIOMASS CULTIVATION AND ITS ENERGY RECOVERY

Emilia-Cornelia DUNCA[1*], *Maria LAZĂR*[2], *Ciprian-Gheorghe DANCIU*[3], *Camelia MADEAR*[4], *Lucia-Ana VARGA*[5]

[1, 2, 4, 5] University of Petroșani, Faculty of Mine, Department of Environmental Engineering and Geology, 332006 code, Petroșani City, Hunedoara Country
[3] University of Petroșani, Faculty of Mine, Department of Mining, Surveying and Construction Engineering, 332006 code, Petroșani City, Hunedoara Country

DOI: 10.2478/minrv-2024-0048

Abstract: *The work is part of the efforts to restore unproductive land in a green and circular economy. The results of the research carried out on non-productive land in the Jiu Valley are presented regarding the suitability of the soil and the cultivated biomass for its energy utilization and obtaining the digestate as fertilizer. The traceability of heavy metals from soil to biomass and the suitability of using biomass for its energy recovery are evaluated.*
Keywords: *biomass, biogas, unproductive land, inorganic pollution*

1. Introduction

The Circular Economy Package adopted by the European Commission in 2015, which will contribute to the EU's efforts to develop a „sustainable, low-carbon, resource-efficient and competitive economy" [1]. Moving from the model of a linear economy to a circular economy „means that materials are recovered from products at the end of the product's life cycle by connecting waste with resources" [2]. In this context, organic waste recycling technologies were put into practice through their anaerobic digestion or their co-digestion with biomass in biogas installations [3]. The biogas obtained through this technology is used for energy and the resulting digestate can be used as biofertilizer, it has a rich content of nitrogen, phosphorus, potassium and micronutrients, and is successfully used in the fertilization process, including degraded lands and unproductive lands. Therefore, through the anaerobic decomposition of the biomass grown on the non-productive lands in Jiu Valley or its mixture with organic waste, the digestate can be obtained as a biofertilizer, which, under certain conditions, can be applied as a fertilizer on these lands to restore the non-productive lands.

2. The limits of innovative research regarding the possibility of energy utilization of biomass and obtaining biofertilizers

The lands on which the experimental plots were established were affected by the activity of coal extraction and processing through pollution with chemical substances, especially with heavy metals. In order to identify the presence of heavy metals in the corn, sorghum and soybeans grown on the experimental lots, it was necessary to carry out chemical analyzes to evaluate the concentration of heavy metals in the soil on which the corn, sorghum and soybeans grown on the experimental lots were grown [4-6]. Thus, the soil content of copper, lead, chromium, cobalt, nickel, zinc, cadmium, manganese, iron and barium was determined. The results obtained were compared with the provisions of Order 756/1997 for normal soils, the conclusions are the following:

The research carried out until now has led to the conclusion that trace elements, such as iron, nickel, cobalt, selenium, molybdenum and tungsten, are important for the development and survival of anaerobic bacteria in the biomass digestion process.

* Corresponding author: University of Petroșani, Faculty of Mine, Department of Environmental Engineering and Geology, 332006 code, Petroșani City, Hunedoara Country,duncaemilia@yahoo.com; Tel.: +40-751-01-04-39

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 114-122

However, in large quantities, heavy metals and persistent contaminants can cause problems and inhibit the biomass fermentation process. For this reason, the contaminant content of the feedstock as well as the digestate must be carefully monitored. Contaminant concentrations in digestate must not exceed legal limits. The biomass was cultivated on the experimental plots on the non-productive lands within the administrative radius of the Petrila place. These lands were affected by the coal extraction and processing activity and therefore it was necessary to carry out chemical analyzes in order to identify the presence of heavy metals in the corn, sorghum and soybeans grown on the experimental plots [7]. Biomass (corn, soy and sorghum) was chemically analyzed in order to determine the content of heavy metals: copper, lead, chromium, cobalt, nickel, zinc, cadmium, manganese, iron, barium. The obtained results were compared with the provisions of Order 756/1997 for normal soils. The analyzes were carried out within the project Restoring soil health on non-productive lands through biomass crops for sustainable energy - Soil - Biomass - Sustainability - SOBIOSUS", PNRR [7].

To determine and evaluate the degree of soil pollution with heavy metals, soil samples are taken avoiding their contamination, unrepresentative samples, unlabeled samples, etc. Reference samples were used to confirm the accuracy and precision of the analytical techniques used. These reference samples were analyzed together with samples taken from each area of the land and all samples were analyzed with the appropriate methodology, according to the standards in force [8].

The following tables show the results obtained and the normal and attention limits imposed by the legislation in force [8]: The variation of elemental copper in the three experimental batches is presented in table no. 1, the values being comparable values for the three types of biomass; It is found that the normal values allowed are exceeded, but it is lower than the alert threshold for sensitive soils (<100) [9].

Table 1. Variation of elemental copper in the three experimental batches

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
Cu (0.5-7.5 (mg/l))							
28.06.2023	L1 P1-1	0.5119	50	1	0.6059	59.18	>20
Maize	L1 P1-2	0.5382	50	1	0.6452	59.94	>20
	L1 P1-3	0.5522	50	1	0.8262	74.81	>20
	L1 P1-4	0.4758	50	1	0.5381	56.54	>20
	L1 P1-5	0.4762	50	1	0.5854	61.47	>20
	L1 P1-6	0.4956	50	1	0.5566	56.15	>20
	L1 P1-7	0.5028	50	1	0.4898	48.71	>20
	L1 P1-8	0.5388	50	1	0.7028	65.22	>20
	L1 P1-9	0.5968	50	1	0.5243	43.93	>20
	L1 P1-10	0.5593	50	1	0.6281	56.15	>20
Soybean	L2 P1-1	0.4859	50	1	0.5005	51.51	>20
	L2 P1-2	0.4871	50	1	0.6483	66.54	>20
	L2 P1-3	0.5064	50	1	0.6327	62.47	>20
	L2 P1-4	0.4956	50	1	0.5941	59.94	>20
	L2 P1-5	0.5077	50	1	0.5927	58.37	>20
	L2 P1-6	0.5126	50	1	0.5222	50.94	>20
	L2 P1-7	0.5785	50	1	0.6975	60.28	>20
	L2 P1-8	0.5019	50	1	0.6659	66.34	>20
	L2 P1-9	0.6302	50	1	0.6001	47.61	>20
	L2 P1-10	0.5635	50	1	0.5417	48.06	>20
Sorghum	L3 P1-1	0.5410	50	1	0.6180	57.11	>20
	L3 P1-2	0.4887	50	1	0.5008	51.24	>20
	L3 P1-3	0.4962	50	1	0.5814	58.59	>20
	L3 P1-4	0.4972	50	1	0.6187	62.22	>20
	L3 P1-5	0.5721	50	1	0.6812	59.54	>20
	L3 P1-6	0.5042	50	1	0.6109	60.58	>20
	L3 P1-7	0.5404	50	1	0.7407	68.54	>20
	L3 P1-8	0.5141	50	1	0.5344	51.97	>20

Date	**Sample / code**	**Drysample mass (g)**	**Final volume (ml)**	**Dilution**	**Reading ICP-OES (mg/l)**	**Final (mg/kg)**	**LQ=10 (mg/kg)**
Cu (0.5-7.5 (mg/l))							
	L3 P1-9	0.4848	50	1	0.5205	53.68	>20
	L3 P1-10	0.5112	50	1	0.4218	41.25	>20
Blank		0.5082	50	1	0.5283	51.98	>20

The results of chemical analyze regarding the variation of elemental lead in the three experimental batches is presented in table 2. Elemental lead is found below the maximum allowed value for normal soils (<20), with the exception of one sample that was determined on soybean culture, the determined value being >20 (20.48 mg/kg) [9].

Table 2. Variation of elemental lead in the three experimental groups

Date	**Sample / code**	**Drysample mass (g)**	**Final volume (ml)**	**Dilution**	**Reading ICP-OES (mg/l)**	**Final (mg/kg)**	**LQ=10 (mg/kg)**
Pb (0.5-7.5 mg/l)							
28.06.2023	L1 P1-1	0.5119	50	1	0.147	14.36	<20
Maize	L1 P1-2	0.5382	50	1	0.162	15.04	<20
	L1 P1-3	0.5522	50	1	0.219	19.85	<20
	L1 P1-4	0.4758	50	1	0.139	14.64	<20
	L1 P1-5	0.4762	50	1	0.109	11.43	<20
	L1 P1-6	0.4956	50	1	0.150	15.18	<20
	L1 P1-7	0.5028	50	1	0.153	15.17	<20
	L1 P1-8	0.5388	50	1	0.209	19.38	<20
	L1 P1-9	0.5968	50	1	0.158	13.27	<20
	L1 P1-10	0.5593	50	1	0.172	15.38	<20
Soybean	L2 P1-1	0.4859	50	1	0.134	13.78	<20
	L2 P1-2	0.4871	50	1	0.138	14.22	<20
	L2 P1-3	0.5064	50	1	0.167	16.46	<20
	L2 P1-4	0.4956	50	1	0.150	15.17	<20
	L2 P1-5	0.5077	50	1	0.186	18.31	<20
	L2 P1-6	0.5126	50	1	0.168	16.41	<20
	L2 P1-7	0.5785	50	1	0.153	13.23	<20
	L2 P1-8	0.5019	50	1	0.206	20.48	>20
	L2 P1-9	0.6302	50	1	0.179	14.23	<20
	L2 P1-10	0.5635	50	1	0.182	16.13	<20
Sorghum	L3 P1-1	0.541	50	1	0.171	15.84	<20
	L3 P1-2	0.4887	50	1	0.179	18.28	<20
	L3 P1-3	0.4962	50	1	0.131	13.24	<20
	L3 P1-4	0.4972	50	1	0.158	15.88	<20
	L3 P1-5	0.5721	50	1	0.180	15.76	<20
	L3 P1-6	0.5042	50	1	0.155	15.35	<20
	L3 P1-7	0.5404	50	1	0.136	12.60	<20
	L3 P1-8	0.5141	50	1	0.138	13.43	<20
	L3 P1-9	0.4848	50	1	0.157	16.18	<20
	L3 P1-10	0.5112	50	1	0.131	12.84	<20
Blank		0.5082	50	1	0.170	16.68	<20

The variation of elemental chromium in the experimental batches is presented in table 3. It is found that elemental chromium is below the maximum value allowed for normal soils (<30) for corn and soy crops. On the other hand, for the sorghum crop, it is found that elemental chromium is found below the maximum value allowed for normal soils (<30) for 6 samples and above the maximum value allowed for normal soils (>30).

Table 3. Variation of elemental chromium in the three experimental groups

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
			Cr (0.5-7.5 mg/l)				
28.06.2023	L1 P1-1	0.5119	50	1	0.238	23.27	<30
Maize	L1 P1-2	0.5382	50	1	0.282	26.18	<30
	L1 P1-3	0.5522	50	1	0.255	23.07	<30
	L1 P1-4	0.4758	50	1	0.222	23.36	<30
	L1 P1-5	0.4762	50	1	0.214	22.52	<30
	L1 P1-6	0.4956	50	1	0.206	20.75	<30
	L1 P1-7	0.5028	50	1	0.211	20.96	<30
	L1 P1-8	0.5388	50	1	0.208	19.32	<30
	L1 P1-9	0.5968	50	1	0.294	24.60	<30
	L1 P1-10	0.5593	50	1	0.237	21.21	<30
Soybean	L2 P1-1	0.4859	50	1	0.271	27.90	<30
	L2 P1-2	0.4871	50	1	0.182	18.70	<30
	L2 P1-3	0.5064	50	1	0.214	21.13	<30
	L2 P1-4	0.4956	50	1	0.260	26.19	<30
	L2 P1-5	0.5077	50	1	0.282	27.75	<30
	L2 P1-6	0.5126	50	1	0.277	27.05	<30
	L2 P1-7	0.5785	50	1	0.311	26.89	<30
	L2 P1-8	0.5019	50	1	0.255	25.36	<30
	L2 P1-9	0.6302	50	1	0.268	21.27	<30
	L2 P1-10	0.5635	50	1	0.264	23.44	<30
Sorghum	L3 P1-1	0.5410	50	1	0.256	23.62	<30
	L3 P1-2	0.4887	50	1	0.193	19.79	<30
	L3 P1-3	0.4962	50	1	0.338	34.04	>30
	L3 P1-4	0.4972	50	1	0.285	28.70	<30
	L3 P1-5	0.5721	50	1	0.328	28.65	<30
	L3 P1-6	0.5042	50	1	0.405	40.15	>30
	L3 P1-7	0.5404	50	1	0.818	75.64	>30
	L3 P1-8	0.5141	50	1	0.230	22.33	<30
	L3 P1-9	0.4848	50	1	0.400	41.30	>30
	L3 P1-10	0.5112	50	1	0.408	39.91	>30
Blank		0.5082	50	1	0.296	29.15	<30

The variation of elemental cobalt in the experimental batches can be found in table 4. It is found that elemental cobalt, for most of the analyzed samples, is below the maximum value allowed for normal soil (<15). There is a sample analyzed on the soil cultivated with corn with double values compared to the maximum allowed value (35.76 mg/kg compared to 15mg/kg). Also, there is one sample analyzed on soybeans and two samples analyzed on the soil cultivated with sorghum with slight excesses of the maximum allowed value.

Table 4. Variation of elemental cobalt in the three experimental groups

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
			Co (0.5-7.5 mg/l)				
28.06.2023	L1 P1-1	0.5119	50	1	0.114	11.10	<15
Maize	L1 P1-2	0.5382	50	1	0.125	11.60	<15
	L1 P1-3	0.5522	50	1	0.395	35.76	>15
	L1 P1-4	0.4758	50	1	0.111	11.70	<15
	L1 P1-5	0.4762	50	1	0.112	11.81	<15
	L1 P1-6	0.4956	50	1	0.113	11.39	<15

	L1 P1-7	0.5028	50	1	0.125	12.45	<15
	L1 P1-8	0.5388	50	1	0.135	12.56	<15
	L1 P1-9	0.5968	50	1	0.131	10.93	<15
	L1 P1-10	0.5593	50	1	0.132	11.82	<15
Soybean	L2 P1-1	0.4859	50	1	0.126	13.00	<15
	L2 P1-2	0.4871	50	1	0.105	10.75	<15
	L2 P1-3	0.5064	50	1	0.157	15.52	>15
	L2 P1-4	0.4956	50	1	0.107	10.84	<15
	L2 P1-5	0.5077	50	1	0.142	14.01	<15
	L2 P1-6	0.5126	50	1	0.122	11.94	<15
	L2 P1-7	0.5785	50	1	0.123	10.60	<15
	L2 P1-8	0.5019	50	1	0.127	12.64	<15
	L2 P1-9	0.6302	50	1	0.172	13.64	<15
	L2 P1-10	0.5635	50	1	0.117	10.34	<15
Sorghum	L3 P1-1	0.541	50	1	0.177	16.34	>15
	L3 P1-2	0.4887	50	1	0.113	11.53	<15
	L3 P1-3	0.4962	50	1	0.127	12.81	<15
	L3 P1-4	0.4972	50	1	0.162	16.32	>15
	L3 P1-5	0.5721	50	1	0.156	13.63	<15
	L3 P1-6	0.5042	50	1	0.134	13.28	<15
	L3 P1-7	0.5404	50	1	0.102	9.45	<15
	L3 P1-8	0.5141	50	1	0.119	11.55	<15
	L3 P1-9	0.4848	50	1	0.139	14.34	<15
	L3 P1-10	0.5112	50	1	0.123	11.98	<15
Blank		0.5082	50	1	0.123	12.14	<15

The variation of elemental nickel in the three experimental groups is presented in table 5. It is found that elemental nickel is found in all samples, above the value allowed for normal soil (<20), in general below the value for the alert threshold for sensitive soil (<75). There are samples analyzed on the soil cultivated with corn (1 sample with the highest value of those analyzed of 106.78 mg/kg) and sorghum in particular (4 samples), where the value for the alert threshold for sensitive soil (<75) is exceeded.

Table 5. Variation of elemental nickel in the three experimental batches

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
Ni (0.5-7.5 mg/l)							
28.06.2023	L1 P1-1	0.5119	50	1	0.573	56.00	>20
Maize	L1 P1-2	0.5382	50	1	0.684	63.52	>20
	L1 P1-3	0.5522	50	1	1.179	106.78	>20
	L1 P1-4	0.4758	50	1	0.601	63.13	>20
	L1 P1-5	0.4762	50	1	0.508	53.36	>20
	L1 P1-6	0.4956	50	1	0.541	54.54	>20
	L1 P1-7	0.5028	50	1	0.578	57.44	>20
	L1 P1-8	0.5388	50	1	0.685	63.60	>20
	L1 P1-9	0.5968	50	1	0.639	53.57	>20
	L1 P1-10	0.5593	50	1	0.619	55.32	>20
Soybean	L2 P1-1	0.4859	50	1	0.704	72.41	>20
	L2 P1-2	0.4871	50	1	0.607	62.29	>20
	L2 P1-3	0.5064	50	1	0.748	73.82	>20
	L2 P1-4	0.4956	50	1	0.561	56.58	>20
	L2 P1-5	0.5077	50	1	0.751	73.97	>20
	L2 P1-6	0.5126	50	1	0.591	57.66	>20
	L2 P1-7	0.5785	50	1	0.590	50.99	>20

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
	L2 P1-8	0.5019	50	1	0.752	74.94	>20
	L2 P1-9	0.6302	50	1	0.784	62.19	>20
	L2 P1-10	0.5635	50	1	0.601	53.29	>20
Sorghum	L3 P1-1	0.541	50	1	0.747	69.04	>20
	L3 P1-2	0.4887	50	1	0.553	56.58	>20
	L3 P1-3	0.4962	50	1	0.749	75.47	>20
	L3 P1-4	0.4972	50	1	0.800	80.45	>20
	L3 P1-5	0.5721	50	1	0.764	66.81	>20
	L3 P1-6	0.5042	50	1	0.676	67.05	>20
	L3 P1-7	0.5404	50	1	1.014	93.85	>20
	L3 P1-8	0.5141	50	1	0.621	60.40	>20
	L3 P1-9	0.4848	50	1	0.727	75.00	>20
	L3 P1-10	0.5112	50	1	0.658	64.31	>20
Blank		0.5082	50	1	0.627	61.67	>20

The variation of elemental zinc in the experimental batches is presented in table 6. The elemental zinc is below the maximum value allowed for normal soil (<100) for the soil samples analyzed with soybeans. For the soil cultivated with corn, there are two samples with a value above the maximum value allowed for normal soil (>100). For sorghum, there are 5 samples with a value above the maximum value allowed for normal soil (>100).

Table 6. Variation of elemental zinc in the three experimental groups

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
Zn (0.5-7.5 mg/l)							
27.06.2023	L1 P1-1	0.5119	50	1	0.905	88.36	<100
Maize	L1 P1-2	0.5382	50	1	0.909	84.46	<100
	L1 P1-3	0.5522	50	1	0.884	80.07	<100
	L1 P1-4	0.4758	50	1	0.938	98.61	<100
	L1 P1-5	0.4762	50	1	0.915	96.06	<100
	L1 P1-6	0.4956	50	1	1.006	101.49	>100
	L1 P1-7	0.5028	50	1	0.788	78.33	<100
	L1 P1-8	0.5388	50	1	1.139	105.71	>100
	L1 P1-9	0.5968	50	1	0.929	77.80	<100
	L1 P1-10	0.5593	50	1	0.780	69.75	<100
Soybean	L2 P1-1	0.4859	50	1	0.840	86.47	<100
	L2 P1-2	0.4871	50	1	0.793	81.45	<100
	L2 P1-3	0.5064	50	1	0.680	67.14	<100
	L2 P1-4	0.4956	50	1	0.860	86.72	<100
	L2 P1-5	0.5077	50	1	0.986	97.06	<100
	L2 P1-6	0.5126	50	1	0.906	88.38	<100
	L2 P1-7	0.5785	50	1	0.932	80.56	<100
	L2 P1-8	0.5019	50	1	1.002	99.79	<100
	L2 P1-9	0.6302	50	1	0.847	67.21	<100
	L2 P1-10	0.5635	50	1	0.800	70.96	<100
Sorghum	L3 P1-1	0.541	50	1	1.204	111.28	>100
	L3 P1-2	0.4887	50	1	0.616	63.06	<100
	L3 P1-3	0.4962	50	1	0.770	77.56	<100
	L3 P1-4	0.4972	50	1	1.014	102.02	>100
	L3 P1-5	0.5721	50	1	1.241	108.48	>100
	L3 P1-6	0.5042	50	1	1.176	116.60	>100

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 114-122

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
	L3 P1-7	0.5404	50	1	0.532	49.18	<100
	L3 P1-8	0.5141	50	1	2.171	211.10	>100
	L3 P1-9	0.4848	50	1	0.760	78.43	<100
	L3 P1-10	0.5112	50	1	0.546	53.42	<100
Blank		0.5082	50	1	0.835	82.16	<100

The variation of elemental cadmium in the three experimental batches is presented in table 7. Elemental cadmium is found below the maximum value allowed for normal soil (<1) for the soil cultivated with soybeans, for the soil cultivated with corn a value above the maximum value allowed for normal soil, 2 values above the maximum value allowed for normal soil for soil cultivated with sorghum.

Table 7. Variation of elemental cadmium in the three experimental batches

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
Cd (0.5-7.5 mg/l)							
28.06.2023	L1 P1-1	0.5119	50	1	-0.004	-0.38	<1
Maize	L1 P1-2	0.5382	50	1	-0.007	-0.68	<1
	L1 P1-3	0.5522	50	1	-0.012	-1.13	<1
	L1 P1-4	0.4758	50	1	-0.008	-0.87	<1
	L1 P1-5	0.4762	50	1	-0.010	-1.01	>1
	L1 P1-6	0.4956	50	1	-0.008	-0.80	<1
	L1 P1-7	0.5028	50	1	-0.008	-0.81	<1
	L1 P1-8	0.5388	50	1	-0.008	-0.70	<1
	L1 P1-9	0.5968	50	1	-0.008	-0.64	<1
	L1 P1-10	0.5593	50	1	-0.008	-0.73	<1
Soybean	L2 P1-1	0.4859	50	1	-0.010	-0.99	<1
	L2 P1-2	0.4871	50	1	-0.009	-0.97	<1
	L2 P1-3	0.5064	50	1	-0.006	-0.63	<1
	L2 P1-4	0.4956	50	1	-0.009	-0.90	<1
	L2 P1-5	0.5077	50	1	-0.010	-0.95	<1
	L2 P1-6	0.5126	50	1	-0.009	-0.92	<1
	L2 P1-7	0.5785	50	1	-0.009	-0.74	<1
	L2 P1-8	0.5019	50	1	-0.009	-0.89	<1
	L2 P1-9	0.6302	50	1	-0.010	-0.81	<1
	L2 P1-10	0.5635	50	1	-0.009	-0.83	<1
Sorghum	L3 P1-1	0.5410	50	1	-0.008	-0.72	<1
	L3 P1-2	0.4887	50	1	-0.011	-1.12	>1
	L3 P1-3	0.4962	50	1	-0.012	-1.26	>1
	L3 P1-4	0.4972	50	1	-0.008	-0.84	<1
	L3 P1-5	0.5721	50	1	-0.010	-0.86	<1
	L3 P1-6	0.5042	50	1	-0.010	-0.94	<1
	L3 P1-7	0.5404	50	1	-0.010	-0.97	<1
	L3 P1-8	0.5141	50	1	-0.009	-0.92	<1
	L3 P1-9	0.4848	50	1	-0.007	-0.76	<1
	L3 P1-10	0.5112	50	1	-0.009	-0.85	<1
Blank		0.5082	50	1	-0.010	-1.01	>1

The variation of elemental manganese in the three experimental batches is presented in table 8. Elemental manganese is below the maximum limit allowed for normal soil (<900). There is a sample analyzed on the soil cultivated with sorghum in which the maximum limit allowed for normal soil for elemental manganese is exceeded (the recorded value is 1202.1 mg/kg).

Table 8. Variation of elemental manganese in the three experimental groups

Date	Sample / code	Drysample mass (g)	Final volume (ml)	Dilution	Reading ICP-OES (mg/l)	Final (mg/kg)	LQ=10 (mg/kg)
Mn (5-100 mg/l)							
28.06.2023	L1 P1-1	0.5119	50	1	2.558	249.9	<900
Maize	L1 P1-2	0.5382	50	1	3.683	342.1	<900
	L1 P1-3	0.5522	50	1	5.174	468.4	<900
	L1 P1-4	0.4758	50	1	2.515	264.3	<900
	L1 P1-5	0.4762	50	1	1.982	208.2	<900
	L1 P1-6	0.4956	50	1	3.056	308.3	<900
	L1 P1-7	0.5028	50	1	3.316	329.7	<900
	L1 P1-8	0.5388	50	1	2.812	260.9	<900
	L1 P1-9	0.5968	50	1	4.471	374.6	<900
	L1 P1-10	0.5593	50	1	3.211	287.1	<900
Soybean	L2 P1-1	0.4859	50	1	3.096	318.5	<900
	L2 P1-2	0.4871	50	1	2.977	305.6	<900
	L2 P1-3	0.5064	50	1	4.890	482.8	<900
	L2 P1-4	0.4956	50	1	1.690	170.5	<900
	L2 P1-5	0.5077	50	1	3.714	365.7	<900
	L2 P1-6	0.5126	50	1	3.509	342.3	<900
	L2 P1-7	0.5785	50	1	3.923	339.0	<900
	L2 P1-8	0.5019	50	1	3.681	366.8	<900
	L2 P1-9	0.6302	50	1	4.099	325.2	<900
	L2 P1-10	0.5635	50	1	4.465	396.2	<900
Sorghum	L3 P1-1	0.541	50	1	4.064	375.6	<900
	L3 P1-2	0.4887	50	1	2.160	221.0	<900
	L3 P1-3	0.4962	50	1	3.118	314.2	<900
	L3 P1-4	0.4972	50	1	2.849	286.5	<900
	L3 P1-5	0.5721	50	1	3.978	347.7	<900
	L3 P1-6	0.5042	50	1	5.541	549.5	<900
	L3 P1-7	0.5404	50	1	12.993	1202.1	>900
	L3 P1-8	0.5141	50	1	2.982	290.0	<900
	L3 P1-9	0.4848	50	1	3.716	383.2	<900
	L3 P1-10	0.5112	50	1	4.234	414.1	<900
Blank		0.5082	50	1	4.500	442.8	<900

Heavy metals present in landfill soils can have significant effects on plant growth. These metals, such as cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu) and mercury (Hg), interfere with various physiological and biochemical processes of plants, leading to reduced growth and development. These heavy metals can inhibit the absorption and translocation of essential nutrients. For example, cadmium can block the absorption of calcium and magnesium, thus affecting the processes of growth and photosynthesis.

3. Conclusions

The research carried out regarding the assessment of the suitability of non-productive land for the cultivation of biomass and its energy utilization led to the following conclusions:

• The chemical analyzes carried out on the soil cultivated with corn, soybeans and sorghum harvested on the experimental plots from the unproductive lands consisted in determining the content of heavy metals: copper, lead, chromium, cobalt, nickel, zinc, cadmium, manganese, iron, barium.

The obtained results were compared with the provisions of Order 756/1997 for normal soils.

• The soil samples on which the biomass was grown contain trace elements important for the development and survival of anaerobic bacteria such as iron, nickel, cobalt, molybdenum. These are generally within the maximum admissible limits provided by Order 756/1997.

• However, it was found that, in the case of some samples, the maximum value allowed according to Order 756/1997 for some heavy metals is exceeded, which cause problems such as inhibition of the fermentation could process of the biomass grown on these soils.

• Considering that the cultivation of biomass was carried out on soils affected by coal mining activity and processing activity, it is necessary to carry out the research in two stages:

- the first stage includes research on the anaerobic digestion of corn, soybeans and sorghum each separately and their co-digestion with the aim of monitoring the influence of heavy metals and the possibility of their annihilation during the biomass fermentation process.

This stage will also include monitoring the traceability of heavy metals from biomass to digestate.

- the second stage of the research is the analysis of the possibility of co-digestion of the biomass grown on the experimental plots with the organic waste resulting from the processing of organic raspberries.

This stage will be carried out after obtaining and validating the results obtained in the first stage.

• Digestion and co-digestion of biomass requires monitoring the traceability of heavy metals throughout the process in order to evaluate the transfer of heavy metals from the fermented biomass to the obtained digestate.

Acknowledgments

This „CeSoH" project received funding from the research and innovation program PNRR-III-C9-2022 – I5. Funded by the European Union – Next Generation EU, under grant no: 760005/30.12.2022, Project code 2. The authors would like to thank all partners of the CeSoH project for their support during fieldwork and sampling, as well as for providing biomass yield data for investigated case study sites.

References

[1] **Arshad, M.N.; Donnison, I.; Rowe, R.**, 2022
Marginal Lands: Concept, Classification Criteria and Management; Supergen Bioenergy Hub; Aston University: Birmingham, UK. DOI:10.13140/RG.2.2.11996.46721

[2] *COM(2015) 614 final - Closing the loop - an EU action plan for the circular economy.* https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF.

[3] **Filip L.O., Dima N., Vereş I.S.**, 2014
Contribution to solving geometric levelling underground networks, Annales of the University of Petroșani, Universitas Publishing House, vol. 15, Petroșani, 2014. https://www.upet.ro/simpro/2014/proceedings/02%20-%20MINING%20ENGINEERING,%20SURVEYING%20AND%20CADASTRIAL%20AREA/2.14.pdf

[4] *Scientific report - ,,Restoration of soil health on unproductive lands through biomass crops for sustainable energy - Soil- Biomass - Sustainability - SOBIOSUS",* PNRR, Establishment and operationalization of a Competence Center for Soil Health and Food Safety-CeSoH, contract no. 760005/30.12.2022. https://www.upet.ro/cesoh-p1-upet/.

[5] **Varela Pérez, P.; Greiner, B.E.; Von Cossel, M.**, 2022
Socio-Economic and Environmental Implications of Bioenergy Crop Cultivation on Marginal African Drylands and Key Principles for a Sustainable Development. Earth 2022, 3, 652–682. https://doi.org/10.3390/earth3020038

[6] **Petrilean, D.C.; Irimie, S.I.**, 2015
Solutions for the capitalisation of the energetic potential of sludge collected in Danutoni wastewater treatment plant, Journal of Environmental Protection and Ecology, Vol.16 No.3 pp.1203-1211, 2015.http://apps.webofknowledge.com.ux4ll8xu6v.useaccesscontrol.com/full_record.do?product=UA&search_mode=GeneralSearch&qid=1&SID=3FvAzmmv78nFQlq1jOT&page=1&doc=1.

[7] **I Burland, A.; von Cossel, M.**, 2023
Towards Managing Biodiversity of European Marginal Agricultural Land for Biodiversity-Friendly Biomass Production. Agronomy, 13, 1651. https://doi.org/10.3390/agronomy13061651

[8] **Catherine M.J. Fayet, Peter H. Verburg**, 2023
Modelling opportunities of potential European abandoned farmland to contribute to environmental policy targets. CATENA, Volume 232, November 2023, 107460. https://doi.org/10.1016/j.catena.2023.107460

[9] *Report on the chemical composition of soil and biomass, Cromatec, ,,Restoring soil health on unproductive lands through biomass crops for sustainable energy – Soil- Biomass – Sustainability – SOBIOSUS",* PNRR, Establishment and operationalization of a Competence Center for Soil Health and Food Safety-CeSoH, contract no. 760005/30.12.2022. https://www.upet.ro/cesoh-p1-upet/.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 123-128

SOLUTIONS FOR THE REUSE OF AREAS AFFECTED BY COAL EXTRACTION AT LUPENI MINE

Andreea Cristina TATARU [1*], *Dorin TATARU* [2]

[1, 2] University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Mechanical, Industrial and Transport Engineering, 335600, Petrosani, Romania

DOI: 10.2478/minrv-2024-0049

Abstract: *Coal extraction in Valea Jiului leaves behind large areas of affected land. Once the mining units in Valea Jiului are closed, they can be given a different destination than the original one. Both surface and underground constructions can be used for other purposes, both economic and environmental protection. One of the mining operations that is currently in the process of closure and greening is the Lupeni Mining. In this paper we will present some solutions for the reuse of the areas affected by coal extraction at the Lupeni Mine.*
Keywords: *reuse, areas, coal, exploitation*

1. Introduction

Coal mining in the Jiu Valley began in the 19th century, with the first systematic coal mining being carried out between 1850 and 1970. During this period, mines were opened in Vulcan and Petrosani, then in Petrila and Lonea. In 1890 they continued in Aninoasa, and in 1892 in Lupeni.[1], [2]

The first owner of the mines in Valea Jiului, which started the first exploitations, was until 1870 the "Brasovean Society for Mines and Furnaces". Since 1870, the mines have been owned by the most powerful Hungarian mining company "Salgö Tarjan Company".

Since 1919, the mines in Valea Jiului pass from the property of the Hungarian state to the property of the Romanian state, forming the company Petrosani S.A.R. Since 1948, the mines in Valea Jiului, owned by the Romanian state, have been grouped into the Valea Jiului Mining Central.

In the last 50 years or so, important investments have been directed to the Jiu Valley both in the field of coal extraction and surface processing, in complementary economic activities, infrastructure and housing.

After 1989, finding that some mining objectives were not profitable, they were abandoned as economic objectives. All mining enterprises reduced their activity, the mining activity entering a phase of decline. [3], [4], [5]

The entire mining activity produces, due to its specificity, multiple and varied negative effects on the environment, exemplified by:

- changes in the relief, manifested by the degradation of the landscape and displacement of households and industrial facilities from the exploitation areas;
- the occupation of large areas of land for the activity of exploitation, dumping, storage of useful mineral substances, industrial installations, access roads, etc., areas that thus become totally unusable for other purposes, for a long period of time;
- degradation of the land, through vertical and horizontal displacements of the surface and the sliding of dumps, causing serious accidents;
- impurity of surface water and ground water;
- the hydrodynamic imbalance of underground waters;
- negative influences on the atmosphere, flora and fauna in the area;
- chemical pollution of the soil, which can affect its fertile properties for many years;
- noises, vibrations and radiation spread in the environment, with a strong adverse effect.

* Corresponding author: University of Petrosani, Faculty of Mechanical and Electrical Engineering, Department of Mechanical, Industrial and Transport Engineering, 335600, Petrosani, Romania, andreeatataru@upet.ro; Tel.: +40-721-04-47-67

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 123-128

With the completion of the mining process, the mining units enter a mine closure program. Under this program, mining units can be permanently closed or found another destination. The future destination of the mining units must not have negative effects on the environment and remedy the current problems. [6], [7], [8]

Fig. 1 Valea de Brazi green mining

2. Soluțions of reuse of areas affected by coal Extraction at Lupeni Mine

The redevelopment of a coal mine involves transforming it into a useful and safe space for other economic, social or environmental activities. This process requires detailed planning, risk assessment and investment in appropriate infrastructure and technologies.

One of the mining operations that entered the process of closure is the Lupeni Mining Operation

The Lupeni Mine is located in the town of Lupeni, which is in Hunedoara County, Romania. The town of Lupeni is part of the Jiului Valley, a region known for its coal mining activities. The Jiu Valley is located in the southern part of the Southern Carpathians, being crossed by the Jiu River.

The town of Lupeni is located at an altitude of approximately 650 meters and is surrounded by the mountains Vâlcan and Parâng, part of the Southern Carpathians.

Lupeni is accessible via the national road DN66A, which connects Valea Jiului with the rest of the country. The municipality of Lupeni is located approximately 20 kilometers west of Petroșani, the administrative and economic center of the Jiu Valley.

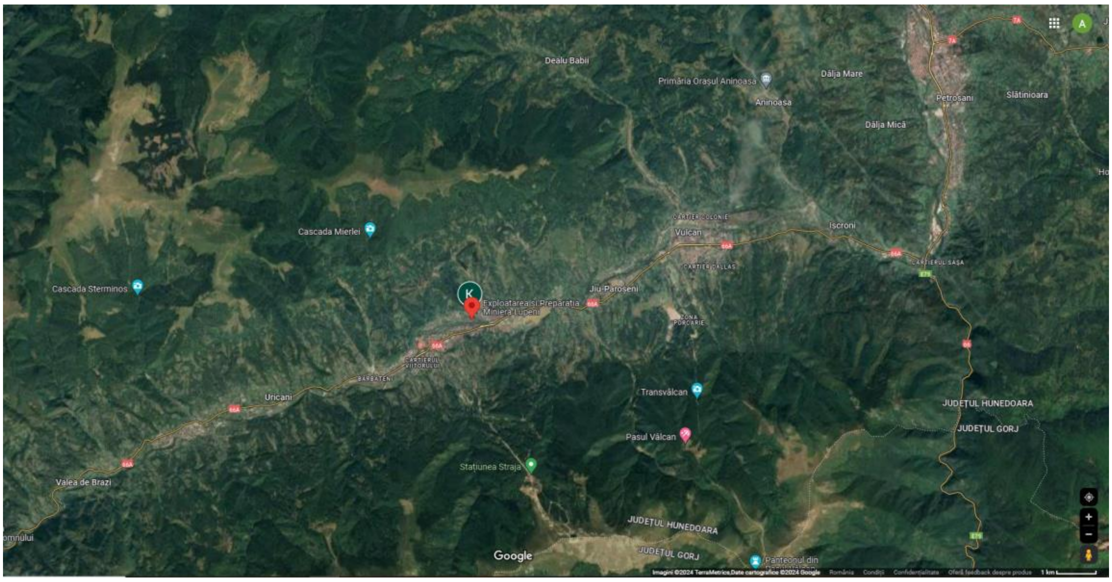


Fig. 2 Location Extraction at Lupeni Mine

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 123-128

2.1. Solutions for reuse of tailings dumps

The tailings dumps of the Lupeni mining operation are located in the vicinity of the mining operation. Currently, Lupeni Mining no longer uses tailings dumps, they must enter the greening process.

Fig. 3 The location of the tailings dumps from the Lupeni Mining Exploitation

Tailings dumps negatively influence the environment in terms of surface and underground water quality, air quality, vegetation and the general aspect of the area and comfort.

Fig. 4 The tailings dump from the Lupeni Mining Exploitation

For the protection of the environmental factors in the areas affected by the presence of dumps, a series of measures must be taken, including:

a) Measures to prevent the pollution of underground and surface water with harmful substances.

b) Measures to avoid entrainment of the dumped material by running water.

c) Canceling the trenches and ensuring some slopes of the piling platforms would ensure a good management of surface waters.

d) Measures to avoid entrainment of dust particles by prevailing winds.

e) Ensuring a good stability of tailings dumps. [9] [10], [11]

After completing the processes regarding stability and environmental issues they can be found another destination.

The surfaces of tailings heaps can be reused for planting trees of different varieties that lend themselves to the soil conditions - a solution still used today (This solution also ensures an additional increase in the stability of tailings heaps by developing the root system of the trees). [12], [13], [14]

Due to the environment in which vines can grow, this can be another solution for reusing tailings dumps.

Also, their surface can be leveled, covered with a layer of topsoil and turned into a camping area, and the lake formed in the vicinity of the tailings dumps can be populated and turned into a fishing area. [15], [16]

Another solution for the reuse of tailings dumps can be their transformation into grazing areas for animals. [17]

The method to be chosen in order to reuse the land surfaces affected by the tailings dumps from the Lupeni Mine depends on the financial resources to be allocated in this regard., [18], [19]

2.2. Solutions for reusing the underground spaces of the Lupeni Mining Exploitation

The underground spaces resulting from the exploitation of coal at the Lupeni Mine represent an important problem from an environmental point of view. In the closing process, we must make sure that these spaces will not cause problems in the next period. [20]

Being a coal mine, where the presence of methane in the underground tunnels is a significant problem that can cause mine fires, these areas are not suitable for reuse of the remaining voids. It is necessary to close the access inside them with protective walls.

A solution for the reuse of these underground areas is to backfill them with ash from Thermal Power Plants (fireproof material). By using ash to fill underground voids, important areas of land that were to be converted into tailings ponds for slag and ash storage are protected.

Access areas in mining galleries and safe underground areas of mining can be turned into museums. Creating an underground museum to showcase the history of mining, the equipment used and the stories of the miners.

Areas can also be set up where guided tours can be organized to educate visitors about mining processes and their impact on the community and environment.

Safe zones can also be used to transform them into research and practice area in partnership with universities and research centers in the field. Here, underground practical and research laboratories for geological, ecological and technological research can be built.

3. Conclusions

The Lupeni Mining operation, like any mining operation, led to the change of destination and the damage of large areas of land.

After the completion of the mining process, the mining units must be closed or possibly found another destination.

Both surface areas, tailings dumps and underground areas must be subjected to the greening process

Tailings dumps can be turned into recreational, agricultural or pasture areas depending on the financial resources allocated over time and underground voids can be used as waste deposits from the mining and energy industries.

Access areas in mining galleries and safe underground areas of mining can be turned into museums.

Another possible solution for the reuse of a certain safe exploitation area is to transform them into research and practice laboratories in partnership with Universities and research centers in the field.

References

[1] **Arad V., Arad S., Samoilă L., Teseleanu G.,** 2019
The coal exploitation in the Jiu Valley between the strategic resource and social impact, Journal of Engineering Sciences and Innovation Volume 4, Issue 1 / 2019, pp. 99 – 114

[2] **Baron M., Dobre-Baron O.**, 2009
The emergence of the Jiu Valley coal basin (Romania) - a consequence of the industrial revolution, Annals of the University of Petroşani, Economics, 9(3), 2009, 53-80

[3] **Baron M., Dobre-Baron O**, 2015
The Concentration of the Capital in The Coal Mining Industry from Jiu Valley in The 30s of the Xx Century, Annals of the University of Petroşani, Economics, 15(1), 2015, 5-20

[4] **Fodor D.**, 2006
Influenţa industriei miniere asupra mediului, Buletinul AGIR nr. 3/2006, iulie-septembrie

[5] *Institutul Naţional de Cercetare Dezvoltare pentru Urbanism şi Amenajarea Teritoriului – URBANPROIECT Bucureşti, Plan de amenajare a teritoriului zonal Valea Jiului.*

[6] **Tataru D., Tataru A.C., Stanci A.**, 2018
Management of affected areas by the pollution of the slag and ash deposits, ICoM 2018 8th International Conference on Management "Leadership, Innovativeness and Entrepreneurship in a Sustainable Economy", Czestochowa University of Technology Faculty of Management, Czestochowa, Conference Proceedings, pg 620-624, 2018

[7] **Radu V.M., Vîjdea A.M., Ivanov A.A., Alexe V.E., Dincă G., Cetean V.M., Filiuță A.E.,** 2023
Research on the Closure and Remediation Processes of Mining Areas in Romania and Approaches to the Strategy for Heavy Metal Pollution Remediation, Sustainability 2023, 15(21), 15293; https://doi.org/10.3390/su152115293

[8] **Tataru D., Tataru A.C., Stanci A.**, 2017
Study on development of vine plant in slag and ash resulting from the burning of coal in thermal power plants, 17th International Multidisciplinary Scientific GeoConference SGEM 2017, www.sgem.org, SGEM2017 Conference Proceedings, ISBN 978-619-7408-09-6 / ISSN 1314-2704, Vol. 17, Issue 52, 875-882 pp, DOI: 10.5593/sgem2017/52/S20.112, 2017.

[9] **Tataru D., Tataru A.C., Stanci A.**, 2017
The use of herbaceous plants to stabilize tailing ponds of thermal power plants, International Multidisciplinary Scientific Conference, University of Miskolc, Hungary, ISBN 978-963-358-061-5

[10] **Vaverková M.D., Maxianová A., Winkler J., Adamcová D., Podlasek A.,** 2019
Environmental consequences and the role of illegal waste dumps and their impact on land degradation, Land Use Policy Volume 89, December 2019, 104234

[11] **Abdel-Shafy H.I., Mansour M.S.M.**, 2018
Solid waste issue: Sources, composition, disposal, recycling, and valorization, Egyptian Journal of Petroleum, Volume 27, Issue 4, December 2018, Pages 1275-1290

[12] **Kharbouche M, El Khalidi K., Aajjane A.**, 2024
Using Mine Tailings as a Soil Improver to Reduce Micronutrient Deficiencies in Wheat Crops, Western Morocco, Journal of Ecological Engineering 2024, 25(9), 44–59 https://doi.org/10.12911/22998993/190287 ISSN 2299–8993, License CC-BY 4.0

[13] **Pollmann O., Van Rensburg L., Lange C.A.**, 2009
Reforestation and landscaping on mine tailings – a step forward in mine closure, Conference: International Mine Water Conference, hosted and organized by Water Institute of Southern Africa's Mine Water Division together with the International Mine Water Association,

[14] **Pollmann O., Van Rensburg L., Lange C.**, 2009
Reforestation and landscaping on mine tailings – a step forward in mine closure, Abstracts of the International Mine Water Conference Proceedings ISBN Number: 978-0-9802623-5-3 Produced by: Document Transformation Technologies cc

[15] **ERM**. 2018.
Casino Mine Project: BAT Study for Tailings and Waste Rock Management. Prepared for Casino Mining Corporation by ERM Consultants Canada Ltd.: Vancouver, British Columbia.

[16] **Chernaik M.**, ELAW Staff Scientists, 2010
Guidebook for Evaluating Mining Project EIAs, ISBN# 978-0-9821214-36

[17] **Araujo F.S.M., Taborda-Llano I., Nunes E.B., Santos R.M.**, 2022
Recycling and Reuse of Mine Tailings: A Review of Advancements and Their Implications. Geosciences; 12(9):319. https://doi.org/10.3390/geosciences12090319

[18] **Tataru A.C., Stanci A.**, 2019
Research concerning the vegetation development on the ash and slag deposits of Thermal Power Plant Paroseni, Journal of Physics: Conf. Series 1297 (2019) 012016, Online ISSN: 1742-6596, doi:10.1088/1742-6596/1297/1/012016, https://iopscience.iop.org/article/10.1088/1742-6596/1297/1/012016/meta

[19] **Petrilean D.C.; Irimie S.I**., 2015
Solutions for the capitalisation of the energetic potential of sludge collected in Danutoni wastewater treatment plant, Journal of Environmental Protection and Ecology, Vol.16 No.3 pp.1203-1211

[20] **Georgescu M.**, 2012
Utilizarea spaţiilor subterane, Editura Universitas, Petroşani

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 129-140

SELECTION OF POST-QUARRYING LAND USES IN WESTERN MACEDONIA, GREECE, USING A HYBRID MULTI-CRITERIA METHOD

Chrisoula PAGOUNI[1], *Francis PAVLOUDAKIS*[2*],
Ioannis KAPAGERIDIS[3], *Evangelos KARLOPOULOS* [4]

[1,2,3] Mineral Resources Engineering Department, University of Western Macedonia, 50150, Kozani, Greece
[4] Chemical Processes & Energy Resources Institute, Centre for Research and Technology Hellas, 50200, Ptolemaida, Greece

DOI: 10.2478/minrv-2024-0050

Abstract: *The region of Western Macedonia is rich in mineral resources. Over the past decades, it has been primarily focused on lignite mining, while also maintaining smaller-scale extraction activities for olivine, attapulgite, talc, calcium carbonate, dolomite, gypsum, marble, slate, and aggregates, which hold significant economic value. This study recorded active public, private, and municipal quarries as well as inactive public and municipal quarries requiring rehabilitation. Furthermore, a methodology was developed and applied for screening three of the inactive municipal quarries and selecting the more suitable land use for each one. For this purpose, the authors assessed opportunities and risks at the regional level and identified strengths and weaknesses specific to each quarrying site carrying out a SWOT analysis. Criteria for selecting between alternative land uses were then determined. An expert panel including geologists, mineral resource specialists, environmental engineers, regional and municipal officials, legal experts, chamber of commerce representatives, and quarry company board members was convened to evaluate these criteria, with weights assigned using the Analytic Hierarchy Process (AHP). Attributes with spatial variation were mapped using GIS, and the final ranking of land uses for each quarry site was determined using a simple algorithm. The scope of this study was to contribute to the development of communities located close to quarries by supporting the selection of the optimum post-quarrying land uses.*
Keywords: *Land management, Rehabilitation, AHP, SWOT, MCDA, Stakeholders' participation*

1. Introduction

Greece has had a history of intense quarrying activity since ancient times. Marble quarries from various regions in Greece provided the raw material for creating elaborate artworks that adorned nearly all buildings, some of which are exhibited in museums worldwide. In modern times, in addition to marble, other quarrying minerals such as natural stones and industrial minerals are extracted in large quantities, serving as raw materials for various production industries. Specifically, these quarrying minerals are categorized into four types: marbles, other natural stones, aggregates, and industrial minerals, all of which are found in almost every region of Greece [1].

Western Macedonia is one of the regions where significant mining operations are established. Since the decade of 1960, the region has produced more than 1.7 billion tonnes of lignite that were supplied to thermal power plants with a total installed capacity of more than 4,300 MW. Other mining activities involve extraction, processing, and trade of industrial minerals, primarily oriented towards export, and aggregates, which are exclusively utilized within the region's boundaries. Concerning quarrying sites in Western Macedonia, these are classified as public, municipal, and private. The types of quarry minerals and rocks extracted in Western Macedonia and their uses are presented in Table 1 [2].

Regardless of their ownership status, all quarries impact the environment and local communities. To mitigate these impacts, specific measures must be taken during their operation, such as minimizing soil and water pollution, reducing disturbances (e.g., noise and vibrations from blasting), and managing hazardous waste. However, land rehabilitation after quarrying activities cease is also necessary. Beyond typical

* Corresponding author: Mineral Resources Engineering Department, University of Western Macedonia, 50150, Kozani, Greece, fpavloudakis@uowm.gr; Tel.: +30-24610-68255

reforestation efforts aimed at partial ecosystem restoration and landscape aesthetics improvement, there is a growing effort to develop new land uses that bolster the local economy, create jobs, and improve living conditions for adjacent communities. Towards this direction, this study seeks to introduce a new methodology for assessing and selecting land uses for multiple small-scale quarries located within a relatively confined geographic area.

Table 1. Categories and types of quarry minerals extracted in Western Macedonia

Categories	Rock types	Uses	Regional units
Marbles	Rocks of various colours, quarried in blocks, amenable to slab cutting, grinding, and polishing	Decoration of buildings, floors, sculptures, monuments, road construction, paving of sidewalks and squares	Kozani
Natural stones	Slate and limestone slabs, and ornamental rocks		
Aggregates	Rocks of various size distributions produced after crushing	Road construction, production of concrete and cement products (pipes, tiles, etc.)	Kozani, Grevena, Florina, Kastoria
Industrial minerals	Olivine	EBT filler, foundry, sandblasting, etc.	Grevena
	Olivine	Manufacture of medium to high-strength basic refractory materials	Kozani
	Attapulgite, other clay minerals	Pet hygiene products, soil improvers, etc.	Grevena
	Quartz	Glass objects and surfaces, sanitary ware, silicone & building materials, cables, etc.	Florina
	Quartz sand	Building & decorative applications, etc.	Kozani
	Huntite, Hydromagnesite	Polymers' filler, flame retarder, etc.	Kozani
	Dolomite, Calcite	Filler in the building, chemical and composite industries, etc.	Kozani

2. Legal framework of quarry land rehabilitation

The years 1986, 1990, 2011, and 2018 mark significant milestones in environmental legislation concerning mining and quarrying activities. Framework Law for the Environment 1650/1986 first introduced the goal of environmental reclamation. Ministerial Decision 69269/1990 was enacted to introduce specific measures for the implementation of the previous law. In this context, it established the requirement for environmental licensing concerning the exploitation of mineral resources. Law 4014/2011 permitted quarrying activities contingent upon following the environmental licensing process. Law 4030/2011 allowed the installation of excavation, construction, and demolition waste treatment plants in inactive quarries, regardless of ownership status. Law 4512/2018 mandated quarry operators to restore the sites they operate in, setting conditions and requirements for completing these procedures, such as the requirement of reforestation in cases of quarries located within areas characterized as forests [1, 3-6].

The Regulation on Mining and Quarrying Operations (RMQO) sets forth rules for rational activities and steps for the restoration of each quarry site. It specifies that the final form of restoration must harmonize with the broader environment. In public, municipal, or communal lands, provisions are made for meeting local needs and for special land uses, according to the Regional Government's and local authorities' written guidelines [7]. Additionally, mineral resource exploitation projects must comply with specific legislative frameworks that govern extractive activities.

In the study area, the Regional Framework for Spatial Planning and Sustainable Development of Western Macedonia, set priorities for the protection, preservation, and promotion of natural heritage and landscapes, while also ensuring the productive use and conservation of natural resources. Specifically for mineral resources, special priority will be given to comprehensive landscape restoration programs and the identification of alternative uses for exhausted mineral extraction sites, in a manner that considers the functions of the natural and human-made environment in their vicinity. Basic guidelines will be provided for the extraction zones located in various areas across all regional units. Restoration programs and alternative use plans for exhausted mineral extraction sites will be developed, taking into account the functions of both the natural and human-made environments in their nearby areas [8].

3. Current quarrying activities in the region of Western Macedonia

In the context of this study, records for public, municipal, and private quarries that are operating in the region of Western Macedonia were used. Moreover, for inactive (abandoned) public and municipal quarries that require ecological restoration and/or land rehabilitation data relevant to the location, acreage, and current stage of rehabilitation works was found. However, due to a lack of updates in the archives of the supervisory authorities, some quarries may have been omitted.

3.1. Public quarries in the region of Western Macedonia

Active public quarries

As indicated by the activity reports, idleness reports, and the surety bonds submitted to the Decentralized Administration of Epirus and Western Macedonia, Directorate of Technical Inspection, Natural Resources Office, the quarrying activities in Western Macedonia within the period 2018-2022 exhibited large fluctuations. This fact is indicative of the lack of investment interest due to the uncertain economic environment and the prolonged crisis of the construction sector for over a decade. Table 2 presents the evolution of the number of quarries operating in Western Macedonia from 2018 to 2022.

Table 2. Number of active quarries in Western Macedonia (2018-2022)

Category of products	2018*	2019*	2020**	2021*	2022**
Industrial minerals	17	13	8	14	8
Slate	7	5	2	4	2
Marble	7	5	4	8	3
Aggregates	8	7	6	8	6
Total	39	30	20	34	19

Source: *[3], **[9]

Although quarrying operations were dispersed across all regional units, Kozani exhibited the highest level of extraction activities in terms of the number of quarries and the variety of extracted quarry products. Specifically, olivine, quartz sand, marble, dolomite, and slate were produced in the regional unit of Kozani, quartz in the regional unit of Florina, and mixed bentonite clays in the regional units of Grevena and Kozani. The map of Figure 1 depicts the active public quarries by regional unit for the year 2021.

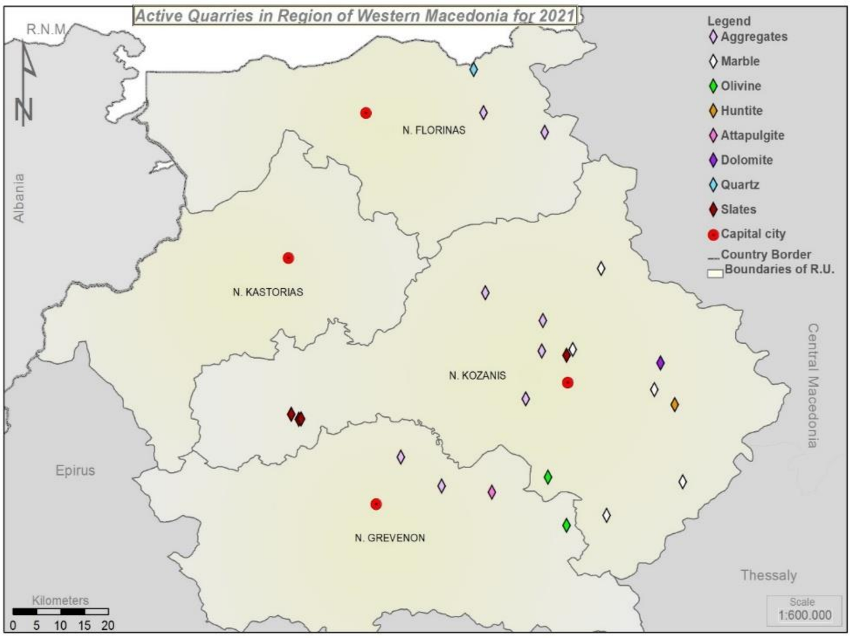


Fig. 1 Map of active public quarries in the four Regional Units of Western Macedonia Region (year 2021)

In the regional unit of Kozani, almost all categories of quarry products that exist in Western Macedonia are mined. The largest percentage is the exploitation of marbles by 35%, followed by mixed Bentonitic clays and aggregates, both with a percentage of 17%. Moreover, the Municipality of Kozani hosts the most quarries in the Regional Unit of Kozani. Specifically, in the Municipality of Kozani are located two quarries of mixed Bentonite clays, two of Olivine, two of Dolomite, three out of four of aggregates, one out of four of slate, and two out of eight of marble [9].

Abandoned and rehabilitated public quarries

According to the current records of the Decentralized Administration of Epirus and Western Macedonia, Directorate of Technical Inspection, Natural Resources Office, sixteen public quarries need ecological restoration and/or rehabilitation. These quarries are either abandoned or the operators have relinquished all administrative responsibility. Of these, twelve are located in the regional unit of Kozani and four in the regional unit of Grevena. Nine public quarries require restoration, while partial restoration has been performed at one quarry (the site has been backfilled), restoration is in progress at another quarry, and at five quarries there are no visible excavation works and the current condition has not been clearly described.

3.2. Private quarries in the region of Western Macedonia

Western Macedonia region hosts four active private quarries, one in each regional unit. Two are extracting aggregates and the other two are extracting industrial minerals.

3.3. Municipal quarries in the municipality of Kozani

As far as the municipal quarries are concerned, the following section refers to the quarries located within the boundaries of the Municipality of Kozani, where the present study is focused.

Active municipal quarries

According to the Department of Primary Sector of the Directorate of Local Economic Development of the Municipality of Kozani, ten active municipal quarries have been recorded. For 2021, the business entities in the Municipality of Kozani that submitted Activity and Inactivity Reports and mining activity occurred were twelve. Figure 4 shows the geographical distribution of business activity based on the submitted Activity and Inactivity Reports where mining takes place in the Municipality of Kozani [3].

Abandoned and rehabilitated municipal quarries

According to the Primary Sector Department of the Directorate of Local Economic Development of the Municipality of Kozani, at least seventeen inactive quarries with a total area of 345,866.77 sq. m. have been recorded on municipal land. In addition, a systematic inventory of the restored municipal quarries around the city of Kozani was carried out and it was found that the Municipality of Kozani has restored two of the quarries located at the boundary of the residential area. One of them has been configured as an open-air theatre, while the second is a transfer station and parking area for the waste collection trucks of the Municipality (ed. these are two different quarries in the same area). For all the other quarries, the restoration works that had been carried out before their closure were incomplete and did not comply with the legislation and the environmental permit [10]. Based on the above, it is necessary to implement projects for the rehabilitation of abandoned quarries, especially for the municipal unit of Kozani, where four quarries are located, corresponding to 62% of the quarry areas of the Municipality of Kozani, and the municipal unit of Ellispontos, where nine small-scale quarries with a total area of 118,322sq.m. are located.

4. Implementation of the land use selection methodology

Figure 2 shows a graphical representation of the land use selection process applied to this paper. The following paragraphs explain the individual steps of the process.

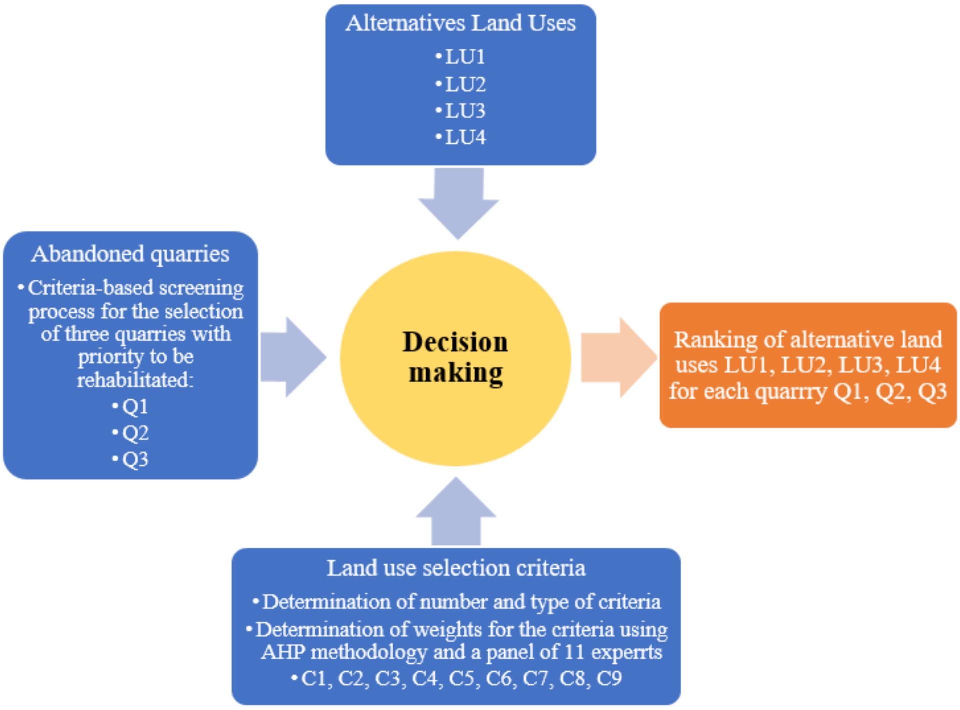


Fig. 2 Schematic description of the multi-criteria (C) decision-making procedure for post-quarrying (Q) land use (LU) selection

4.1. Screening the quarrying sites that require rehabilitation

To assess the efficacy and applicability of the proposed land use selection methodology for quarry sites, the authors assumed the role of a task force that coordinates and implements the entire process. Initially, the task force identified three quarries within the Municipality of Kozani, which require rehabilitation and will be used as case studies in the framework of this study (Figure 3). The selection criteria that guided the screening process for the inactive quarries are detailed in Table 3.

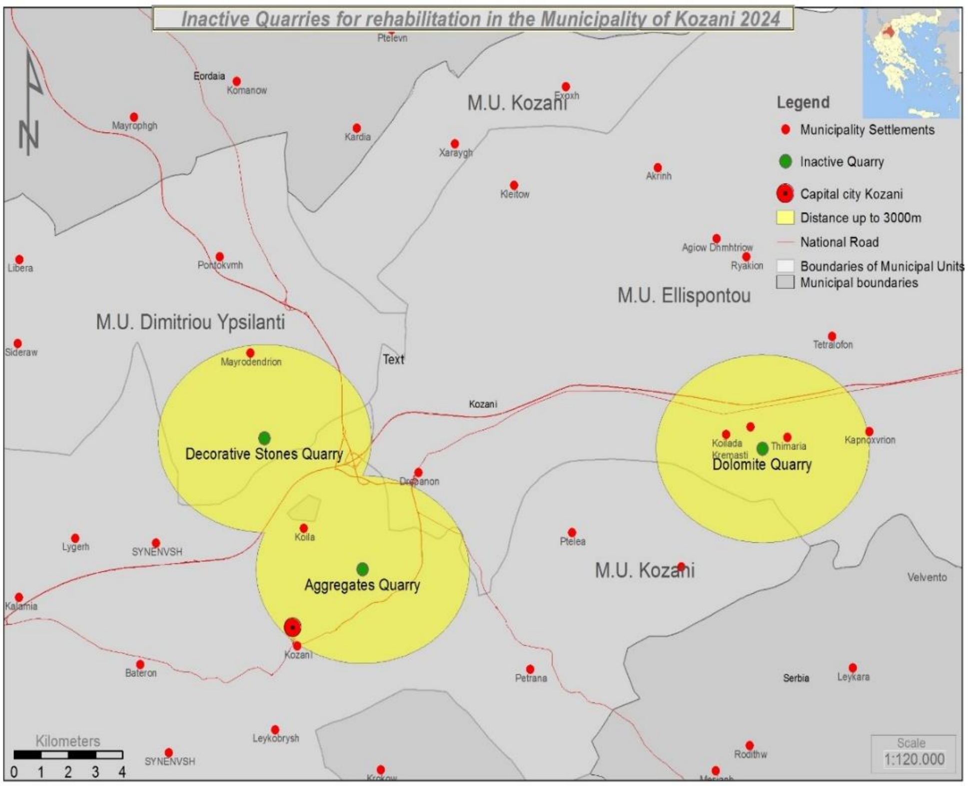


Fig. 3 Map of selected quarries produced using GIS: the buffer zones indicate the communities located at a distance of less than 3km from the quarries

Table 3. Screening criteria of inactive quarry sites that must be rehabilitated

Screening criteria	**Preferable values**
Quarry location	Municipality of Kozani
Product mined	Priorities: 1. Aggregates, 2. Natural stones, 3. Industrial minerals
Health risks	Illegal waste disposal
Accident risks	High slopes, landslides, no or destroyed fences, etc.
Visual impacts (aesthetics)	Quarry site and infrastructures visible from nearby communities and main roads
Environmental impacts	Disturbance of fauna and flora
Area occupied	>20.000 sq. m
Topography	Mountainous terrain that favors erosion and soil instability phenomena
Distance from communities	< 3,000m from the nearest building of a city or village
Proximity to other economic activities	Preferable values depend on the type of activity and the synergetic or antagonistic effects concerning the planned land uses
Distance from public utility networks	Short distance
Access	Easy access to the quarry site

The three quarries selected are briefly presented below.

Case study 1: The ‘Koiniarika’ aggregates quarry (figure 4) today is located very close to the city of Kozani, at the boundary of the urban plan, and occupies an area of 143,181.33 sq. m [11]. However, when it began to operate, fifty years ago, it was located at least two kilometres from the nearest limit of the city. During its operation, it supplied the regional units of Kozani and Grevena with aggregates.

Case study 2: The quarry is located within the land area of the local community of Mavrodendri, in the municipal unit of Demetrios Ypsilantis (figure 5), and started its operation in the 1960s. Natural decorative stones and serpentines were mined, which were used in the manufacture of mosaics, as well as in other decorative applications due to their intense green cypress color. After the abandonment of this quarry, a deep hole remained in the mining area, which was filled with rainwater over time, creating a lake that exists until today. The quarry occupies a total area of 45,702.70 sq. m [11].

Case study 3: The Dolomite quarry is located near the local community of Kilada in the municipal unit of Hellespontos (figure 6). The area had an inflow of foreign exchange from exports of this material. The quarry occupies a total area of 27,538.72 sq. m [11].

Fig. 4 Inactive quarry of aggregates near the city of Kozani (case study 1)

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 129-140

Fig. 5 Inactive quarry of natural stones near the village of Mavrodendri (case study 2)

Fig. 6 Inactive quarry of dolomite near the village of Kilada (case study 3)

4.2. SWOT analysis

The opportunities and risks at the regional level and the strengths and weaknesses, separately for each one of the three quarrying sites under investigation, were identified and assessed carrying out a SWOT analysis. For this purpose, all the environmental, economic, and social components that affect the quality of life of local communities were investigated. Table 4 presents the main parameters that shape the internal and external environment of the land rehabilitation projects of the inactive quarries under investigation.

4.3. Determination of the land use selection criteria

This stage of the study includes the elaboration of a methodology for selecting the optimal land use based on society, economy, employment, natural environment, quality of life, and priorities and potential of the area by applying multicriteria analysis. The main criteria involved in the land use choice were determined based on a literature review conducted by the authors and are summarised in Table 5 [12-18].

4.4. Determination of the selection criteria weights

To determine the weights of the selection criteria, a panel of eleven experts was assembled, including a mineral resources engineer, an environmental engineer, a land planner, a legal expert, a Director of the regional development company, a representative of an environmental NGO, two officials from the regional authority of Western Macedonia and the Municipality of Kozani, two representatives from the technical and economic chambers, and a member of the board of directors of a quarrying company. Using the Analytical Hierarchy Process (AHP), the experts carried out pairwise comparisons of the selection criteria. For this purpose, a Microsoft Excel-based program developed by Klaus D Goepel was used [19-20]. The methodology prioritized the nine criteria comparing each one against the others. Each criterion's relative importance over another was rated on a scale from 1 to 9. The results of this procedure are summarized in Table 6.

According to these results, the criteria of environment, governance, and economy were assigned the highest weights, indicating that environmental protection, national and governmental policies, legislation, and cost of rehabilitation significantly influence the choice of post-quarrying land uses. The weights of these three criteria were about 50% higher than the weights of four other criteria that are following, namely geoethics, regional development, quarry site characteristics, and technical aspects. This fact highlights that the restoration of the ecosystem and the employment opportunities that can be created, both during the rehabilitation phase and afterward, are highly significant and greatly influence land use choices. Moreover, the experts did not ignore the role of technical aspects and limitations arising from site-specific characteristics in the final choice of feasible and self-sustained land use. The quarry's distance from settlements, roads, utility networks, and neighbouring economic activities, the potential for new business creation, the possibility of reusing quarry facilities (buildings, infrastructure, etc.), the orientation of the quarry, the physical properties of the quarry's components, and the morphology of the terrain greatly shape the opinions of authorities, experts, and citizens regarding quarry rehabilitation.

4.5. Land use selection

The alternative land uses proposed by the task force are the following:

- *Reforestation (RF).* The legislation mandates the reforestation of quarries operated within a forested area [5]. In general, reforestation is considered by the extractive industry and the supervisory authorities as a land use that can be successfully developed in mining and quarries with low to moderate cost.
- *Recreational activities (RA).* Quarries located close to settlements that lack open spaces, and the few available within their plans for similar activities are intended for residential purposes due to their high economic value. Additionally, quarries that cover a large area and are close to roads ensure unobstructed user access. Furthermore, existing utility infrastructure reduces the cost of construction and connection to these networks.

Table 4. Results of SWOT analysis

	Strengths	**Weaknesses**
Internal environment	**Aggregates quarry** • Large area, suitable for uses that require many acres of land • Non-visible from nearby communities • Non visible from roads • Easy access • Short distance from main roads • Proximity to utility networks	**Aggregates quarry** • High slopes • Steep slopes of quarry benches • Illegal waste disposal • Disturbance of fauna and flora • Short distance from the city
	Natural stone quarry • Proximity to future industrial area • Proximity to airplane models' runway • Non-visible from nearby communities • Non visible from roads • Easy access	**Natural stone quarry** • Insufficient area for various uses • Active quarry in the same area • Steep slopes of quarry benches
	Dolomite quarry • Moderate area occupied • Easy access • Short distance from main roads • Proximity to utility networks	**Dolomite quarry** • Visible from nearby communities • Visible from main roads • Illegal waste disposal • Mountainous terrain • Proximity to many small communities • Disturbance of fauna and flora • Steep slopes of quarry benches

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 129-140

External environment	Opportunities	Threats
	• Legal framework • Land planning • Financial support available • Social demand for the rehabilitation of inactive quarries • Interest already expressed by private enterprises • Numerous successful stories known all over the World • Numerous studies have already been conducted • Subject within the scope of the University of Western Macedonia	• High rehabilitation cost • Land use conflicts • Delays in decision-making • Fear of political costs • Bureaucracy • Lack of consultation between interested parties.

Table 5. Land use selection criteria and attributes

Criteria	Attributes measured or considered
Economy	Cost of land rehabilitation and new land use development
Society	The welfare of local communities
Culture	Traditions Aesthetic values
Environment	Soil, water, and air quality
Technical aspects	Distance to residential areas, roads, public utilities, etc.
Mine site characteristics	Surface topography
Governance	Legal and regulatory framework
Regional development	New economic activities Employment Promotion of regional climate change policies
Geoethics	Ecosystem conservation

Table 6. Results of the pairwise comparison of the nine selection criteria and criteria weights

Criteria		**Economy** 1	**Society** 2	**Culture** 3	**Environment** 4	**Technical Aspects** 5	**Mine Site Characteristics** 6	**Governance** 7	**Regional Development** 8	**Geoethics** 9	**Weights**	**+/-**
Economy	1	1	2	2 5/9	7/8	1 1/4	1 4/9	1	1 4/9	1 1/3	14.22%	1,3%
Society	2	1/2	1	1 4/5	1/2	5/7	4/5	5/9	2/3	6/7	7.90%	0,8%
Culture	3	2/5	5/9	1	1/2	4/9	2/5	1/3	4/9	2/5	4.96%	1,1%
Environment	4	1 1/7	2 1/7	2	1	2	1 3/7	1 1/8	1 1/2	1 1/2	15.71%	2,5%
Technical Aspects	5	4/5	1 3/7	2 1/4	1/2	1	1 1/8	1/2	7/8	1	10.00%	1,4%
Mine Site Characteristics	6	2/3	1 1/4	2 1/2	5/7	8/9	1	1/2	4/5	1 2/9	10.13%	1,8%
Governance	7	1	1 4/5	3 1/6	8/9	2	2	1	1 1/2	1 1/7	15.47%	2,6%
Regional Development	8	2/3	1 1/2	2 2/9	2/3	1 1/7	1 1/4	2/3	1	3/4	10.66%	1,2%
Geoethics	9	3/4	1 1/6	2 1/2	2/3	1	5/6	7/8	1 1/3	1	10.96%	1,9%

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 129-140

Construction & Demolition Waste (C&DW) Processing Unit. According to legislation, the installation of these units is permitted in inactive quarries to restore the natural landscape and environment, regardless of their ownership status.

High-disturbance production facilities (HD). Plants of renewable energy sources, with or without energy storage facilities, industrial facilities, professional workshops, craft facilities, transport terminals, offices, research centres, and business incubators are paradigms of installations allowed in sites characterized as high-disturbance production facilities [21].

For each of the three abandoned quarry areas, the above-described alternative land uses were given a score against the nine selection criteria (Table 7) and were ranked (Table 8) based on a final score calculated using the following formula:

$$S_n = \sum_{c=1}^{9} W_c S n_c \qquad (1)$$

where W, the weights, Sn, the score of each criterion (0< <10), c, the criteria, and n, the land uses.

Based on the ranking of the alternative land uses for each one of the examined inactive quarries, the following comments are noticed: In Quarry No. 1, located near the city of Kozani, the possibility of hosting high-disturbance production facilities (HD) has a slight lead over the construction of recreational facilities or a construction, demolition, and excavations waste treatment and/or disposal unit. The proximity of the quarry site to the urban fabric creates the conditions to be utilized in various ways, taking into account the lack of plots of this acreage in the greater area and the cost of land purchase or rent. In Quarry No. 2, the development of recreational activities is a top priority because of the existing lake of the final pit, which has already attracted the interest of local cultural and environmental organizations. The scores of the three alternative land uses are less than half of the one given to recreational activities. Finally, regarding Quarry No. 3, it is also clear that reforestation is by far the most suitable land use. The mountain area, where the quarry is located, was forested long before the dolomite extraction. According to the legal framework in force, reforestation is the main option for restoring the ecosystem functions and reducing the visual impacts, which are high because of the close distance of the quarry from three communities and a national road.

Table 7. The scores of the alternative land uses for each one of the selection criteria

		Quarry 1 (Kozani)				**Quarry 2 (Mavrodendri)**				**Quarry 3 (Kilada)**			
Land Uses / Criteria	*Weights*	**RF**	**RA**	**C&DW**	**HD**	**RF**	**RA**	**C&DW**	**HD**	**RF**	**RA**	**C&DW**	**HD**
Economy	*14.22*	5	6	6	6	1	6	5	6	9	6	2	3
Society	*7.90*	2	5	5	7	1	3	1	1	9	5	2	2
Culture	*4.96*	4	6	5	8	4	6	1	1	9	4	2	2
Environment	*15.71*	2	7	8	5	3	5	1	2	9	1	3	1
Technical Aspects	*10.00*	1	6	5	9	1	6	4	3	9	1	1	1
Mine Site Characteristics	*10.13*	1	9	5	8	1	9	4	1	9	1	1	1
Governance	*15.47*	6	6	6	7	2	9	1	1	9	9	9	9
Regional Development	*10.66*	7	7	7	7	7	7	7	7	7	7	7	7
Geoethics	*10.96*	1	9	5	8	1	3	2	1	9	1	1	1
Final scores	*100*	3.4	6.8	6.0	**7.0**	2.3	**6.2**	2.9	2.7	**8.8**	4.0	3.5	3.3

Table 8. Ranking of alternative land uses based on their suitability for rehabilitating the three quarries under investigation

Quarry / **Land Uses**	**Quarry 1 (Kozani)**		**Quarry 2 (Mavrodendri)**		**Quarry 3 (Kilada)**	
	Total	**Rank**	**Total**	**Rank**	**Total**	**Rank**
Reforestation (RF)	3.4	4	2.3	4	8.8	1
Recreational activities (RA)	6.8	2	6.2	1	4.0	2
Construction & Demolition Excavation Waste Unit (C&DW)	6.0	3	2.9	2	3.5	3
High-disturbance production facilities (HD)	7.0	1	2.7	3	3.3	4

5. Discussion and conclusions

The rehabilitation of lands following the cessation of operations in surface mines and quarries has been a point of contention between mining companies and local communities for many decades. Today, legal and regulatory frameworks bind mining companies to carry out restoration projects, while the best available techniques known to industrial partners, consultants, and the scientific community facilitate the design of optimal interventions.

The digital and energy transitions are causing upheavals in traditional sectors of the economy that affect regional development. This is particularly true in regions such as Western Macedonia, with a long history of large-scale mining operations and a strong dependence on the primary sector, in general. In this framework, the choices regarding mining and quarry land rehabilitation methods and the selection of new land uses must go beyond the restoration of ecological functions, creating new economic activities and employment.

In areas where numerous inactive quarries exist, the regional authorities are called upon to decide on the future utilization of these abandoned sites, especially if the quarry operators have relinquished any jurisdiction. For these cases, the present study proposes a methodology applicable for simultaneously selecting land uses across multiple abandoned quarries located within the same geographic unit. This methodology was tested in the Municipality of Kozani, the capital of the Western Macedonia Region, Greece.

The methodology started with a screening procedure based on 9 criteria, in order to select the quarries to be rehabilitated as a priority. This first phase is necessary, since the available financial resources may not be sufficient for the simultaneous rehabilitation of all 17 inactive quarries of the Municipality of Kozani.

The selection process for optimal land use per quarry area, which followed, was characterized by the following:

- It relied on SWOT analysis and AHP methods, proven in multiple cases to be straightforward, effective, and reliable in application.
- It allowed stakeholders to express their opinions through a process of determining weights on land use selection criteria.
- It maintained complete control over the entire process through a task force composed of the authors of this study, thus avoiding delays and conflicts among stakeholders.
- It produced results that were clear and understandable to decision-makers, both in the form of ratings on a 0-10 scale and in the creation of a ranking of alternative land uses based on their suitability for each quarry area.

Based on the above, the proposed methodology for selecting land uses is considered capable of contributing to regional development by choosing sustainable solutions that enhance social cohesion and prosperity.

References

[1] *N. 4512. Law for Exploration and Exploitation of Quarry minerals and other Provisions.* Greek Government Gazette A’5/17-1-2018 2018 p. 28–66.

[2] **Pagouni C, Pavloudakis F, Karlopoulos E, Roumpos C.**, 2023
Leveraging Regional Mining Activities for Sustainable and Just Energy Transition and Decarbonisation

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 129-140

[3] *http://www.latomet.gr/ypan/StaticPage1.aspx?pagenb=16515. (accessed on 08May2024).*

[4] *N. 4014. Law Environmental licensing of projects and activities. Greek Government Gazette A'4014/21-09-2011 2011.*

[5] *N.4030. New way of issuing building permits, construction inspection and other provisions. Greek Government Gazette A΄249/25.11.2011 2011.*

[6] *Greek Government Gazette 69269/1990. Classification of projects and activities into categories, content of Environmental Impact Study, determination of content of special environmental studies and other related provisions according to Law 1650/1986. 1990.*

[7] *KMLE. National Regulation of Mining and Quarries Works. Greek Government Gazette 122714/06/11, YA2223, 2011 p. 213.*

[8] *MoEE. Regional Spatial Framework of Western Macedonia. Greek Government Gazette Δ'398/2024 2024.*

[9] *Directorate of Technical Control Natural Resources Office. Update on quarrying activity in the Western Macedonia Region. 2024.*

[10] *Quality of Life Committee. Opinion on the rehabilitation or non-rehabilitation of the inactive municipal quarries of the municipality of Kozani. Municipality of Kozani; 2022.*

[11] *Hellenic Cadastre [Internet]. [cited 2024 Jun 22]. Available from: https://www.ktimatologio.gr/*

[12] **Bennett, Fourie AB, Tibbett M.**, 2016
Abandoned mines — environmental, social and economic challenges [Internet]. Australian Centre for Geomechanics; 2016 Mar [cited 2024 Mar 28] p. 241–52. Available from: https://papers.acg.uwa.edu.au/p/1608_16_Bennett/

[13] **Verchagina I, Kolechkina I, Shustova E.**, 2020
The Experience of Legal Regulation of Reclamation of the Developed Space by the Leading Countries of Coal Mining. E3S Web Conf. 2020;174:02012.

[14] **Amaro SL, Barbosa S, Ammerer G, Bruno A, Guimerà J, Orfanoudakis I, et al.**, 2022
Multi-Criteria Decision Analysis for Evaluating Transitional and Post-Mining Options—An Innovative Perspective from the EIT ReviRIS Project. Sustainability. 2022 Jan;14(4):2292.

[15] **Worden S, Svobodova K, Côte C, Bolz P.**, 2024
Regional post-mining land use assessment: An interdisciplinary and multi-stakeholder approach. Resour Policy. 2024 Feb 1;89:104680.

[16] **Akbari A, Osanloo M, Hamidian H.**, 2006
Selecting post mining land use through analytical hierarchy processing method: case study in Sungun copper open pit mine of Iran. In 2006. p. 252.

[17] **Soltanmohammadi H, M O, B R, Aghajani Bazzazi A.**, 2008
Achieving to some outranking relationships between post mining land uses through mined land suitability analysis. Int J Environ Sci Technol. 2008 Sep 1;5.

[18] **Lazăr M, Faur FG, Dunca E, Ciolea DI.**, 2017
New methodology for establishing the optimal reuse alternative of degraded lands. Environ Eng Manag J EEMJ [Internet]. 2017 [cited 2024 Aug 25];16(6). Available from: https://www.researchgate.net/profile/Maria-Lazar-5/publication/319454791_New_methodology_for_establishing_the_optimal_reuse_alternative_of_degraded_lands/links/59abe86aaca272f8a1585989/New-methodology-for-establishing-the-optimal-reuse-alternative-of-degraded-lands.pdf

[19] **Goepel KD**, 2018
Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS). Int J Anal Hierarchy Process [Internet]. 2018 Dec 6 [cited 2024 Jun 30]; 10(3). Available from: https://ijahp.org/index.php/IJAHP/article/view/590

[20] **Goepel K.**, 2018
BPMSG – Business Performance Management Singapore [Internet]. 2018 [cited 2024 Jun 30]. Available from: https://bpmsg.com/

[21] *PD 59/2018. Land use categories and content. Greek Government Gazette A'114 /29-06-2018 2018.*

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 141-151

PROPOSAL FOR A QUICK METHOD FOR CHOOSING PLANT SPECIES TO ACCELERATE PEDOGENESIS ON WASTE DUMPS

Izabela-Maria APOSTU[1], Maria LAZAR[2], Eugen TRAISTĂ[3], Florin FAUR[4]*

[1]University of Petrosani, Petroșani, Romania, izabelaapostu@upet.ro
[2] University of Petrosani, Petroșani, Romania, marialazar@upet.ro
[3]University of Petrosani, Petroșani, Romania, eugentraista@upet.ro
[4]University of Petrosani, Petroșani, Romania, florinfaur@upet.ro

DOI: 10.2478/minrv-2024-0051

Abstract: *Mining is one of the activities that require large areas of land for the storage of sterile rocks resulting from the extraction of useful mineral substances. Waste dumps are wide-spread, are unpleasant components of the landscape causing a negative visual impact, the modification of ecosystems and their functions, environmental pollution (depending on their content, it can result atmospheric pollution by entrainment of dust particles and powders by winds, generation of acid waters, land and soil pollution with trace elements, etc.), and may present risks for the objectives in the area as a result of the sliding potential. The waste dumps consisting of inert rocks like sands, clays, and dust in different mixtures, which present various degrees of aeration and permeability and which lack the fertility given by organic matter, need proper interventions and works to support the development of more valuable plants and to reintegrate them into the natural landscape. The research presented in this paper aims to identify the necessary steps in order to accelerate the pedogenesis process on mining dumps and, as a result, a logical scheme type method was developed that could be easily applied to any type of mining dump. Also, the logical scheme was applied and verified through an experimental study carried out at the level of the interior dump of North Pesteana open-pit from Rovinari mining basin, Romania.*

Keywords: *Anthropogenic soils, dumps, fertility, plants, protosols*

1. Introduction

The soil is formed under special conditions at the interaction between the atmosphere, lithosphere, hydrosphere and biosphere, but the actions/events carried out within the anthroposphere, which cannot be prevented or removed, cause major changes at the soil level, both qualitatively and quantitatively, which is a real environmental problem.

On mining affected lands, the remaining lithological materials (sands, clays, dusts, marls) lack fertility, that property that defines an evolved soil capable of supporting the development of vegetation. These materials constitute anthropogenic protosols, undeveloped soils in terms of the physical, chemical, biological and pedological properties that define them [1].

On anthropogenic soils (anthropogenic protosols) in the early phase of their formation as fertile soil, in order to support the growth and development of vegetation, it is necessary to apply some amendments (chemical fertilizers, compost, sludge from water treatment plants, manure, wood waste, etc.) [2, 3, 4].

In the case of waste dumps that do not contain harmful or toxic elements and that present appropriate characteristics and structure or whose conditions can be improved, the constituent rocks represent the necessary inorganic base. Although in low and variable proportion, depending on the type of rocks, reaching or even exceeding 10%, organic matter plays an essential role in the functions of a healthy soil and has positive effects on the physical, chemical and biological characteristics of the soil [5, 6, 7, 8, 9, 10].

* Corresponding author: Apostu Izabela-Maria, Lect.dr.eng., University of Petrosani, Petrosani, Romania (University of Petrosani, University Street no. 20, izabelaapostu@upet.ro)

Similar to lands affected by mining activities or natural phenomena, partially or totally destroyed soils can be restored, rehabilitated (recovered) or regenerated. Restoration refers to returning soil at least to its original conditions (or even improving the soil to a superior class of fertility), while rehabilitation is the process that initiates or accelerates recovery from its historical trajectory, and regeneration refers to the total replacement of original conditions. Restoration and regeneration represent long-term, expensive activities that face major challenges, such as: extensive areas with a wide variety of land and soil uses, achieving a fair balance between biodiversity conservation and improving the well-being of the population, etc. Rehabilitation focuses on historical or pre-existing conditions, only as models or references [11, 12].

Regardless of the option, it is desired to ensure the health, integrity and sustainability of resources and ecosystems, and concerns in solving these types of problems are numerous. Depending the country and some specific conditions (regarding the types of rocks in sterile dumps, local climatic conditions, and other ecological futures) the literature presents diverse case studies with more or less original solutions [13, 14, 15, 16, 17, 18].

Generally, the optimal solution is to support the recovery of the soil. This type of intervention allows the use of local resources it is an economic advantage with positive effects for the neighbouring communities.

In Romania, the use, improvement, conservation, and protection of the soil is the responsibility of persons who own the lands and constructions of any nature, including mining perimeters. Law 246/2020 regarding the use, conservation, and protection of soil [19] must be respected and applied. The experimental study, presented in the paper, was carried out in accordance with the limitations imposed by the legislation in force and the specialized studies elaborated by the Research Institute for Pedology and Agrochemistry (ICPA) or by the Offices of Pedological and Agrochemical Studies (OSPA) [20, 21].

2. Important stages in pedogenesis process

The main characteristics of the dumped rocks, which affect productivity, are the following: excessive texture (too sandy or too clayey), excessive parent material content, low humus content, low nitrogen, potassium, phosphorus, micronutrients, air-water regime deficient, reduced biological activity. Revegetation projects play a significant role in improving soil quality and mitigating the negative effects of mining activities on land and soil as they could accelerate natural soil recovery processes on waste dumps and increase the biological diversity of these degraded lands [22, 23, 24, 25].

The main aspects in pedogenesis process were followed in order to develop a logical scheme for accelerating pedogenesis on sterile dumps. This is a method that seeks to synthesize the steps to be taken, highlight and consider potential influencing factors in order to achieve the desired results.

The advantages of logical schemes are that they are simple, clear, easy to understand, summarize the stages of solving a problem, and ensure quick visualization of actions. A logical scheme represents the totality of operations needed to solve a problem in an orderly way. An algorithm can be used in any field, but it is mostly used in mathematics and computer science.

The theoretical stages of developing a logical scheme consist of studying, formulating, and analyzing the problem, structuring it in standardized forms, and programming (coding in a programming language). After the development follows the verification and elimination of possible errors, the improvement of the program, the creation of the instructions for use, and the actual use of the program in practice [17, 26].

Several stages were taken into account in the development of the logical scheme [5, 6, 7, 8, 9, 10, 27, 28, 29, 30]:

I – ensuring a base of uncontaminated inorganic matter;
II – providing organic matter and the necessary nutrients;
III – creating the right conditions for aeration (porosity);
IV – creating the right moisture conditions;
V – choice of species;
VI – identifying and writing the optimal recipe and species.

Within the proposed scheme, sequential, alternative, and repetitive structures are found and decision and procedural blocks predominate. Alternative and repetitive structures are based on a condition imposed by the decision block. The procedures are applied according to the decision (starting from the imposed condition), and the conditions are represented by several key questions whose answers must be satisfactory to fulfill the process of accelerating pedogenesis on sterile dumps.

3. The proposed method for accelerating pedogenesis on anthropogenic soils

To simplify the presentation of the scheme, the decision blocks were numbered from 1 to 8, each block being assigned a key question:

1. Does it contain toxic, dangerous substances?
2. Does it contain at least 5% organic matter?
3. What is the nutrient content (macro and micronutrients)? The step is applied first for macronutrients until the content is established as being optimal, then repeated for micronutrients.
4. Optimal micronutrient content? If not, the cycle of checking nutrient content/level is repeated until the micronutrient content is also optimal.
5. Does the material have a suitable porosity for most crops (30 – 60 %)?
6. Does the material have a suitable moisture for most crops (35 – 75 %)?
7. Does the chosen species yield (> 75%)?
8. Is the dry matter content satisfactory (> 25%)?

The elaborated logical scheme is presented in stages in Figures 1 – 6.

The first step is represented by the choice of the objective, namely the sterile dump on which the intervention is desired to accelerate the pedogenesis process. The logical scheme can be applied to any sterile dump for which the physical stability conditions have been ensured.

Figure 1 shows the scheme for ensuring the base of uncontaminated inorganic matter. The presence and content of toxic, dangerous substances must be checked. If the material does not contain such substances, so it is uncontaminated, you can proceed to the next step. Otherwise, it is necessary to develop the decontamination procedure that can be carried out by [28, 29]:

- phytoremediation – a method that involves the use of plants to extract and eliminate pollutants from the soil or sterile dumps by absorbing them through the roots;
- chemical methods – involve the use of chemical treatments to carry out reduction and oxidation reactions.

After decontaminating the sterile material, we can proceed to the next step.

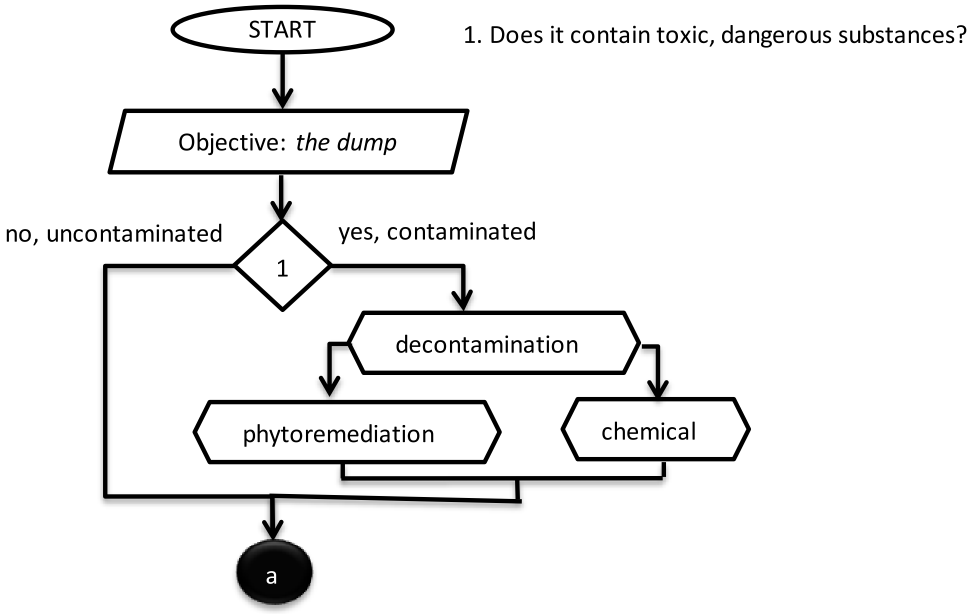


Fig. 1. Scheme for ensuring the base of uncontaminated inorganic matter

Figure 2 shows the scheme for providing organic matter and the necessary nutrients. Identifying and verifying the content in organic matter, macronutrients, and micronutrients is required. Organic matter has multiple and important roles, its absence negatively influencing the physical, chemical, and biological characteristics of the soil. Nutrients support the healthy growth of plants, and their lack is not desired as it raises development problems.

One of the important roles that organic matter has is that of supporting the nutrient cycle and mobilizing nutrients for their efficient use by plants.

Depending on the type of soil, organic matter is found in variable amounts. In the experiments carried out, it was chosen to impose a content of at least 5 % organic matter, the logic scheme being designed according to this value, but it can be modified, as necessary.

If the sterile material contains at least 5 % organic matter, we can proceed to the next step. Otherwise, the organic matter enrichment procedure is applied until the imposed condition is met using one or more of the following methods: crop rotation, use of perennial crops, year-round ground cover, incorporation of unharvested plant residues into the soil (organic waste), the use of compost, organic fertilizers, and, if necessary, bio coal to supplement soil carbon, animal husbandry and grazing (but avoiding overgrazing) are methods that balance the level of soil organic matter or even artificial organic fertilizers (not wanted, but sometimes necessary) [5, 6, 7, 8, 27, 30].

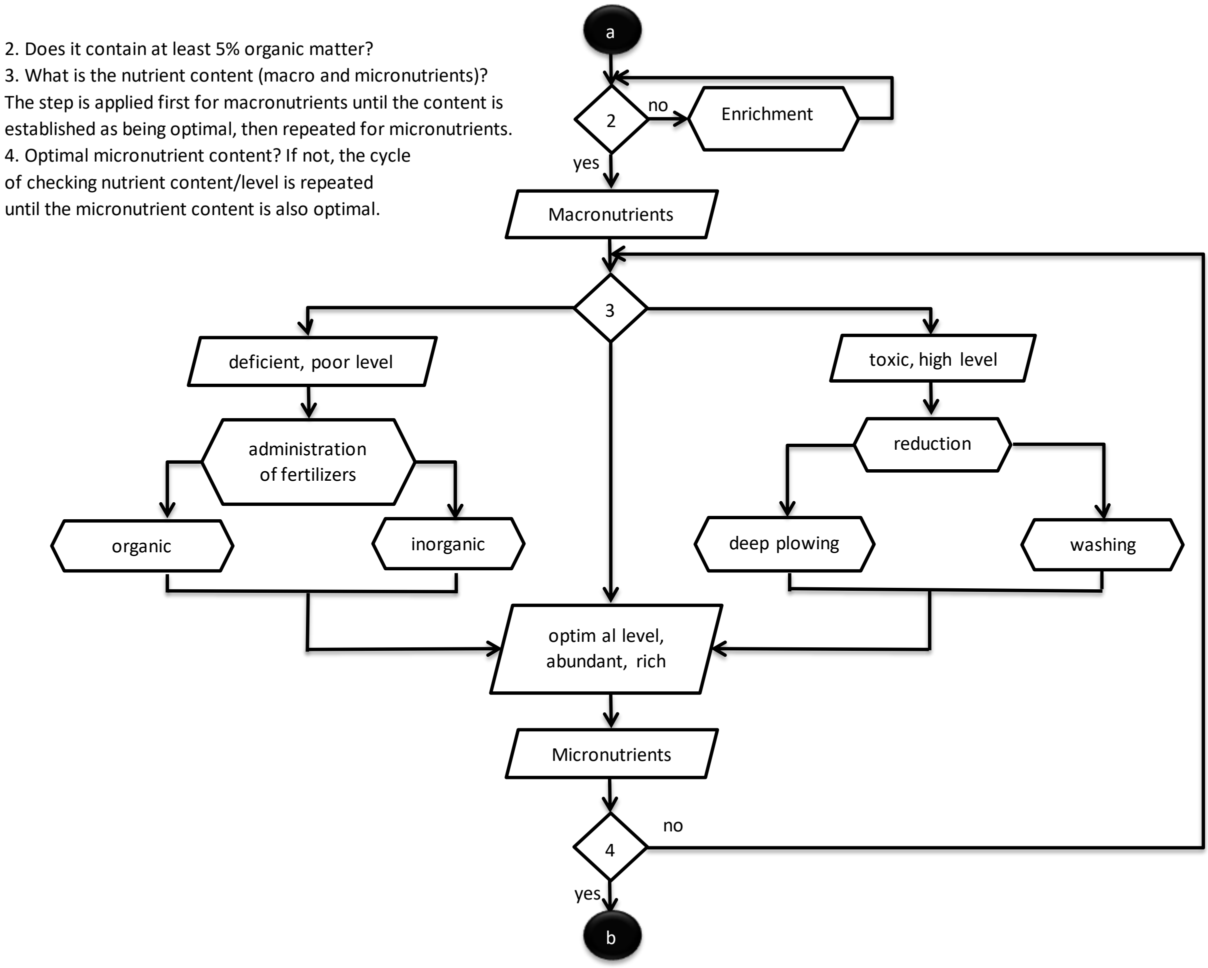


Fig. 2. Scheme for providing the necessary organic matter and nutrients

The next condition imposed is that the material contains nutrients in optimal amounts. If the nutrient level is optimal we can proceed to the next step. Otherwise, if the level of nutrients is deficient, the administration of organic or inorganic fertilizers is required. If the level of nutrients is high and toxic, it is required to reduce them through procedures such as deep plowing or washing. The step is applied first for macronutrients until the content is optimal, then it is repeated for the micronutrients until their content is also optimal.

Figure 3 shows the scheme for creating the right aeration (porosity) conditions. Although some plants also grow in soils with higher or lower loosening degrees, most crops prefer medium loosening conditions. A porosity between 30 – 60 % ensures the proper fixation and development of the roots in the soil and influences the permeability ensuring good water drainage.

As long as this condition is satisfied (porosity between 30 and 60 %), it is possible to proceed to the next stage. Otherwise, if the porosity is less than 30 %, intervention on the material is required through loosening procedures, and if the porosity is greater than 60 %, intervention on the material is required through compaction procedures, until the imposed condition is satisfied.

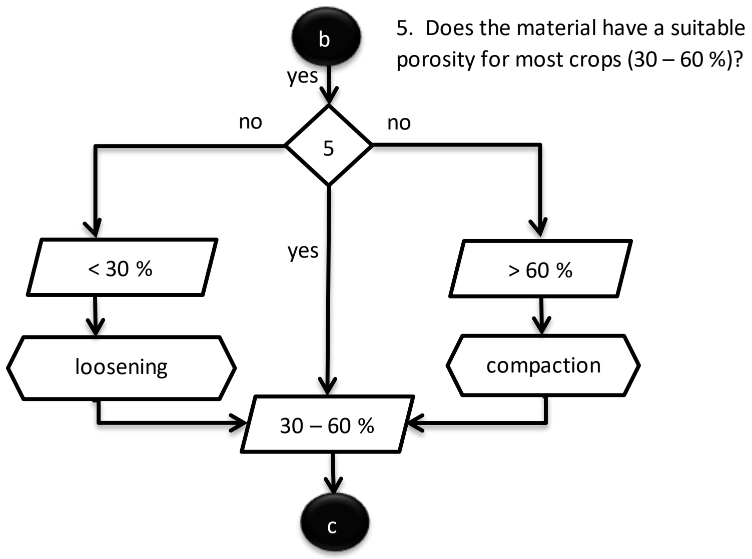


Fig. 3. Scheme for creating suitable aeration conditions (porosity)

Figure 4 shows the scheme for creating the optimal moisture conditions. In low moisture to dry conditions (< 35 %) or high moisture to saturated conditions (> 75 %), experienced for long term (days, weeks, or even longer), plants can be affected to death by drying or rotting. Depending on the type of plant and especially the stage of development, the effects of substrate moisture may appear sooner or later.

As long as the moisture condition is satisfied (35 – 75 %), we can proceed to the next stage. Otherwise, if the moisture is lower than 35 %, intervention through irrigation procedures is required, and if the moisture is higher than 75 %, intervention through drainage procedures is required, until the imposed condition is satisfied.

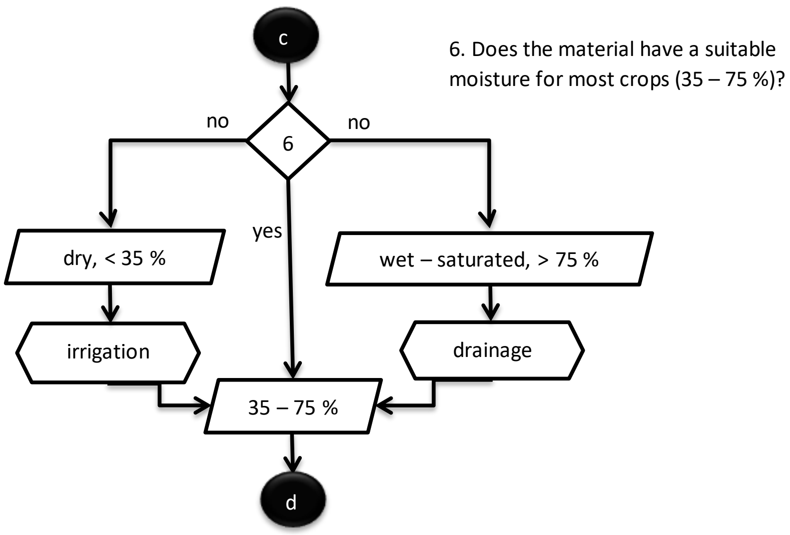


Fig. 4. Scheme for creating the right moisture conditions

Figure 5 shows the scheme for choosing species. The species are chosen so that they ensure a satisfactory yield (> 75 %) and a dry matter (D.M.) quantity of at least 25 %. Since it is not known how species will develop on a substrate constituted based on the previous stages, tolerant species are chosen one by one. Also, the species must have beneficial effects on the quality of the substrate, and experiments are carried out on a small scale (in pots) on the basis of which the yield and dry matter content are evaluated.

If the yield is not satisfactory (< 75 %), a new species is selected. If the yield is satisfactory (> 75 %), the dry matter content is checked. If the D.M. is < 25 %, a new species is selected. When the condition D.M. > 25 % is satisfied, we can proceed to the next stage.

This stage is long lasting. To increase the chances of obtaining the desired results, it is recommended to carry out experiments in pots using several plant species in parallel.

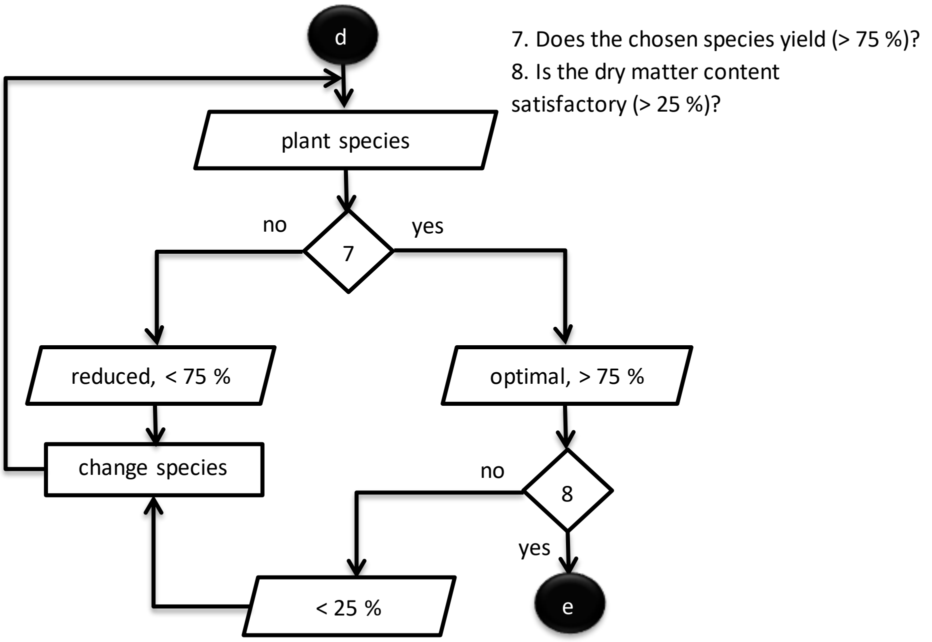


Fig. 5. Scheme for choosing species

Figure 6 shows the scheme for identifying and writing the optimal soil mixture. This stage is reached only when all the required conditions have been met. At this moment, the soil mixture and the plant species that best accept the given conditions are written.

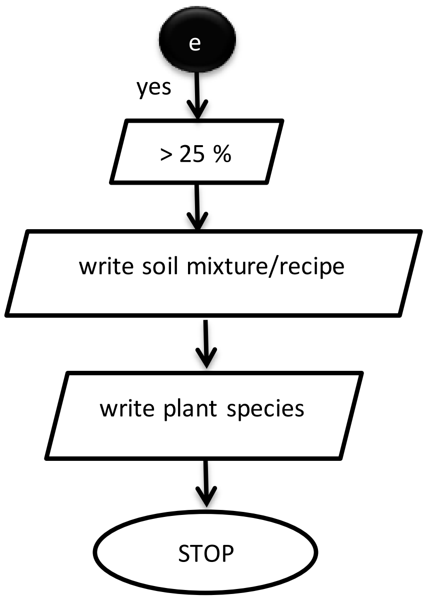


Fig. 6. Scheme for identifying and writing the optimal soil mixture and plant species

These species will be incorporated into the sterile material, even through deeper plowing (20 – 50 cm), aiming from now on the enrichment the sterile material with organic matter and nutrients (without further adding organic and mineral fertilizers). From now on, the pedogenesis process can continue naturally, without human intervention, these interventions being necessary only in the planting, monitoring, and maintenance stage depending on the future uses of the land.

4. Results and discussions

The proposed method for accelerating pedogenesis on anthropogenic soils was applied and verified through an experiment. The case study was carried out at the level of the internal dump of the North Pesteana lignite open-pit, in the Rovinari mining basin, Romania (Figure 7).

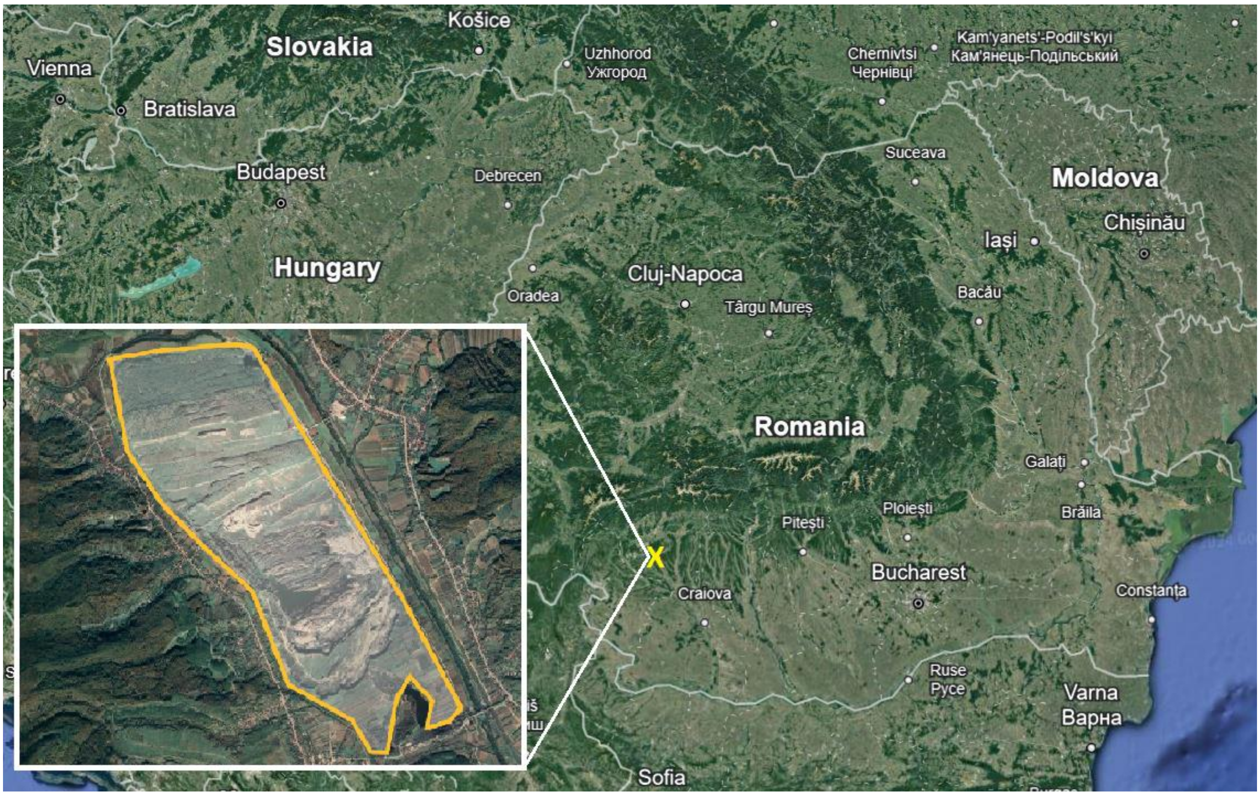
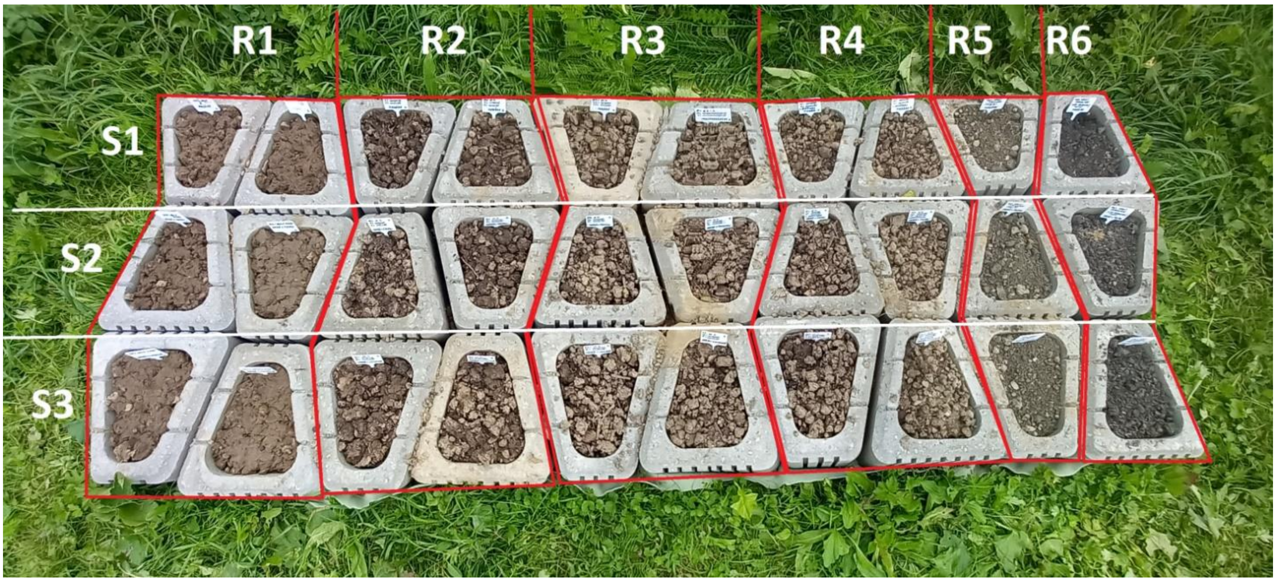


Fig. 7. Location of North Pesteana mining perimeter – Rovinari Mining Basin, Romania

The 8 stages considered to be essential were taken into account when carrying out pot experiments (Figure 8). Following the physical, chemical, and pedological analyzes carried out on the sterile material from the dump, the following were found [31]:

- the sterile material does not contain toxic or dangerous substances, it is made up only of clays, sands, and marls and different mixtures of these types of rocks, representing the inorganic basis necessary in the pedogenesis process;
- the sterile material is poor in organic matter and nutrients, but in order to increase the content of micro and macro elements to a level considered optimal, the experiment assumed:
    - o on one side, the enrichment of sterile material with nutrients using fertilizers (a fertilizer with a content of macroelements N - P - K (13% - 5% - 24%) and a series of microelements (Fe, S, MgO , Mn, Zn, Cu, B) with slow release, for tracking the way in which the growth of some plants is supported,
    - o and on the other side, the possibility of finding a soil substitute (for which mixtures of waste, compost, and cow manure in different proportions were created) that would support the growth of some plants with an ameliorating role, with the aim of the subsequent incorporation of them in the sterile material (for enrichment with organic matter).
- the sterile material has a relatively high degree of compaction as a result of the use of high-tonnage dumping trucks, which influenced the permeability and porosity of the rocks in the sense that they are moderately to hardly permeable, with adequate to insufficient ventilation. In order to improve these conditions, mechanized and manual loosening works were carried out;
- the sterile material, at the time of sampling, showed a wet to dry state, respectively a humidity between 3.65 – 27.97 %. These variations are determined both by the testing depth (20 cm) and by short-term weather conditions. In order to improve the humidity conditions, watering norms were established depending on the daily amount of precipitation;
- the productivity was estimated by the soil coverage index method, based on which a normal coverage was found, the surfaces of all pots being occupied in a proportion of at least 100% two months after sowing and was evaluated according to the plant mass obtained and compared with the theoretical mass known from the long-term experiences of the farmers and guaranteed by the seed producers, according to which it was found that the production was adequate;
- the dry matter (D.M.) represented between 24 and 50 % of the mass of the plant in its natural-moist state, the difference representing the water content of the plant.



Day 1

R3 – day 34

S1R4 – day 62

S2R1 – day 77

R1 = 100 % sterile material (blank sample); R2 = 90 % sterile material + 5 % compost + 5 % manure; R3 = 85 % sterile material + 10 % compost + 5 % manure; R4 = 85 % sterile material + 10 % compost + 5 % manure + fertilizer; R5 = 100 % sterile material from intercalations (sandy clay; blank sample); R6 = 100 % sterile material from intercalations (coaly marl; blank sample); S1 = green peas; S2 = 50 % red clover + 50 % grass; S3 = 50 % alfalfa + 50 % grass.

Fig. 8. Photo captures during the experiment

Table 1 shows data on the mass of the plant in its natural-wet state, respectively the mass of the dry matter.

Table 1. Plant mass

Soil receipt / **Plant species**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**
Green plant mass, kg/m^2						
Peas (with grains)	1.6	1.1	2.0	1.1	3.2	0.2
Grass + red clover	6.6	4.5	2.7	4.5	7.7	8.1
Grass + alfalfa	5.2	4.0	3.5	6.6	8.2	9.4
Dry plant mass, kg/m^2						
Peas (without grains)	0.4	0.4	0.56	0.42	0.72	0.12
Grass + red clover	1.55	1.15	0.65	1.43	2.04	2.62
Grass + alfalfa	1.21	1.01	0.8	1.89	2.53	3.22

Going through all the stages imposed by the logical scheme, following the experiment we concluded:

- quantitatively, good results were obtained in most of the pots, and the pots with alfalfa generally offered (R3-R6) larger amounts (up to 48%) of plant mass than those with clover.

- the dry matter of the plant varied between 33 and 50 % for peas and between 24 and 35 % for herbaceous species. The difference represents the amount of water contained in the mass of the plant, being greater in mixtures of herbaceous plants.
- the optimal soil mixture ware identified as follows:
    - peas provide the largest amounts of D.M. in the case of substrates consisting of 85 % sterile, 10 % compost, 5 % manure, and fertilizer (R4) and 100 % sandy clay from intercalations (R5);
    - herbaceous species provided large amounts of D.M. in 100 % sterile material (R1 – mixture of sterile rocks from the dump, R5 – sandy clay from intercalations, and R6 – coaly marl from intercalations).
- comparing R4 with R3 (R3 lacks the fertilizer) significant plant growths were observed at a given moment during the experiment and the increase in D.M. in R4 which is explained by the use of fertilizer.

5. Conclusions

An increasingly studied and applied method for restoring fertility on mining dumps is represented by techniques for stimulating the pedogenesis process based on the dumped material itself instead of much more expensive and difficult to apply techniques that consist of the "import" of a topsoil layer (of different thicknesses depending on the intended use: agriculture, forestry, orchards, vineyards, etc.) often difficult to procure. Inert clay and clayey–sandy rocks represent a good base of inorganic matter for the reconstitution of topsoil when mixed with biodegradable organic matter and enriched with nutrients necessary for plant growth and life support.

The quick method for selecting plant species to accelerate pedogenesis on anthropogenic protosols was developed in the form of a logical scheme consisting in the 6 steps described in the paper.

The proposed logical scheme facilitates the understanding of how the soil is formed but also highlights the directions and interventions necessary to bring an anthropogenic protosol to an acceptable quality that supports the development of vegetation.

Improving the quality of anthropogenic protosols will allow the development of more and more varied and valuable types of plants, which will support the creation of strong, complex ecosystems, increase the value of land, and offer multiple possibilities for their reuse.

In general, sterile substrates had good and very good results, supporting the growth of the chosen species and achieving high productivity. The resulting plants can contribute to the enrichment of the substrate with organic matter in order to accelerate the pedogenesis process.

The proposed methodology can be applied in most cases of reclamation of waste dumps and/or degraded lands and represents a quick way to establish the species that can support the processes of improving their quality.

Acknowledgements

This research was funded by University of Petrosani from research funds, grant number CSU 4283/31.05.2023.

References

[1] **Singer, M.J.,** 2015
Basic Principles of Pedology, Reference Module in Earth Systems and Environmental Sciences; Elsevier: Amsterdam, Netherlands

[2] **Kim, M.-S., Min, H.-G., Kim, J.-G.,** 2020
Integrating Amendment and Liquid Fertilizer for Aided-Phytostabilization and Its Impacts on Soil Microbiological Properties in Arsenic-Contaminated Soil, Appl. Sci., 10, no. 3985

[3] **Bosch-Serra, A.D., Cruz, J., Poch, R.M.,** 2023
Soil Quality in Rehabilitated Coal Mining Areas, Appl. Sci., 13, no. 9592

[4] **Apostu I.M., Lazar M., Faur F., Traistă E.,** 2024
An overview of sustainable mining practices for ecological rehabilitation of degraded lands in the Rovinari Mining Basin. Case study: North Peșteana interior dump, Inżynieria Mineralna (Mineral Engineering) - Journal of the Polish Mineral Engineering Society, Vol. 2, No 1, pp. 235–245

[5] **Grand, A., Michel, V.,** 2020
Soil organic matter (in Romanian), Best 4 Soil, EUs Horizon 2020 Program, 2020. Available online: https://orgprints.org/id/eprint/43417/16/RO_MATERIA%20ORGANICA%CC%86%20DIN%20SOL.pdf (accessed on 8 January 2024)

[6] **da Silva, G.O.A., Southam, G., Gagen, E.J.,** 2023
Accelerating soil aggregate formation: a review on microbial processes as the critical step in a post-mining rehabilitation context, Soil Research, 61, pp. 209–223

[7] **Schulte, R.P.O., Creamer, R.E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C., O'hUallachain, D.,** 2014
Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture, Env. Sc.&Pol., 38, pp. 45–58

[8] **Burleigh County Soil Conservation District (BCSCD),** 2017
5 Soil Health Principles, Bismarck, North Dakota. Available online: https://menokenfarm.com/5-soil-health-principles/ (accessed on 21 January 2024)

[9] **Gerke, J.,** 2022
The Central Role of Soil Organic Matter in Soil Fertility and Carbon Storage, Soil Syst., 6, no. 33

[10] **Khalidy, R., Arnaud, E., Santos, R.M.,** 2022
Natural and Human-Induced Factors on the Accumulation and Migration of Pedogenic Carbonate in Soil: A Review, Land, 11, no. 1448

[11] **Lima, A.T., Mitchell, K., O'Connell, D.W., Verhoeven, J., Van Cappellen, P.,** 2016
The legacy of surface mining: Remediation, restoration, reclamation and rehabilitation, Env.Sc.&Pol., 66, pp. 227-233

[12] **Mentis, M.,** 2020
Environmental rehabilitation of damaged land, For. Ecosyst., 7, no. 19

[13] **Fodor, D., Lazăr, M.,** 2006
Occupation and ecological rehabilitation of land in the Oltenia area (in Romanian), AGIR Bulletin, 3, pp. 37-31

[14] **Vickers, H., Gillespie, M., Gravina, A.,** 2012
Assessing the development of rehabilitated grasslands on post-mined landforms in north west Queensland, Australia, Agric.Ecosyst.&Env., 163, pp. 72-84

[15] **Lei, H., Peng, Z., Yigang, H., Yang, Z.,** 2016
Vegetation and soil restoration in refuse dumps from open pit coal mines, Ecol. Eng., 94, pp. 638-646

[16] **Ussiri, D. A.N., Lal, R., Jacinthe, P.-A.,** 2006
Post-reclamation land use effects on properties and carbon sequestration in minesoils of Southeastern Ohio, Soil Sc., 17 (3), pp. 261-271

[17] **Pietrzykowski, M., Krzaklewski, W.,** 2018
Chapter 27 - Reclamation of Mine Lands in Poland, In Bio-Geotechnologies for Mine Site Rehabilitation; Majeti Narasimha Vara Prasad, Paulo Jorge de Campos Favas, Subodh Kumar Maiti, Eds.; Elsevier: Amsterdam, Netherlands, pp. 493-513

[18] **Lazăr, M., Faur, F., Dunca, E., Ciolea D.I.,** 2017
New methodology for establishing the optimal reuse alternative of degraded lands, Env. Eng. & Manag. J., 16 (6), pp. 1301-1308. https://eemj.eu/index.php/EEMJ/article/view/3290

[19] *****,** 2020
Law 246 regarding the use, conservation, and protection of soil (in Romanian), Bucharest, Romania

[20] **National Research-Development Institute for Pedology, Agrochemistry and Environmental Protection (ICPA),** 2023
Assessment of soil nutrient content (in Romanian), Bucharest, Romania. Available online: https://www.icpa.ro/documente/coduri/Evaluarea_continutului_de_nutrienti_din_sol.pdf (accessed on 8 May 2024)

[21] *****,** 2012
Office for Pedological and Agrochemical Studies (OSPA) (in Romanian), Gorj, Romania

[22] **Dorneanu, A., Dumitru, M., Anton, I., Preda, C., Cioroianu, T.M., Sîrbu, C., Călinoiu, I., Oprică, I.,** 2010
Organomineral fertilizers on the lignite support – ecological sources of balanced fertilization of crops in sustainable agriculture (in Romanian), Annals of the Univ. of Craiova – Agric.Mount.Cad., XXXX, pp. 340-351

[23] **Dumitru, M., Cărăbiș, D., Pârvan, L., Sârbu, C.,** 2016
Environmental rehabilitation of mining dumps, Agric.&Agric. Sc. Proc. S., 10, pp. 3-9

[24] **Eyheraguibel B., Silvestre J., Morard P.,** 2008
Effects of humic substances derived from organic waste enhacement on the growth and mineral nutricion of maize, Bioresource Technology, 99 (10), pp. 4206-4212

[25] **Becherescu C., Susinski M., Dobre M., Dascălu D., Dodocioiu A.M.,** 2008
Aspects of the actual humus content of dumps resulting from surface coal mining (in Romanian), NEW AGRIS Publishing House – Agricultural Revue, Bucharest, Romania

[26] **Weil, R.R., Brady, N.C.,** 2016
The nature and properties of soils, 15th ed.; Pearson: London, United Kingdom

[27] **González-Martínez, A., de Simón-Martín, M., López, R., Táboas-Fernández, R., Bernardo-Sánchez, A.,** 2019
Remediation of Potential Toxic Elements from Wastes and Soils: Analysis and Energy Prospects, Sust., 11, no. 3307

[28] **Spagnuolo, M., Adamo, P., Garau, G.,** 2022
Assessment and Remediation of Soils Contaminated by Potentially Toxic Elements (PTE), Soil Syst., 6, no. 55

[29] **Subašić, M., Šamec, D., Selović, A., Karalija, E.,** 2022
Phytoremediation of Cadmium Polluted Soils: Current Status and Approaches for Enhancing, Soil Syst., 6, no. 3

[30] **Gross, C.D., Harrison, R.B.,** 2019
The Case for Digging Deeper: Soil Organic Carbon Storage, Dynamics, and Controls in Our Changing World, Soil Syst., 3, no. 28

[31] **Apostu, I.-M., Faur, F., Lazăr, M., Traistă, E.,** 2024
Quality of the soils on degraded mining lands and possibilities of restoring their fertility - Case study: Rovinari coal basin, AgroLife Scientific Journal, 13 (2)

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 152-157

PRELIMINARY STUDIES ON THE UTILIZATION OF SILICOMANGANESE SLURRY

Mariana Ionela DUMITRACHE[1*], *Camelia TRAISTĂ*[2], *Mihaela Dana LANG*[3]

[1]University of Petrosani, Doctoral School, Petrosani, Romania, mariana.ionela.dumitrache@gmail.com
[2]University of Petroșani, Faculty of Mining, Department of Environmental Engineering and Geology, Petroșani, Romania
[3]Petrila City Hall, Petrila, Romania

DOI: 10.2478/minrv-2024-0052

Abstract: *Silico-manganese sludges are a waste resulting from the ferroalloy industry, more precisely from the manufacture of silico-manganese. From a technological point of view, they come from the sludge resulting from the filtration of furnace gases. From a chemical point of view, they are made up of a large number of combinations of manganese and silicon. The manganese content varies widely between 5-35% MnO. Due to the fact as there are limitations for the manganese content in waters and soils, the presence of these sludge deposits constitutes a permanent risk of environmental contamination. In addition to the definitive closure (greening) of the deposit, there is also the possibility of valorizing this waste. The present paper presents the preliminary research carried out to identify a sustainable technology for the recovery of useful elements from the sludge.*

Key words: *environmental contamination, manganese, manganese recovery, silico-manganese, sludge, slurry*

1. Introduction

The metallurgical industry is facing major problems that are not strictly related to a crisis of raw materials and energy resources but to the stringent requirements for environmental protection. The development of the metallurgical industry is conditioned by solving the major problems arising from the industry-environment relationship, being strictly directed at the control of pollution and the protection of natural and energetic resources. The small and pulverulent waste, mainly from the steel industry but also from the mining and energy industry, due to the high content of iron, manganese, carbon and various oxides (elements useful in the production process of cast iron or steel) should be called by-products and be considered components of natural capital because they can be exploited in the steel industry.

The ecological concept applied to the steel industry involves the development of closed-loop production technological flows in which no waste should be disposed of, all by-products should be continuously reused and no waste should be discharged into the environment. In specialized literature, this system is called "waste free steel industry". Finding efficient solutions from an economic and ecological point of view for technological flows in the steel industry is currently a major concern. Adequate management in terms of waste management and recovery, completely eliminating storage will lead to the protection of natural resources and the recovery of those consumed, thus reducing costs and the impact of disposed waste on the environment. [1].

The concern for compliance with the legislative requirements regarding environmental protection and the need to harmonize the processes of economic progress, with the rational management of material and energy resources, must lead to the valorization of waste through technologies that offer both from an economic and ecological point of view, the optimal solution.

It is necessary to promote technologies that ensure: rigorous waste management, controlled storage of all categories of waste, reduction at the source of the quantity and harmfulness of the produced waste, the most advanced recycling of the resulting waste by re-introducing it in various stages of the technological flow, thus ensuring the protection of natural resources of raw materials and increasing the degree of use of waste by transforming it into raw materials for other industries.

[*] Correspondence: Mariana Ionela Dumitrache, University of Petrosani, Doctoral School, Contact details: University Str., no. 20, 332006, Petrosani, Romania, mariana.ionela.dumitrache@gmail.com; Tel.: +40-752-17-16-17

The continued depletion of mineral resources, rising energy costs and strictly environmental regulations have resulted in increased efforts to recover metals.

2. Silicomanganese production

S.C. FERAL S.R.L. operates in the field of Ferrous Metallurgical Industry producing ferroalloys. The company is located in the industrial area of the city of Tulcea Western Platform, Taberei street no. 2.

The objective produces raw non-ferrous metals from ores, through metallurgical processes, through the FERO I and FERO II processing sections with an average annual production capacity of approx. 240,000 tons of alloys, 2400 tons of powder/slag briquettes [2].

This industry produces and markets: ferroalloys (silicomanganese, ferromanganese), powders and slags low in manganese oxide. About 99% of the unit's production is destined for export. The main uses of the developed ferroalloys are in the metallurgical industry to obtain steels, using them as a deoxidizer and/or alloying material [1]. The basic raw material is: manganese ore, concentrated manganese ore, coke, quartzite, limestone, manganese slag.

The slag dump and silicomanganese dust dump represent a fixed anthropomorphic source, with periodic emissions of pollutants in the form of particles whose frequency and intensity depends on meteorological conditions. Factors favoring pollutant migration to receptors are strong winds and precipitation. On the dust dump belonging to S.C. Feral S.R.L., nothing has been stored since 2012 and contains approximately 830,000 tons of silicon manganese dust [3].

Silicomanganese (SiMn) is an alloy composed primarily of silicon (Si), manganese (Mn), and iron (Fe). It is produced by smelting in a submerged electric arc furnace and is used extensively in the steel industry due to its beneficial properties. Here are the key details about silicomanganese:

Composition:

- Silicon (Si): Typically, between 10-30%
- Manganese (Mn): Usually, around 60-70%
- Iron (Fe): The remainder, with trace amounts of other elements such as carbon, sulfur, and phosphorus.

Production Process: The primary raw materials for producing silicomanganese are manganese ore, silica (quartz), and coke. These materials are smelted in a submerged electric arc furnace, where high temperatures facilitate the reduction of manganese and silicon from their oxides. [4] The molten alloy is then refined to achieve the desired chemical composition and is typically cast into ingots or other forms for further processing. Uses in the Steel Industry:

- Deoxidizer: Silicomanganese is used to remove oxygen from molten steel, preventing the formation of undesirable oxides.
- Alloying Element: It adds manganese and silicon to steel, improving its strength, hardness, and resistance to wear and corrosion.
- Desulfurizer: Manganese helps to remove sulfur from steel, improving its overall quality.

Benefits:

- Improved Mechanical Properties: Enhances tensile strength, ductility, and toughness.

In the present work, the preliminary tests will be presented for the identification of a technology for the valorization of silicomanganese dust resulting from the purification of gaseous effluents stored in the silicomanganese dust dump [5].

Analyzing the existing market for manganese products, it was found that in the last year the price of its ores has decreased significantly. In this context, the material in the warehouse can no longer be used as such, not even after a simple classification. If before it was possible to exploit products with a content of more than 22% manganese, at the present time the price offered for such material is below 30 USD/t (transported to the port), with no purchase interest. Reasonable purchase prices are offered for products with over 42% manganese and in rare cases over 37% manganese.

3. Establishing the characteristics of the initial material

In order to determine the characteristics of the material stored in the silicomanganese dust dump, 7 samples were taken from its entire surface (Fig. 1). The samples were processed in the chemistry laboratory of the University of Petroșani by X-ray fluorescence spectrometry (XRF) using a Rigaku Supermini 200 spectrograph.

Fig. 1. Sample for analysis

After the chemical analysis, the following chemical compositions of these samples resulted (Table 1):

Table 1. Results of the chemical analysis of the initial samples

Component	**MU**	**Sample**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Mn	%	19.461	18.610	15.388	20.005	2.8240	13.652	18.527
SiO_2	%	20.777	24.962	29.175	18.682	76.239	28.703	50.481
$Al2O_3$	%	0.3990	0.5570	1.3380	0.7420	0.4750	1.6050	0.8870
S	%	1.1060	0.7930	0.4520	0.6240	0.8950	0.8340	0.7040
P	%	0.0260	0.0430	0.0340	0.0230	0.0470	0.0320	0.0320
Fe	%	2.3310	2.6210	3.6460	2.0670	3.9630	5.3080	3.2460

From the presented results, it is concluded that the tested material is very inhomogeneous both in terms of manganese content and the ratio between the contents of different chemical elements.

Next, an average sample of samples 1, 2, 3, 4, and 7 was made and also sample 7 was retained for further granulometric tests.

4. Preliminary manganese recovery tests

4.1 Densimetric separation tests

Densimetric separation is a process used to separate solid materials of different densities. This process uses a fluid (usually air or water) to separate materials based on their density. Dense materials will sink, while less dense materials will float. The densimetric tests were performed with bromoform, which is a liquid with a density of 2.89 g/cm^3 [6].

The results obtained after the densimetric separation in bromoform are presented in Table 2:

Table 2. Results of densimetric separation in bromoform

Parameter	**MU**	**Heavy Fraction**	**Light Fraction**	**Original**
		Share [%]		
		17.73	82,27	100,00
Mn	%	25.43	14,08	18,47
SiO_2	%	13.31	50,08	36,26
Al_2O_3	%	0.68	2,35	1,72
S	%	0.44	0,61	0,54
P	%	0.05	0,05	0,05
Fe	%	3.28	4,70	4,17
Extraction of Mn	%	24.41		

From the obtained results, it can be observed that the material is relatively homogeneous, so that by densimetric separation, a concentrate with an acceptable manganese content does not result. Also, metal extraction has very little value.

4.2 Granulometric separation tests

Size separation is a technique used to separate solid particles based on their size. This is essential in many industries, including mining and materials processing, to obtain products of uniform size or to remove impurities. [7]

Particle size separation is based on the use of sieves, filters, or other equipment to sort particles according to their size. Larger particles are retained by the sieve, while smaller particles pass through them [4].

To carry out the test, a quantity of 400 g of material from sample 7 was weighed, which was separated into 4 granulometric classes (-75 microns, +75 microns, +1mm, +3.15mm).

After the granulometric separation, the following results were obtained (Table 3):

Table 3. Results of particle size separation

Parameter	**MU**	**Granulometric class**			
		Share			
		- 0.075 mm	0.075 - 1 mm	1 - 3.15 mm	+ 3.15 mm
		6.61	24.80	27.72	40.87
MnO	%	24.98	24.05	23.96	23.63
SiO_2	%	49.36	50.22	50.73	50.65
Fe_2O_3	%	4.09	4.09	4.06	4.13
CaO	%	2.95	2.94	2.97	2.95
K_2O	%	1.57	1.59	1.58	1.58

From the obtained results it is very clear that there are no notable differences in the manganese contents of different granulometric classes.

4.3 Magnetic separation tests

Magnetic separation is a separation technique used to separate magnetic from non-magnetic materials. It is a common process in industry for mineral separation, metal recycling and waste processing. This method is based on the differences in the magnetic susceptibility of different materials [4].

Magnetic separation uses magnetic forces to attract ferromagnetic materials (such as iron, nickel, and cobalt) or paramagnetic materials into a magnetic field. Diamagnetic and non-magnetic materials are not affected by the magnetic field and remain separated.

Magnetic Separation Methods:

- Wet Magnetic Separation: Materials are mixed with water to form a slurry, which is passed through a magnetic separator.
- Dry Magnetic Separation: Materials are passed directly through a magnetic separator without being mixed with water.

Depending on the strength of the magnetic field, the magnetic separation can be:

- High Intensity Separation: Use of high intensity magnetic separators to separate materials with low magnetic susceptibility. It is used for the separation of paramagnetic minerals and for the cleaning of non-metallic minerals [6].
- Low Intensity Separation: Low intensity magnetic separators are used to separate strongly magnetic materials. Equipment: Permanent magnetic separators, electromagnets [6].

The preliminary magnetic separation tests were performed in a weak magnetic field (classic permanent ferrite magnet) for all 4 particle size fractions shown in table 3. The results obtained from these tests are shown in Tables 4, 5, 6 and 7:

Table 4. Results of magnetic separation in magnetic field for particle size fraction – 0.075 mm.

Parameter	**MU**	**Magnetic fraction**	**Non-magnetic fraction**	**Original**
Extraction	%	46.24	53.76	100.00
MnO	%	27.11	23.25	24.98
SiO_2	%	46.11	51.53	49.36
Fe_2O_3	%	4.14	4.08	4.09
CaO	%	2.92	2.98	2.95
K_2O	%	1.58	1.58	1.57
Mn extraction	%	50.17		
Mn extraction relative to total sample	%	3.32		

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 152-157

Table 5. Results of magnetic separation in magnetic field for particle size fraction 0,075 – 1 mm.

Parameter	MU	Magnetic fraction	Non-magnetic fraction	Original
Extraction	%	21.20	78.80	100.00
MnO	%	27.11	23.25	24.05
SiO_2	%	46.11	51.53	50.22
Fe_2O_3	%	4.14	4.08	4.09
CaO	%	2.92	2.98	2.94
K_2O	%	1.58	1.58	1.59
Mn extraction	%	23.90		
Mn extraction relative to total sample	%	5.93		

Table 6. Results of magnetic separation in magnetic field for particle size fraction 1 – 3,15 mm.

Parameter	MU	Magnetic fraction	Non-magnetic fraction	Original
Extraction	%	23.08	76.92	100.00
MnO	%	27.11	23.25	23.96
SiO_2	%	46.11	51.53	50.73
Fe_2O_3	%	4.14	4.08	4.06
CaO	%	2.92	2.98	2.97
K_2O	%	1.58	1.58	1.58
Mn extraction	%	26.11		
Mn extraction relative to total sample	%	7.24		

Table 7. Results of magnetic separation in magnetic field for particle size fraction + 3,15 mm.

Parameter	MU	Magnetic fraction	Non-magnetic fraction	Original
Extraction	%	13.04	86.96	100.00
MnO	%	27.11	23.25	23.63
SiO_2	%	46.11	51.53	50.65
Fe_2O_3	%	4.14	4.08	4.13
CaO	%	2.92	2.98	2.95
K_2O	%	1.58	1.58	1.58
Mn extraction	%	14.96		
Mn extraction relative to total sample	%	6.11		

From all these tests it is found that both the extraction in the metal and the concentration of manganese in the concentrates have low values.

5. Hydrometallurgical processing tests

Within this experimental cycle, only one sulfuric acid leaching test was performed.

For this purpose, a quantity of approximately 10 grams of material was taken and placed in an acidic solution of sulfuric acid 1:2. The reaction proceeded energetically, with strong release of heat [8]. After the reaction stopped, the acid solution was separated by filtration from the unreacted fraction. Dissolved metals were separated by selective precipitation. The pH of the solution was adjusted using 40% KOH to 3.2-3.4 to obtain iron precipitation. After filtering the iron, the pH of the solution was adjusted to a value between 5 and 5.5 for aluminum precipitation. After filtering the aluminum, the pH of the solution was adjusted to 8-9 to obtain the precipitation of manganese. The results obtained from these tests are presented in Table 8:

From the results of the preliminary leaching test, a high purity manganese concentrate and a residue very poor in manganese, consisting of a mixture of quartz and coke powder were obtained. In conclusion, the only method by which silico-manganese sludge can be exploited is the hydrometallurgical one, provided that high-purity, high-value products are obtained [9].

Table 8. Results of manganese separation by sulfuric acid leaching.

Component	Manganese concentrate	Final residue
MnO	99.878	1.067
SiO_2	0.018	94.648
Fe_2O_3	0.087	0.875
CaO	0.007	0.775
K_2O	0.011	1.555

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 152-157

6. Conclusions

The material in the dumps is inhomogeneous in terms of granulation, being made up of brown-colored manganese powders, gray-colored quartz powders, brown-colored spherical silico-manganese pellets, pieces of slag and other foreign bodies (waste of construction materials).

Following the physical and chemical analyses, manganese concentrations of approximately 18% were obtained, a value that corresponds to that indicated in the test reports provided by the beneficiary.

By simple granulometric classification, significant increases in the manganese content are not obtained, except to the extent that part of the foreign bodies and larger slag grains are removed.

Separation tests indicated that manganese can be concentrated by granulometric and magnetic classification methods in a weak magnetic field up to a concentration of 24 - 27% Mn, which is absolutely unsatisfactory.

Through hydrometallurgical processes, a high-purity manganese concentrate can be separated, from which economically valuable products can be obtained, such as manganese dioxide, manganese sulfate or the manganese salt of diethyldiaminetetraacetic acid with applications in agriculture.

References

[1] **Shelburne,W.M., Degroot, D.J.**, 1998
The use of waste & recycled materials in highway construction, Civ. Eng. Pract., 13, pp. 5–16, Available from: https://www.researchgate.net/publication/291355218_Use_of_recycled_materials_in_highway_construction (accessed on 04 July 2024)

[2] *******, 2016
Autorizația Integrată de Mediu, Nr. 3 din 28.10 2016, S.C. FERAL SRL TULCEA

[3] *******, 2016
Raport de amplasament, pentru obținerea autorizatiei integrate de mediu S.C. Feral S:R.L. Tulcea https://www.anpm.ro/documents/28797/2290065/Feral+Raport+de+amplasament+mai+2016.pdf/0345fea2-d425-4c3a-9503-91cec4509e56

[4] **Craescu I., Krausz S., Constantin D., Sarbu R., Hanes N.**, 1982
Prepararea substanțelor minerale utile, E.D.P., București

[5] **Qasrawi, H.**, 2014
The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment. Constr. Build Mater. 54, pp. 298–304. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0950061813012208 (accessed on 04 July 2024)

[6] **Ayala J., Fernández B.**, 2015
Recovery of manganese from silicomanganese slag by means of a hydrometallurgical process. Hydrometallurgy, 158, pp. 68-73, Available from: https://www.sciencedirect.com/science/article/abs/pii/S0304386X15301134 (accessed on 10 March 2024)

[7] **Buruiana, D.L., Obreja, C.D., Herbei, E., Ghisman, V.**, 2021
Re-Use of Silico-Manganese Slag. Sustainability, 13, no. 11771, Available from: https://doi.org/10.3390/su132111771 (accessed on 10 June 2024)

[8] **Das, B., Prakash, S., Reddy, P.S.R., Misra, V.N.**, 2007
An overview of utilization of slag and sludge from steel industries. Resour. Conserv. Recycl., 50, pp. 40–57. Available from: https://www.researchgate.net/publication/228673702_An_Overview_of_Utilization_of_Slag_ and_Sludge_from_Steel_Industries (accessed on 06 July 2024)

[9] **Qasrawi, H.**, 2014
The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment. Constr. Build Mater., 54, pp. 298–304. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0950061813012208 (accessed on 04 July 2024)

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 158-163

TRAINING SCENARIOS FOR MINE RESCUERS AIMED AT SELECTING AND BUILDING RESCUE TEAMS ABLE OF INTERVENING IN MAJOR INCIDENTS

Cristian NICOLESCU[1], George Artur GĂMAN[2], Daniel PUPĂZAN[3], Cosmin ILIE[4]*

[1]INCD – INSEMEX Petroşani, Romania, cristian.nicolescu@insemex.ro
[2]INCD – INSEMEX Petroşani, Romania, Technical Sciences Academy of Romania
[3]INCD – INSEMEX Petroşani, Romania,
[4]INCD – INSEMEX Petroşani, Romania,

DOI: 10.2478/minrv-2024-0053

Abstract: *In mining rescue operations, the practical training of rescue personnel plays an essential role in the selection and configuration of rescue teams that intervene in critical situations, major incidents, accidents or other events occurring in underground mining works. Practical training can be conducted through monthly scheduled practical exercises at rescue stations within a mining unit, as well as through modern training means available at INCD-INSEMEX Petroșani (virtual reality, mobile training facility for rescuers) used in the process of instruction and re-instruction of mining rescuers. Mining rescuers' training level can be quantified through both physical and mental training by their reactions in certain critical situations, which can be created using virtual reality. Furthermore, the monitoring of the rescuers' physiological parameters before, during and after performing the practical exercise is also of particular importance. This monitoring can be carried out through the equipment available in the mobile training facility. The current paper aims to establish complex training scenarios for mining rescuers to select and configure rescue teams that can act in case of explosions, mine fires or other events.*
Keywords: *mining rescuer, training scenarios, virtual reality, mobile training polygon, rescue teams*

1. Introduction

Mining rescue operations require thorough physical and psychological preparation of mining rescue team members, given the risks they face during their underground interventions. While risks in surface activities can be evaluated with greater precision, in underground mining operations, it is very difficult to assess risks, especially in the case of major incidents such as explosions, endogenous fires in coal mines, gas or water eruptions, etc.

In mining activities, during disasters, work accidents or major events, mining rescuers are the ones who intervene (Figure 1). Any other state intervention structure (Emergency Situations Inspectorate, Military Firefighters, SMURD, Ambulance) does not have procedures for underground interventions, they are able to perform interventions only up to the gallery entrance or to the access ways of underground shafts [1].

Interventions are carried out by mining rescuers, members of the mining rescue station that operate at each mining unit, to rescue those caught in the event or to restore normal conditions in the underground. These interventions are often conducted under the protection of closed-circuit breathing apparatuses based on compressed oxygen, which regenerate exhaled air and have an autonomy of 2 or 4 hours.

The closed-circuit oxygen-based breathing apparatuses allow intervention and rescue personnel to operate in the area affected by major incidents without considering the concentration of toxic gases and provide sufficient working time for the intervention [2].

* Corresponding author: Cristian Nicolescu, National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani, Contact details: 32-34 G-ral Vasile Milea Street, Postcode: 332047, Petroşani, Hunedoara County, Romania, Tel.: +40-724-04-00-01, cristian.nicolescu@insemex.ro

Mining rescue activities can only be performed by trained and authorized personnel in accordance with current legislation. These personnel are prepared through practical and theoretical training sessions conducted at the rescue station to which they belong.

Fig. 1. Occurrence of a major incident in an underground mine

A crucial aspect of mining rescue operations is the practical training of mining rescuers within rescue stations, which underpins their physical preparedness and is critical to the success of an underground intervention. Besides proper physical training, mining rescuers must also be psychologically prepared to handle critical situations that may arise during their underground interventions.

Monthly practical and theoretical training programs are developed at the rescue stations, including scenarios that can be implemented at each mining unit based on its specific characteristics and the equipment available at the rescue station. These scenarios involve simulating events within mining operations, alerting rescue teams and conducting the actual intervention, as outlined in the training program prepared by the rescue station chief and approved by the unit leader [3].

The Authorization Group for Rescue at INCD INSEMEX Petroșani is equipped with a mobile training facility that includes a fitness equipment area and an enclosed space area. This facility is used in the training and re-training process of mining rescuers, allowing for complex training scenarios to be created, with continuous monitoring of rescuers' physiological parameters and work consumptions. Additionally, the Group is equipped with a virtual reality training system, enabling rescuers to be placed in scenarios that cannot be recreated in reality, such as fires, explosions, working at great heights, etc.

Using these two modern training tools, various training scenarios can be created, highlighting both the physical readiness of rescuers and how they psychologically handle complex events. The current paper presents complex training scenarios for mining rescuers using these modern training tools, monitoring the rescuers' physical and psychological preparedness and thereby building rescue teams that are efficient in disaster interventions.

2. Practical training scenarios for mining rescuers using the mobile training facility

The mobile training facility (Figure 2) is a modern piece of equipment for the practical training of mining rescuers. It is equipped with a compartment containing fitness equipment (infinity staircase, ergometer, treadmill, bicycle and stepper) that subjects the rescuer to intense physical exertion. Additionally, it features a compartment with enclosed spaces, consisting of cages measuring 80 cm by 80 cm, organized in two rows and two levels, totaling a length of 22 meters. These cages are equipped with horizontal, vertical and inclined blockers, as well as duct systems. In the enclosed space compartment reduced visibility atmosphere (by flooding it with smoke), high humidity, elevated temperatures and disaster-associated noises can be created [4].

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 158-163

Fig. 2. Mobile training facility

Thus, after installing and verifying the closed-circuit breathing apparatus based on compressed oxygen, the mining rescuer is registered by the training instructor. A personal record is created, containing personal data such as the rescuer's identification number, name, age, qualifications, the unit they work for within the rescue station, etc. All this information is stored within the information system of the mobile training facility's command console, located in the fitness equipment area [5].

After the rescuer's registration, they are introduced to the equipment in the mobile training facility and shown how to use it. A telemetry system is then attached to the rescuer, allowing for the monitoring of certain physiological parameters (respiratory rate, blood pressure, blood oxygen saturation, the amount of energy expended on the equipment, etc.), which are transmitted directly to the information system.

A first training scenario (Figure 3) involves setting the fitness equipment to predefined parameters (speed and incline of the treadmill, number of pulls on the ergometer, speed of the infinity staircase, distance to be cycled and power on the stepper).

Fig. 3. Rescuer's training in the fitness area

Under the protection of the breathing apparatus, mining rescuers will spend 8 minutes on each piece of equipment. This setup ensures that the rescuers work under the same conditions, but they are differentiated by the physiological parameters measured (pulse, blood oxygen saturation, blood pressure) and the energy expended during the training (kcal).

After completing the fitness equipment circuit, rescuers are introduced to the enclosed spaces compartment of the mobile training facility. They will traverse the enclosed space course twice: the first time with normal visibility just to get used to the route and the second time with the compartment filled with smoke, providing reduced visibility. Throughout their time in the enclosed spaces, their physiological parameters are monitored via the telemetry system, which displays the data on the control console [6].

At the end of this training scenario, the oxygen pressure in the cylinder is recorded to quantify the remaining time the mining rescuer can use the breathing protection apparatus. For this scenario, the selection of rescue team members is primarily based on the values of physiological factors, which should fall within certain normal limits for intense physical exertion and on their endurance during the exercise.

Another scenario can be created by quantifying the actual time the mining rescuer spends on the training, with specific targets set for each piece of fitness equipment based on their characteristics. The objectives are as follows:

- Infinity staircase: cover a specific distance, with the rescuer choosing the operating speed.
- Ergometer: complete a fixed number of pulls.
- Bicycle: cover a set distance.
- Stepper: set to a performance level (power) between 0-600W, quantifying the energy expended.
- Treadmill: cover a running distance, with the rescuer setting the walking speed of the treadmill.

After completing the exercises in the fitness equipment area, the rescuer moves to the enclosed spaces compartment (Figure 4) and traverses the course three times under conditions of reduced visibility, high temperature (achieved with a 6 kW heater installed in the compartment), and high humidity. In this scenario, the time taken to complete the enclosed spaces course is quantified.

These training scenarios ensure that rescuers are not only physically fit but also capable of handling the challenging conditions they may encounter during actual underground rescue operations. By monitoring their physiological responses and performance, training can be tailored to improve their endurance and efficiency, making them more effective in real-life rescue situations.

Fig. 4. Rescuers training in the enclosed spaces area

In this scenario, mine rescuers are also monitored physiologically through the telemetry system, with values being transmitted to the control console. In this scenario, team members are selected primarily based on the time the mine rescuer has spent training and successfully completing the entire specified route within physiological parameter limits, considering conditions of high exertion.

The two training scenarios using the mobile facility can be continuously improved based on the specific mining area from which rescuers come, type of equipment they use and core functions in which they operate.

It is ideal that the rescue team responding to a major incident includes experienced mine rescuers selected based on their performance in exercises conducted at the rescue station, and ideally, those who are very familiar with the intervention area.

3. Scenarios for practical training of mine rescuers using virtual reality systems

Virtual reality is increasingly integrated into training processes across various fields, and in this regard, INCD INSEMEX Petroșani has equipped the rescue authorization group with 4 virtual reality training devices for intervention and rescue personnel.

Compared to traditional methods of training mine rescuers, virtual reality training provides a superior level of preparation as a modern method that can simulate situations impossible to recreate in real life (such as

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 158-163

explosions, fires, working at great heights, etc.). The equipment used for training scenarios through virtual reality includes controllers, VR goggles, perimeter sensors and hardware equipment on which training scenarios software is installed.

One virtual reality training scenario involves testing a mine rescuer on the assembly and verification process of an isolating apparatus (Figure 3) used during operations. This step is a legal requirement in the intervention and rescue procedures. The scenario quantifies the steps for assembling the apparatus and verifying its parameters, requiring the rescuer to strictly follow the assembly and verification sequence; otherwise, progression to the next stage is impossible [7].

There's also the possibility for the trainer, using the hardware equipment (laptop), to allow the rescuer to proceed from one stage to another without following the correct sequence. At the end of the scenario, the trainer can assess and penalize the mine rescuer for any mistakes made throughout the exercise.

Another virtual reality training scenario for mine rescuers involves navigating through a labyrinth of enclosed spaces (simulating an underground mining network). After assembling and verifying the isolating apparatus, the rescuer enters the labyrinth area, which includes small sections, various blockades, circular tube-like areas and vertical climbing and descending areas resembling mining works. This scenario assesses how well the rescuer reacts to extreme situations involving movement through confined spaces and a diverse range of obstacles, which are typical challenges during major mining incidents like methane or coal dust explosions.

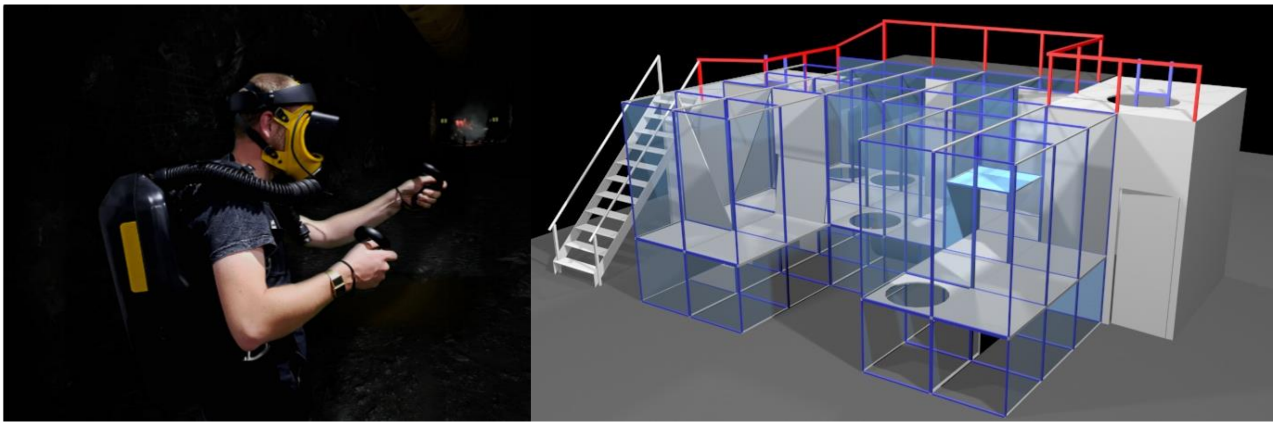


Fig.5. Scenario for navigating through a closed-space polygon

Through the use of hardware equipment, events such as fires or explosions can be generated during the rescuer's journey along the route. This aims to assess the mine rescuer's reaction, behaviour and emotional response in such scenarios, which cannot be reproduced in real life [8].

Within the virtual reality labyrinth, a high-altitude area (approximately 10-15 meters) is simulated, which the rescuer must navigate, potentially challenging those who have not faced such situations in reality.

Using a laptop, while the mine rescuer progresses through the labyrinth, a simulation can increase explosive gas levels beyond normal limits. This tests the rescuer's procedural response, whether they choose to leave the area or continue advancing under these conditions.

Implementing these scenarios using virtual reality and observing the reactions of mine rescuers helps in selecting and training teams for rescue operations, depending on the type and scale of the incident. This is due to the complexity of events that can be simulated through virtual reality, which are impractical to replicate in real-life exercises but only occur during disasters.

4. Conclusions

The practical training undertaken by mine rescuers, in accordance with current legislation and based on the scenarios described in this paper, conducted through modern training methods, will enhance intervention capabilities during major incidents in our country's mines. These scenarios do not replace the practical training conducted monthly at each mining rescue station but represent a complementary alternative using modern equipment to simulate situations beyond daily mining activities.

The mobile training facility's equipment allows for building databases that encompass a mine rescuer's training activities from authorization until retirement. These data highlight their progression or regression during their tenure as mine rescuers at a rescue station. The telemetry system in the mobile facility can monitor rescuers' physiological parameters, a capability not feasible during practical exercises taking place within mines, which can be a crucial criterion in building rescue teams.

Virtual reality provides the most modern form of training for rescue personnel by simulating situations impossible to recreate during exercises (such as fires, explosions, water eruptions, etc.), challenging rescuers both in decision-making and emotional resilience.

Acknowledgements

This work was carried out through the "Nucleu" Program within the National Plan for Research, Development and Innovation 2023-2026, with the support of the Romanian Ministry of Research, Innovation and Digitalisation, project no. 23 32 01 02, title: Development of assessment, testing and intervention methods for explosive atmospheres generated by facilities for the production, storage, transport and use of hydrogen.

References

[1] **Gaman G.A., Pupazan D., Ilie C**., 2012
Development and implementation of an expert system for the management of crisis events in mining industry, Environmental Engineering and Management Journal, 11 (7), pp. 1331-1335

[2] **Nicolescu C., Kovacs I., Ilie C.**, 2018
Training of intervention and rescue personnel in toxic / explosive / flammable environments, INSEMEX Publishing House

[3] **Pupazan D., Gaman G.A., Ilie C.**, 2012
*Information system for simulation and assessment of rescuers interventions in toxic, explosive and flammable environments***,** Environmental Engineering and Management Journal, 11 (7), pp. 1337-1341

[4] **Gaman G.A., Lupu C., Pupazan D.**, **Tănasă M.**, 2005
Rescuer and rescue station mechanic guide, INSEMEX Publishing House

[5] **Gaman G.A., Lupu C., Pupazan D.**, 2009
*Procedures and Regulations of Intervention and Exploitation teams in toxic / explosive / flammable environments***,** INSEMEX Publishing House

[6] **Ilie C.**, 2012
Research on issues related to the design of physical and psychosocial effort for optimizing the training process of intervention and rescue personnel in toxic / explosive / flammable environments, Nucleus Programme INCD INSEMEX Petroşani

[7] **Pupazan D.**, 2013
Upgrading the infrastructure of practical training of personnel for intervention and rescue in toxic / explosive / flammable environments by means of integration in their training facility of continuous monitoring of changes in the pulse and oxygen level in the blood assembly, Nucleus Programme INCD INSEMEX Petroşani

[8] **Nicolescu C.**, 2019
Development of the infrastructure for practical training of intervention and rescue personnel in toxic / explosive / flammable environments by creating a mobile training facility, Nucleus Programme INCD INSEMEX Petroşani

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 164-173

APPROACHING HUMAN ERROR IN INDUSTRIAL SETTINGS: MEMENTO FOR ROMANIAN OCCUPATIONAL HEALTH AND SAFETY PROFESSIONALS

Roland Iosif MORARU[1], Gabriel Bujor BĂBUȚ[2], Mihai POPESCU-STELEA[3]*

[1]University of Petroşani,Petroşani, Romania, rolandmoraru@upet.ro
[2]University of Petroşani, Petroşani, Romania, gabrielbabut@upet.ro
[3]University of Petroşani, Petroşani, Romania, mihaipopescu@upet.ro

DOI: 10.2478/minrv-2024-0054

Abstract: *In recent decades, in addition to numerous work accidents in which tens of thousands of deaths, disabilities and millions of days of temporary inability to work have been recorded, we have unfortunately witnessed some major disasters and accidents due to human errors. Indeed, one of the main identified contributors to the occurrence of these undesirable events stems from latent/active human errors. In this article, we try to develop a selective synthesis of some approaches to human error, different characteristic types, models and methodologies that have been developed to support the minimization of these errors. Relevant aspects of human error are systematized, including applicable systems for effective risk management in order to provide Romanian OSH specialists with tools for deepening/understanding a decisive and - at the same time - insufficiently studied aspect at the national level.*

Keywords: *Occupational Health and Safety (OHS), human error, performance shaping factor, human reliability, taxonomy*

1. Introduction

Although a large percentage of accidents are attributed to human error, the integration of human contribution into the safety of technical systems is often rudimentarily analyzed in industrial engineering [1]. The focus is on reliability, availability, maintenance and especially safety. Technical risks concern the main characteristics of the operational safety of a product, considered in a broad sense (system, equipment, mechanism, organization, procedure) [2]. The safety state of a system can be defined as representing the absence of circumstances that may favor the disruption of the system's operation. Starting from the application of this concept to the preliminary architecture of the system, it is possible to identify events such as failures combined or not with human errors and external risk factors, which can induce unsafe conditions. Until recently, the safety of complex systems was approached in a so-called "positivist" manner, which consists in predicting and controlling risks during the design of the systems. Developed especially by engineers and ergonomists, this approach considers technique as a real phenomenon (the "ontological principle"), having an existence outside the subject who observes and realizes it (the "objectivity principle"), having a determined functioning and laws of success that are their own ("principle of the wired universe") being able to lead to the optimal solution ("principle of unique optimum") [3].

It is considered that the reliability of a system can be built by acting on the technology, the work environment of the operators and on the definition of the procedures to be followed. Man is often identified as the "weak link", an element that reduces the overall reliability of the system, as "a black box capable of unpredictable and irrational behavior, at the origin of mistakes, failures and shortages" [4].

The operator has only a small margin of action or reaction in front of an organizational and technical reality that is external to him, because it was foreseen a priori by those who designed the system. A complementary approach, called "constructivist" was proposed by certain authors [5]. This considers technique

* Corresponding author: Roland Iosif Moraru, University of Petroşani, Petroşani, Romania, contact details: University Street, No. 20, Petroșani, Hunedoara County, Romania, Tel.: +40-723-62-41-05 rolandmoraru@upet.ro

as a construction ("principle of the constructed universe"), encompassing the subject who tries to master it or is content to observe it, by means of the representation it makes ("principles of representability and projectivity"), having a complex functioning, which cannot be broken down into simple independent elements and can only lead to more or less satisfactory solutions ("the principle of intelligent action"). This approach capitalizes on the role of operators in the reliability and safety of systems, not limiting their action to a simple follow-up of predetermined procedures, but seeking to benefit as much as possible from their intelligence and their own ability to react to new situations [6].

Based on a "safety culture" and on the development of the spirit of initiative within organizations, at the antipode of the quasi-military discipline required of operators until then, this approach gives the central role to the individual and is part of the "organizational communication" sphere [7].

Contrary to the positivist conception, the constructivist approach considers that safety is, above all, a social and organizational construction, which is the product of the symbolic representations that the operators build together, in action. From this perspective, the safety conditions reside, in particular, in the organizational and human variables. This ability of the organization to fix dysfunctions would be mostly related to a clear definition of everyone's role and a strong personal responsibility [8].

From the perspective of this approach, safety is considered a "dynamic non-event". Thus defined, safety becomes a problem of interaction, elaboration and management of the representations that will give meaning to the situations experienced by the operators. Risk management is only partially the result of the application of some principles established at the level of theory. Risk management is a continuous process of learning from past experiences, one's own or others [9].

In this constructivist approach, risk control is, above all, the ability of operators to anticipate and recover from abnormal situations. It presupposes an ability of the actors to understand the environment in which they are, starting from their own experiences; the perceived meaning of the various stimuli that reach them is the product of cognitive operations and not the result of a previously existing meaning independent of them. The constructivist approach also emphasizes the performance of the actors involved and the place of communication in everyday interactions; it considers communication as an integral part of an organizational structuring process.

2. HFACS: Human Factors Analysis and Classification System

HFACS, the Human Factors Analysis and Classification System is a general human error framework originally developed and tested within the US military as a tool for investigating and analyzing the human causes of aviation accidents. Based on Reason's model of latent and active failures, HFACS addresses human error at all levels of the system, including flight crew status and organizational factors [10].

Let's examine the accident investigation and prevention process separately for the mechanical and human components involved. Figure 1 illustrates the current process of investigating and preventing accidents caused by human factors [11].

This example begins with the occurrence of a flight crew error during flight operations that leads to an accident/incident. An investigation of human performance is then to determine the nature and causes of such errors. Of course, unlike the tangible and quantifiable evidence surrounding mechanical / electrical / hydraulic / technical failures in general, the evidence and causes of human error are generally qualitative and elusive. Additionally, human factors investigative and analytical techniques are often less refined and sophisticated than those used to analyze mechanical and engineering concerns. As such, determining the human factors that caused the accident is a "poor" practice at best; and as a result, the information entered in the database associated with the human factor should be rare, vague and insufficiently clearly defined. As a result, when traditional data analyzes are performed to determine common human factors problems in accidents, the interpretation of the findings and the subsequent identification of important safety issues are of limited practical use. Since its initial development, however, HFACS has been used by other military organizations (eg, the U.S. Army, Air Force, and Canadian Defense Force) as an adjunct to pre-existing accident investigation and analysis systems. By 2010 alone, the HFACS framework had been applied to more than 1,000 military aviation accidents, generating objective, data-driven response strategies while increasing both the quantity and quality of human factors information collected during accident investigations.

 vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 164-173

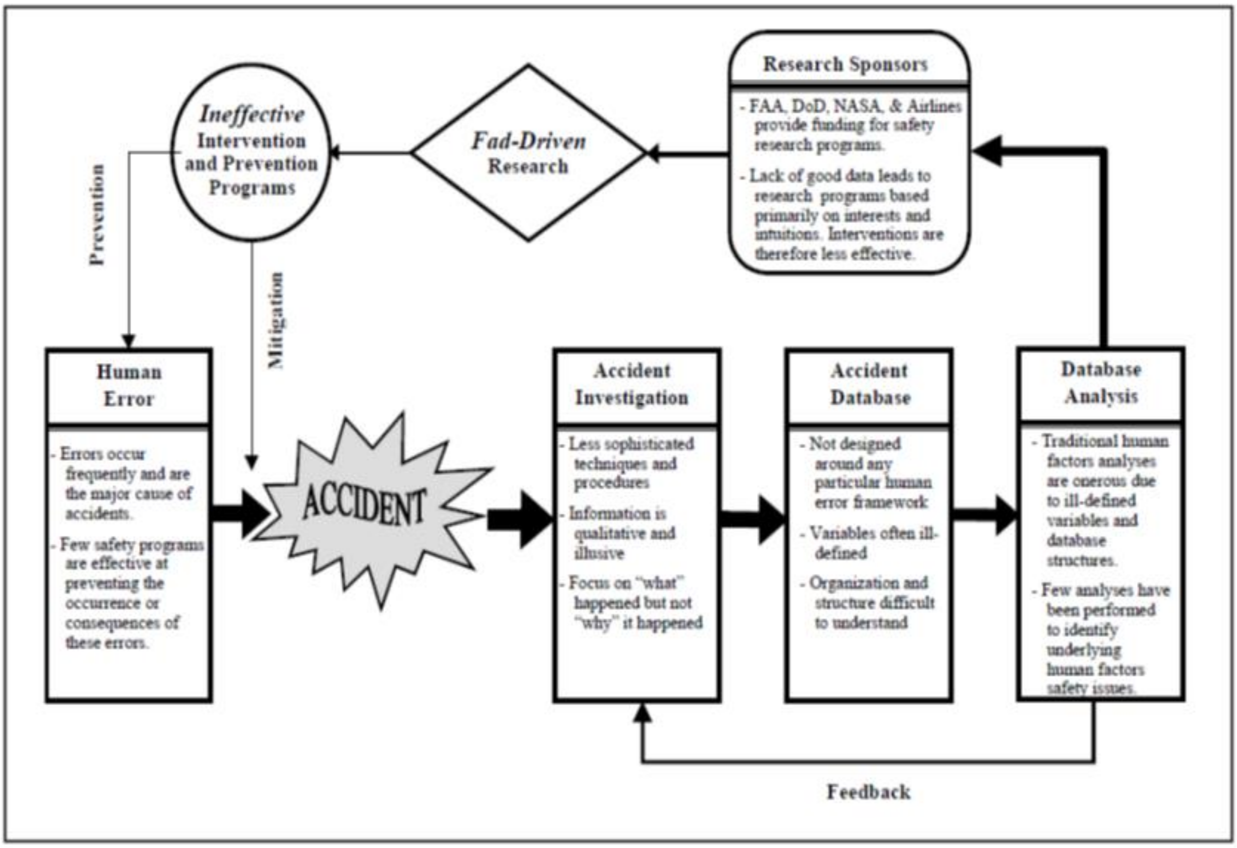


Fig. 1. The overall process for investigating and preventing aviation accidents involving human error (adapted from Shappell, S., Wiegmann, D., 2000) [11]

HFACS describes human error at each of four levels of "failure":
i. unsafe acts of operators (e.g. flight crew),
ii. preconditions for unsafe actions,
iii. unsafe surveillance/monitoring and
iv. organizational influences.

A brief description of each causal category follows (Figure 2). The HFACS framework bridges the gap between theory and practice, offering safety professionals a theoretically grounded tool for identifying and classifying the human causes of aviation accidents, but also of other categories of unwanted events that operates industrial technical systems. Because the system focuses on both latent and active failures and their interrelationships, it makes it easier to identify the root causes of human error [12].

3. Analyzing the probability of human error and human reliability (HEP & HRA)

For decades there have been methods that allow quantifying, for a given task, the probability of human error (HEP, Human Error Probability), using the relationship (1):

HEP= No. of observed errors/No of. Possibilities of error occurrence (1)

The role of these methods is to guide the evaluator in the process of estimating the probability of the occurrence of human error, and the percentage of errors is calculated starting from the databases that contain type errors and from the reasoning of experts. The first analytical approach to human reliability is based on breaking down the workload into elementary steps. The THERP (Technique for Human Error Rate Prediction) method proposed by Swain [13] and then developed in collaboration with Guttman [14] is presented as an example. The method for estimating the probability of occurrence of human error THERP includes, in essence, the following stages (Fig. 2):

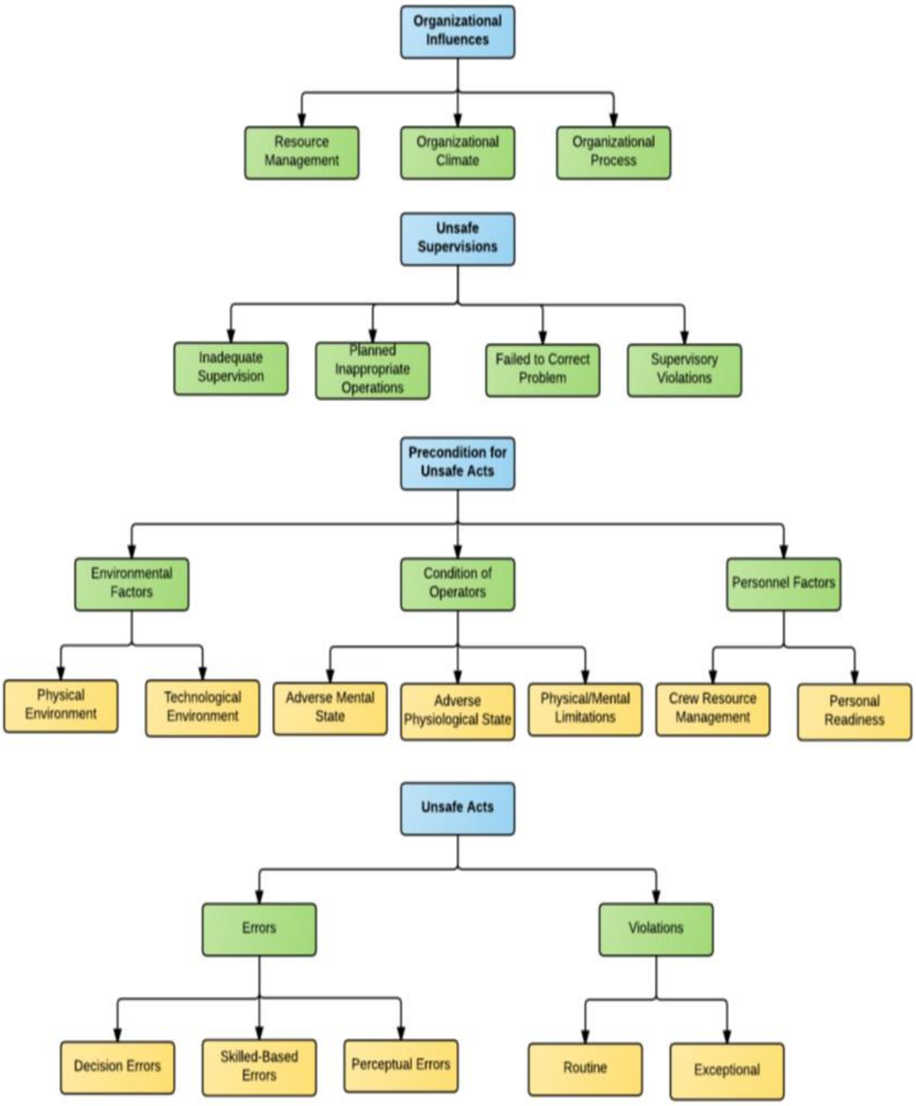


Fig. 2. General description of the human factors analysis and classification system (HFACS) (adapted from Shappell, S., Wiegmann, D., 2000) [11]

1. Defining system failures due to human errors whose probability is to be estimated;
2. Identification, listing and analysis of all operator tasks and their relationships with system functions;
3. Estimating the probability of the occurrence of errors;
4. Determining the consequences of human errors on the system;
5. Proposing measures to reduce the probability of system failure to an acceptable level.

The first stage allows getting to know the system and understanding its way of functioning. In order to achieve the mentioned objectives, a systematic analysis of the defects is carried out (by applying the AMDE method) and then a descriptive and causal analysis of their chaining, by AAD. In the second stage, the analysis of work tasks is completed by a list of elementary actions. The third stage is dedicated to the presentation, in chronological order, of the elementary actions in the form of an event tree of the type represented in figure 3. Each action is associated with three states, namely: success, failure and recovery. These states are represented by branches that each have associated a probability value obtained from the databases. For each action, the error probability P(E) is determined with the relation (2):

$$P(E) = P_1 \cdot K \cdot P_2 \tag{2}$$

where:

P1 is the basic probability;

K - correction coefficient depending on the stress level of the operator;

P2 - the probability that the error will not be recovered.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 164-173

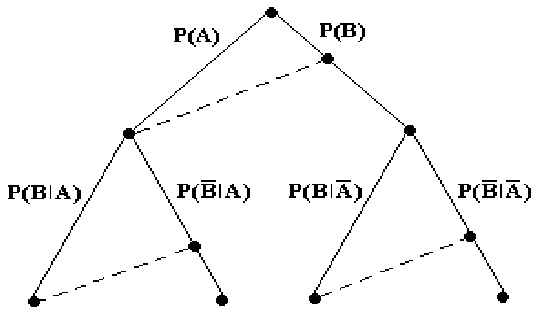


Fig. 3. The human reliability tree

The accuracy of the evaluation can be increased if the PSF (Performance Shaping Factor) performance modeling factors are taken into account, as in the case of the SLIM (Success Likelihood Index Methodology) method. The SLIM method was developed by Embrey [15]. It includes the definition of situations and work tasks and proposes the quantification of the probability of human error by taking into account the PSF values that influence the analyzed work tasks [16].

The success probability of the task P(S) is determined using relations (3) and (4):

$$\mathrm{Log}P(S) = a \cdot SLI + b \tag{3}$$

with

$$SLI = \sum_{k=1}^{n} PSF_k \cdot w_k \tag{4}$$

where:

n is the number of performance shaping factors;

PSFk - the influence of the performance factor;

wk - weight of performance factor "k";

a, b - constants whose values are set by experts based on the probabilities of errors evaluated for known work tasks (during a phase called "calibration").

Another pioneering method that can be used to quantify human error is the MAFERGO method (Méthodologie d’Analyse de la Fiabilité et ERGonomie Opérationnelle) which allows the study and analysis of operational reliability by combining ergonomic aspects with those related to technical reliability. The method involves going through the following steps [17]:

1. Structural and functional analysis: aims to describe the normal operation of the system/installation. The technical point of view describes the technological system and process, and the ergonomic point of view includes the description of the prescribed tasks.
2. Operational analysis: the objective of this stage is to ascertain the operational realities. The actual operation of the installation is analyzed and the level of availability is identified. At this stage, the ergonomic analysis refers to the activities of the operators and their degree of occupation.
3. Identification of malfunctions: going through this stage allows the listing of malfunctions, based on AMDE-type methods. The consequences of the dysfunctions on the activity of the operations are highlighted through the ergonomic analysis.
4. Causal analysis of malfunctions: it consists in establishing a causal graph of the scenarios of malfunctions, a graph that highlights the relationships between technical, human and organizational events.
5. Proposing improvement measures: its objective is to propose improvement measures that are validated by simulation, repeating the previous stages.

The joint study of technical and human aspects is the main original component of the MAFERGO methodology, a methodology that allows taking into account the real operating situations of a system. Quantifying human reliability remains a controversial topic. Moreover, there is a difference between the results obtained by using different methods existing worldwide, but also between the results obtained by different evaluators who apply the same method. Considering the previously mentioned aspects, it can be concluded that the qualitative approach is more pertinent. Moreover, this approach is predicted by Vanderhaegen, who proposes an original method of analyzing human reliability, APPRECIH [18].

This method studies the consequences of human fallibility and allows the analysis of human activity according to the context of the work load. If for technical components it is possible to take into account almost all modes of operation and failure, in the case of human factors this is not possible, because the human operator is considered a reactive agent (reacting) to the states of the system. Deviant behaviors, in this case violations or violations of prescriptions, are not taken into account in this type of approach. Human reliability analysis methods allow determining the probability of error or success, being based on the analysis of human work. As a result, they represent the potential tools for analyzing human errors in the work system. The conventional approach to risk analysis is probabilistic, generally aiming to evaluate the probability of the occurrence of dysfunctions at the level of the components of the work system. Probability values are obtained from available databases that are often created by component designers and builders. The data is obtained through laborious tests, in which a very large number of identical components are requested many times. Such data banks are practically not constituted for human errors. As previously mentioned, the few available information come, in particular, from the field of the nuclear industry and are mainly obtained through simulations. Effectively, data banks are extremely rare and are specific to certain industrial fields, and the application in other fields is delicate and requires adaptations. For this reason, obtaining the values of the probabilities of the occurrence of human errors results, most frequently, from estimates made through the reasoning of experts guided by certain methods.

In the field of human reliability analysis, the probability of human error is the subfield that deals with human performance in a sense of empirical data. Human reliability analysis basically talks about three vectors which are: human action identification, human activity modeling and HEP –Human Error Probabilities [19].

That said, HEP is defined as the calculated probability that a work task will be performed incorrectly/nonconformingly within a well-known time period and in a sense of relative frequency. Moreover, the methods and techniques used in calculating probabilities related to human performance must be as close to accurate as possible, where miscalculation or underestimation would lead to dangerous failures. Numerous methods are available to perform a probabilistic assessment of human error, of which we only mention here:

i. Human Error Rate Prediction (THERP) technique
ii. Human Error Evaluation and Reduction Technique (HEART)
iii. Standardized Site, Risk, Human Reliability Analysis (SPAR-H)
iv. Technique for Retrospective and Predictive Analysis of Cognitive Error (TRACEr)
v. Absolute Probability Judgment (APJ)
vi. Success Likelihood Index Method (SLIM)
vii.Paired Comparison (PC)
viii. Systemic Human Action Reliability Procedure (SHARP)
ix. Onboard Operation Human Reliability Analysis (SOHRA)
x. Cognitive Reliability and Error Analysis Method (CREAM))

In addition, in human error assessment, not all techniques deal with error probability calculation, as some of the methods are concerned with identifying the most repeated errors. In the context of HEP calculation, which results in a systematic quantification of human error, parameters such as performance modeling factors (PSFs) must be defined in advance. Determining the modeling factors is related to the error modes where the expert described some error modes that would help in the selection of PSFs. PSFs are defined as the effect of general human operations, which leaders/managers can list according to specific maintenance activities and the environment in which operators and technicians work [19]. The identification of PSFs is a part of the HEP calculation; in some methods such as THERP, the performance modeling factors are identified in the form of dependency patterns, and in the SLIM method, the PSFs are combined into a single-valued index/index. It is also important to mention that the variables that can control the quality of PSFs so that the modeling factors are considered a global and integrated aspect of the characteristics of an operator/technician, the work environment, the vision of the organization and the nature of the task that could influence human performance. Furthermore, in human reliability analysis, research has identified different terminologies related to HRA, such as Time Cantered HRA, where operators in maintenance departments are required to work for a longer period of time without stopping/pausing or setting up new equipment. Also in simplification efforts, a HEP calculation equation is demonstrated by and Böllhoff, et al. [20], as having the following form:

$$\text{HEP} = \text{Number of perceived errors}/\text{Number of possibilities for errors to occur} \qquad (5)$$

Quantitative approaches are concerned with assigning numerical values to the probabilities of human error, and qualitative approaches are usually concerned with classifications of failure modes to analyze an application or activity where human error occurs repetitively.

4. General model of the work system and factors shaping performance

In recent years, researchers in the field have offered several ways to identify human errors and their different classifications. Several taxonomies are presented in the specialized literature by Böllhoff, et al. [20] (Figure 4).

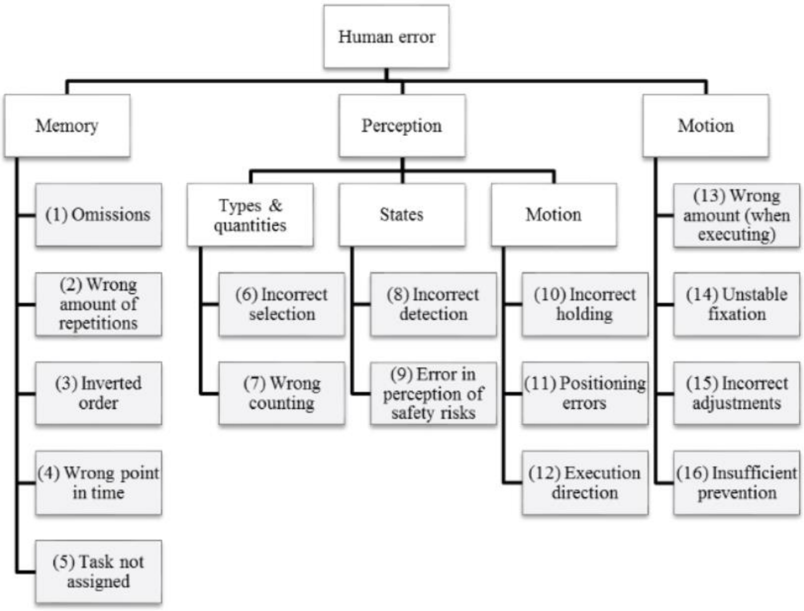


Fig. 4. Classification of human errors (adapted from Böllhoff et al., 2016) [20]

Figure 5 highlights the fact that human factors appear especially in the phases of design, construction, operation and maintenance. People's workstations are shaped by design engineers, the employer and the operator himself. The designer is not necessarily located only at the manufacturer, because the operating company (ie the employer) often sets the requirements very closely, through specifications, etc. [21]

Therefore, the designer neither estimates the deviations from the user's perception of risk at the time of operation nor takes into account his own error. However, systematic errors must be controlled by requirements determined by Safety Integrity Levels (SIL) and by new safety management systems [22].

Risk assessment and control processes still vary in many European countries. During harmonization there is a chance to integrate human input into system safety and performance to establish not only technical interoperability but also human interoperability.

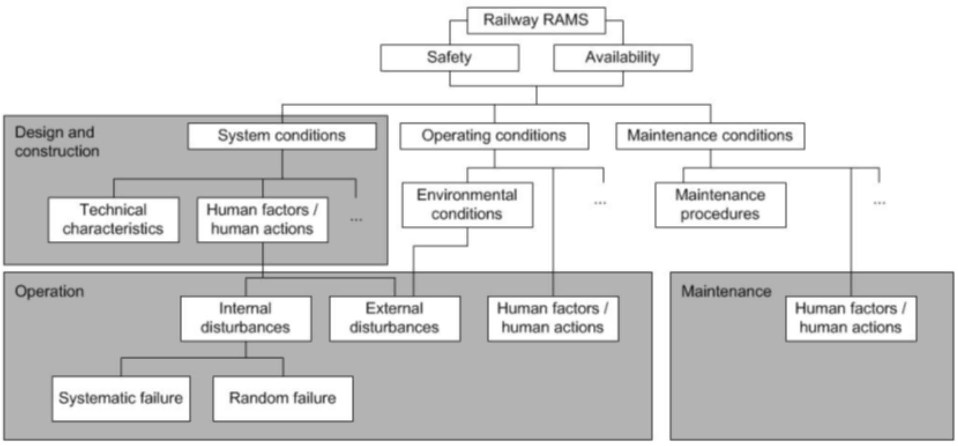


Fig. 5. Human factors in the system safety life cycle

Quantitative risk analyzes are required. So, a frequently used, but not sufficient, way to assess the human contribution to reliability is to integrate human error into classical risk analysis techniques. By using this approach, there is a risk of limiting the human operator to a single error-prone brick in a complex construct. The work systems model defines the core of the system as an interaction of a human operator, his task, and his tools (see center of Figure 6). The set variables are physical, personal and organizational factors, i.e. performance shaping factors.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 164-173

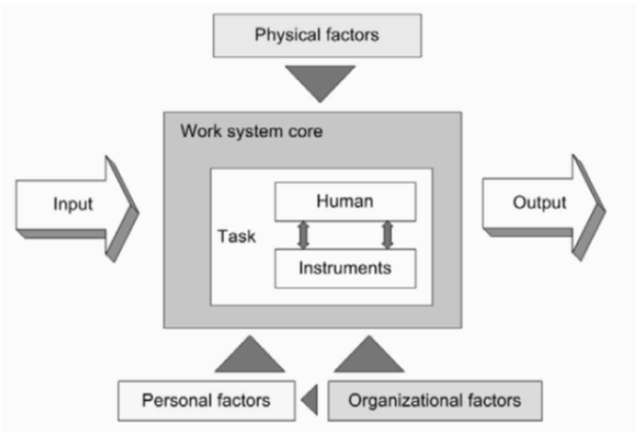


Fig. 6. General model of work system and factors shaping performance

A zoom on human reaction in these surroundings has been added to the core of the work system to account for the high mental demand of today's systems [23].

An extended approach to the multiple interdependent determinations that compete for the set of variation states of the performance modeling factors is shown in the generic network of influence in figure 7. Phenomena such as workload, stress and vigilance level will be understood here – somewhat simplified – as passive variables, i.e. dependent variables, and as a subjective human reaction to influencing factors. For example, alertness depends on fatigue (personal factor), work planning (organizational factor) and how human-machine interaction is designed. Rather, influencers offer the chance for changes through redesign. So, a change in the independent variables (causes) results in effects in the man-machine system. Personal factors can be with or without the influence generated by organizational factors. It should be emphasized that PSFs are constant for a working period, while the cognitive response changes with the situation and with the corresponding inputs.

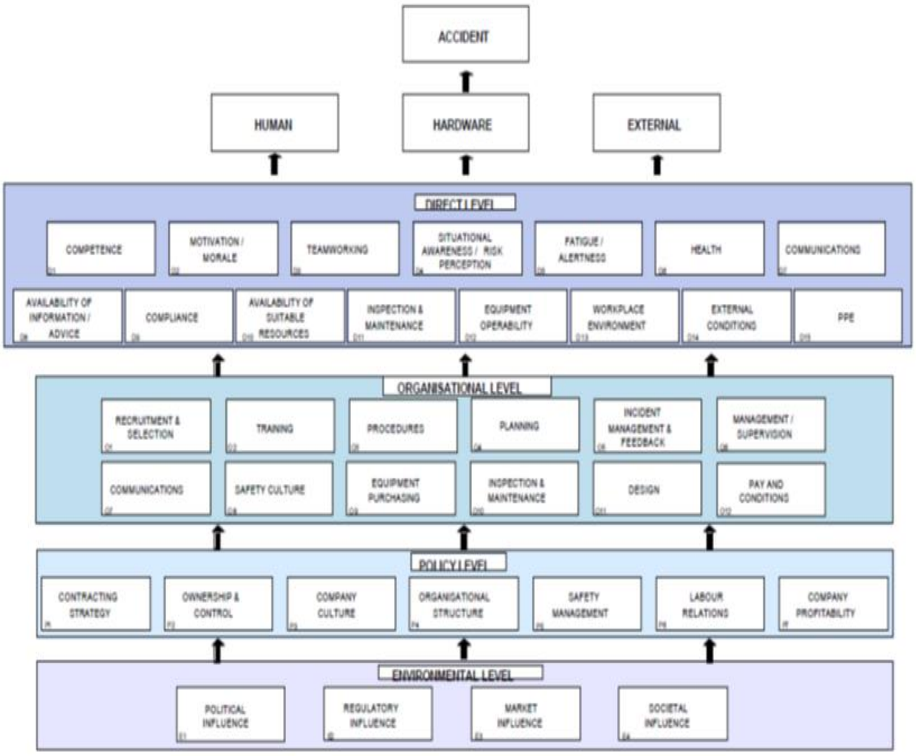


Fig. 7. The generic network of influence on human error

We can consider safety culture as an organizational factor, safety awareness as a permanent attitude of the operator and risk awareness as situation-dependent awareness. High subjective workload, less vigilance, incomplete situational awareness, and reduced risk awareness are examples of error-promoting conditions. So, the diagram provides a practical tool to qualitatively illustrate the performance influences (causes and effects) of a human-machine system.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 164-173

5. Conclusions

The holistic approach of industrial, technological, financial systems, etc., through the components of their hierarchical, organizational and decision-making structures, is a necessary condition to ensure their proper management. In order to have the expected importance and efficiency, risk management must be an integral part of the general management of the system. This has a specific importance in the management of technological systems, where system failure can be caused by the appearance of dysfunction in hardware, in software, in the organization or at the level of the human factor. The positivist approach to risk control, which consists in predicting and controlling risks during the design of systems, focuses on work equipment, the environment and the work load, and the human being is at the center of the constructivist approach, based on the concept of "safety culture" and on the development of the spirit of initiative within organizations. From the perspective of the systemic approach to professional security, the two approaches appear as complementary, with the task of harmonizing them falling on the practitioners. The corollary of a constructivist approach involves a process of auditing organizations in which not only the practices are systematically examined, but also the way in which the actors involved represent and elaborate them. In this framework, organization and communication, building each other, become emergent realities, forming an indissociable couple. This position, which allows the analysis of the set of elements that are sometimes, artificially, approached in isolation, gives way to a global heuristic for interpreting the phenomena. There are numerous examples of collective errors, occurring especially in stressful situations, during which some actors evade the decision-making act, transferring it to others. At the same time, the culture that this communication develops in the organization is not necessarily beneficial; the critical sense, in the sense of the permanent vigilance of individuals for any dysfunction and openness to novelty, can pale in the face of conformity. The transition from the conception phase to the operation phase is often delicate and sometimes opens real chasms of representation. Thus, the actors of the conception phase sometimes have the tendency to diminish the role of the operators and to consider them, if not as causers of problems, at least as a necessary evil. As for the operators, they do not precisely express their way of proceeding in a context of permanent expectation of a danger (absent most of the time), a stress-generating context. On the other hand, their representation on the system decisively influences the manner of reacting to the unpredictable and imposes constraints when the system is complex. This distance between representation and reality is the cause of many accidents and incidents which, in statistics, are considered to be generated by the human factor.

References

[1] **Cacciabue P.**, 2004
Guide to applying human factors methods - human error and accident management in safety-critical systems, Springer Verlag.

[2] **Chandler F.T., Chang J.Y.H., Mosleh A., Marble J.L., Boring R.L., Gertman D.I.**, 2006
*Human Reliability Analysis Methods: Implementation Guidance for NASA***,** NASA/OSMA Technical Report

[3] **Le Moigne J-L.**, 1990
Epistemologies constructivistes et sciences de l'organisation, in Martinet, A.C., Epistemologies et Sciences De Gestion, Paris: Economica.

[4] **Journe B.**, 1997
Positivisme et constructivisme dans la gestion de surete et de la fiabilite des centrales nucleaires, **Constructivisme et Sciences de gestion, Lille, France.**

[5] **Le Moigne J-L.**, 1990
*La modélisation des systèmes complexes***,** Editions Dunod, Paris, France

[6] **Chang Y.H.J., Mosleh A.**, 2007
*Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents: Part 1: Overview of the IDAC Model***,** Rel Eng & System Safety, 92(8), pp. 997-1013

[7] **Gort J., Starren A., Zwetsloot G.I.J.M.**, 2006
*Embedding safety in the company's core business - case studies***,** 3rd Working in Safety Conference, Delft, Netherlands

[8] **Hale A., Hovden J.**, 1998
*Occupational Injury: Risk Prevention and Intervention***,** Taylor & Francis, UK.

[9] **Păun A.P., Dura C.C., Mihăilescu S., Moraru R.I., Isac C.A.**, 2020
OHS Disclosures Within Non-Financial Reports: The Romanian Cas, Sustainability, 12, no. 1963

[10] **Reason J.**, 1995
A system approach to organizational error, Ergonomics, 38 (8), pp. 1708-1721

[11] **Shappell S., Wiegmann D.**, 2000
The Human Factors Analysis and Classification System-HFACS, DOT/FAA/AM-00/7 Office of Aviation Medicine, Washington, U.S.A

[12] **Shappell S., Wiegmann D.**, 2001
The Human Factors Analysis and Classification System-HFACS, Human Factors and Aerospace Safety, 1, pp. 59-86

[13] **Swain A.D.**, 1987
Accident Sequence Evaluation Program Human Reliability Analysis Procedure, NUREG/CR-4772, U.S. N.R.C.

[14] **Swain A.D., Guttmann H.E.**, 1983
Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications, NUREG/CR-1278, U.S. N.R.C.

[15] **Embrey D.E., Henderson J.**, 2012
An independent evaluation of the UK process industry association gap analysis tool for addressing the use of an operator as a SIL 1 component in tank overfill protection systems, IChemE Hazards XXIII conference, Stockport, UK

[16] **Embrey D.E., Humphreys P., Rosa E.A., Kirwan B, Rea K.**, 1984
SLIM-MAUD, an approach to assessing human error probabilities using structured expert judgement, USNRC Technical Report, Washington D.C., USA

[17] **Jouffroy D., Demor S., Ciccotelli J.**, 1999
An Approach to Integrate Safety at the Design Stage of Numerically Controlled Woodworking Machines, Integrated Design and Manufacturing in Mechanical Engineering ’98. Springer, Dordrecht

[18] **Vanderhaegen F.**, 2020
*Human-error-based design of barriers and analysis of their uses***,** Cognition Technology and Work, 12 (2), pp. 133-142

[19] **Islam T.M., Khan F., Abbassi R., Garaniya V.**, 2017
Human Error Probability Assessment During Maintenance Activities of Marine Systems, Safety and Health at Work, 9. 10.1016/j.shaw.2017.06.008

[20] **Böllhoff J., Metternich J., Frick N., Kruczek M.**, 2016
Evaluation of the Human Error Probability in Cellular Manufacturing, Procedia CIRP 55, pp. 218-223

[21] **Ziębacz I., Moraru R.I.**, 2017
*The quality of human capital and the risk in terms of evolutionary psychology***,** Quality - Access to Success, 18 (S1), pp. 51-56

[22] **Băbuţ G.B., Moraru, R.I.**, 2016
*Occupational risk assessment framework in Romania: an institutional perspective***,** Proc. of the 16th International Multidisciplinary Scientific GeoConference SGEM 2016: 2, pp. 635-642

[23] **Moraru R.I., Băbuţ G.B., Cioca I.L.**, 2012
Operational safety measures in human-machine systems: an overview, Proc. of the 18th Int Conf - The Knowledge-Based Organization: KBO 2012, pp. 86-91, Sibiu, Romania

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 174-182

TOWN PLANNING AND CADASTRE IN MINING AREAS. CASE STUDY OF THE FORMER BAIA BORȘA MINING ZONE, MARAMUREȘ COUNTY

Marius CUCAILĂ[1], Simona CUCAILĂ[2], Ioan BOROICA[3]*

[1] University of Petroșani, Hunedoara, mariuscucaila@upet.ro, tel. 0722514763
[2] University of Petroșani, Hunedoara, simona_cucaila@yahoo.com, tel. 0767919162
[3] Maramureș Museum, Sighetu Marmației, ionboroica@yahoo.com, tel. 0742400590

DOI: 10.2478/minrv-2024-0055

Abstract: *Some relationship between the cadastre and urban planning regulations can be detected since the second half of the 19th century, together with the introduction of the stable cadastre in Maramureș County and later in Transylvania. With the introduction of the cadastre, the first functional zoning of the territory of the cadastral localities was also carried out, which involved the cadastral registration of all parcels and the recording of the use categories, together with the delimitation of the intravilan or built area and extravilan lands grouped in fields according to the local toponymy. Both before the First World War and in the interwar period, town planning regulations paid little attention to the cadastre introduced in the second half of the 19th century, which is still in force today. During the communist period, urban planning, called also systematization, had a political purpose, especially in rural localities, when through the systematization sketches, the political authorities aimed to group within the intravilan area as narrow as possible to the advantage of agricultural surrounded areas and to standardize the built environment. Also during this period, delimitations of industrial zones, including mining areas, are introduced, as well as the first urban planning considerations regarding the planned evolution of these areas. In the post-December period, there are some regulations regarding urban planning, made concrete by several laws, especially the Law no. 350/2001 regarding territorial development and urban planning. The general and mining cadastre for mining or former mining areas does not find the place it should occupy in urban planning. The purpose of the paper is to follow through the chosen case study – the case of former Baia Borșa mining area, the particular situation of urbanism-cadastre relationship, with a focus on the relationship between the urbanism of mining areas - mining extractive cadastre. The working hypotheses are described based on the analysis of available working materials: archival documents and General Urban Plans. GIS analysis methods are adopted as work methodology. The results and conclusions will serve as a basis for the formulation of proposals that can be incorporated into future urban planning policies for mining areas.*
Keywords: *historical cadastre, mining cadastre, urban planning, former mining town*

1. Introduction

Acording to a report from 2015 of the Society for the Conservation and Closure of Mines, CORSERVMIN [1], from 1998 till 2015, by 11 Government Decisions, the definitive closure of 556 mines was approved. They were located on the administrative territory of 227 local communities from 28 counties. A number of 78 settling ponds with a total stored volume of 341.31 million cubic meters and an occupied surface of approximately 1,770 ha, as well as 675 mining dumps with a volume of 3,101.92 million cubic meters and an occupied surface of approx. 9,260 ha, were the subject of conservation. Safety works were carried out for 2,504 mining works connecting to the surface (galleries, shafts, raises). Closed mines are carring forth a high degree of associated risk due to underground technological voids that generate accumulations of toxic and potentially explosive gases, subsidence phenomena, uncontrolled surface collapses and massive landslides, destabilization of hazardous waste deposits with catastrophic consequences for adjacent communities and the environment with possible cross-border effects.

Integrating the issue of mine closures into urban planning and local development strategies in former mining towns represents a complex and multidimensional challenge for local administrations and urban

[*] Corresponding author: University of Petroșani, Hunedoara, mariuscucaila@upet.ro, tel. 0722514763

planners. The Romanian legislation on urban planning and local development, applicable to former mining localities, includes a series of laws and regulations that establish the necessary framework for urban planning, environmental protection and economic development.

Both urban planning and cadastre (together with real estate advertising) through the specific tools have in mind the organization of space in its multiple meanings: territory, land, real estate, etc.) and its relations with individuals or communities. The configuration of space by means of urban planning is recently approached [2] from the perspective of space as an overlap of dynamic particular spaces, which through conjugation, articulation implicitly changes their balance. În general, urban development plans provide for the implementation of contingent, interdependent actions with the aim of generating desirable development patterns. These actions include, according to urban planning legislation, various regulations, such as zoning, subdivision regulations and official maps. Urban planners are involved in land use regulation, with distinctions between plans and regulations. Urban planning regulations affect the system of rights that have a spatial reference, modifying or resizing some of these rights that otherwise seem to be well regulated by laws or social norms.

The main normative act that regulates land use and urban planning activities is Law no. 350/2001 on territorial planning and urbanism According to the law, territorial (spatial) planning represents the harmonization activity of territorial structures, through territorial development management and coordination the territorial impact of sectoral policies. It defines the types of urban planning documents required, including the General Urban Plan (GUP), Zonal Urban Plan (ZUP), and Detailed Urban Plan (DUP) and refer to urban and rural localities regulating the land use and the conditions of their occupation with constructions. The GUP is drawn up based on the development strategy of the locality and correlates with the locality's budget and public investment programs, in view implementing the provisions of the public utility objectives. Each administrative-territorial unit is obliged to draw up and approve its GUP, which is periodically updated every 10 years at most and includes short-, medium- and long-term regulations. In the first category are included: the demarcation of the boudary line of the built-up territory in relation to the locality administrative territory, the land use within the built-up area, functional zoning according to different land use, like those for the traffic network, areas with public servitudes, historical monuments and archaeological sites as well as the areas for which a special protection regime provided by the legislation. The modernization and development of the technical-municipal infrastructure, ownership type and the legal sale provisions, also provisions on the conditions of location and compliance of built volumes, of landscaped and planted areas, of the natural risk areas delimited and declared as such and risk areas are considered due to historical waste storages. In the medium and long term, its provisions cover aspects such as: the future evolution of the locality, the directions of functional development in the territory, the routes of the circulation and equipment corridors provided for in the national, zonal and county land development plans, delimited natural risk areas and declared, the list of the main development and restructuring projects, the establishment and delimitation of the areas of temporary and definitive ban on construction, the delimitation of the areas where urban regeneration operations are expected.

Other tools in urban planning are the general and local town planning regulations provided by Government Decision 526/1996 and taken over by Law 350/2001. They detail the urban conceptual elements as well as those regarding the town's development strategy, accompanied by their implementation measures.

These urban planning tools actualize the proposals included in the national, zonal and county land development plans to the locality level. The law expressly provides that urban planning documents have a specific regulatory character and establish rules that apply directly to localities and parts of them up to the level of cadastral parcels.

The cadastre is a foundational element in urban planning and local development strategies by providing detailed information on land ownership, boundaries, and land use. The legal framework in force in Romania is represented by law no. 7/1996 of the cadastre and real estate advertising. The cadastre law envisages the creation of a national record-keeping system at the level that involves the realization of technical works (plan elevations), economic (credit rating-evaluation) and legal-administrative (insurance, conclusion and keeping records of various acts and other documents) grouped in cadastral documentation (plans and registers). It has the purpose of registration in the register of real estate advertising, called land register, operation that has legal character. The cadastre, which involves the systematic recording of land parcels with their boundaries, ownership, use, encumbrances and easements, is essential for the effective management and development of urban and rural areas including the former mining areas. It has to provide a clear legal framework for land ownership, reducing disputes and enhancing property security, which is crucial for attracting investment and development. Cadastral records can be used to monitor changes in land use and urban growth, aiding in the assessment of urban development trends. Cadastral data supports the creation and enforcement of zoning regulations, ensuring land is used appropriately according to urban planning goals. Planners use cadastral data and maps to control development, ensuring it aligns with the urban plan and community needs, for spatial analysis and modeling, helping to predict future urban expansion and infrastructure needs, also help to identify environmentally sensitive areas and existing land uses that must be protected or managed carefully.

In the case of former mining localities having the potential to resume exploitation works, there must be correlations between urban planning and cadastre in order to ensure the protection and access to mineral ores while balancing other land uses, ensuring sustainable development. The cadastre, which involves the systematic documentation of land ownership, boundaries, and land use, plays a critical role in the redevelopment and revitalization of these regions. By integrating cadastral data with regulatory frameworks planners has to ensure that the future mining operations adhere to planning regulations, promoting orderly and lawful development. Combining cadastral data with environmental regulations helps planners designate protected areas and monitor the impact of former mining activities.

The mining cadastre can be used as a tool in territorial planning based on interrelationships established through the prism of the two specific branches of law: mining law and urban planning law. The concept of overlapping spaces was introduced long before through the mining law and applied through the extractive-mining cadastre through which the surface property rights e were separated from the mineral resources property rights. Both through urban planning and by the establishment of the mining cadastre, the exercise of certain rights involving individuals or collectives is assumed. These rights have as their object certain particular spaces that have a three-dimensional extension from the parcel, group of parcels, to the level of the territorial administrative unit, including rights over certain mineral ores from underground definitely identified and evaluated. In urban planning law, the rights beared on particular spaces with their attributes are taken into account.[3]. Certain rights, such as mining rights, are exclusive. Non-exclusive rights are usually associated with collective goods. In mining law, the attribute of exclusivity manifests itself as an attribute of priority, as a right conferred on the first applicant or the first occupier of the land intended for mining. Some rights, such as mining rights, are transferable to an individual or collective entities, but can also be withdrawn by the right holder, who is represented by the public authority. By laws or urban planning regulations, some rights, such as public properties, can only be granted, but cannot be transferred to another person.

Extractive legislation in Romania, consisting mainly of the Mining Law 85 of 2003 and the law and the Petroleum Law no. 234 of 2004, has no special provisions for the extractive cadastre. With the change in the ownership regime after 1989, it would have been necessary to carry out the cadastre in terms of mine closures. The normative-technical framework, already outdated in relation to trends in the cadastre, is provided by some orders of the director of the National Agency for Mineral Resources (NAMR) related to the mining book and the technical works of the mining cadastre. Taking into consideration the interrelationship with urban planning, the mining cadastre works have as their main purposes the demarcation of mining perimeters and locations, acquisition of land possesion and access, the creation of a topographic background necessary for determining the configuration of the ores and the technical data recording for mining book. The setting up of the shapes of the mining perimeters is left up to the the National Agency of Mineral Resources decision being in relation to the shape and dimensions of geological structures and ores.

Among the issues related to the interrelationships of urban planning, general cadastre and mining cadastre, two aspects will be analyzed by means of the case study method: the use of existing cadastral cartographic material, mining maps and plans as well as urban planning documentation as their use for GIS analyzes related to feasibility for construction.

2. Study case: materials and metods

2.1. Geographic, historical and geological background

Borsa located at the extremity southeast of Maramureș county, having been declared a town following the administrative reformfrom 1968, still having an important rural component today. The relief of Borșa is mountainous, uneven with large differences in level from 613 m up to an altitude of 2300 m. The mining activities documented since the 16th century took place within the area of Baia Borsa, today a district of Borșa. Relative to the built area of Borșa town, the Baia Borșa district is located at a distance of 6.5 km. Mining

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 174-182

activities have been carried out in areas with different levels of mineralization in igneous rocks in vein form or in crystalline shales in the form of compartmentalized stratiform bodies that occur as compact ore or as impregnations in various rocks. The mineralization zones, located in the basins of the Cisla and Vișeu rivers, are separated from the bedding and cover zones by banks of porphyrogenic rocks and are divided into three groups: the vein ores within the Toroioaga massif, the vein ores within the contact zone of the original andesite laccolite tertiary (Gura Băii, Valea Colbului, Valea Arinieșului) and the lentiform ores from the crystalline schists (Burloaia, Măgura, Vaser, Pui, Cornul Idei and generally those located in the northeastern part of the Baia Borșa district).

2.2. Materials

2.2.1. The stable cadastre as the basic cadastral plan for urban planning

Since the systematic cadastre has not yet been introduced in the city of Borșa, the cadastral plans made during the introduction of the so-called stable cadastre made in the period 1856-1864 can be used as a basic cadastral plan for urban planning works.

The first known functional zoning of the Borșa town was carried out with the introduction of the cadastre during the second half of the 19th century, with the two forms, the so called ”concretual” cadaste and stable cadastre. The ”concretual” cadastre introduced in the decade after 1854 also includes written and graphic inventory works executed without respecting the principles and methods of cadastral cartography. Only a little less than 215 fields named according to local toponymy have been inventoried and graphically represented in the form of figurative maps. They are important because the ”concretual” cadastre introduced during this period is still in force today.

Until 1856, skechy cadastral works were carried out drawing up the so-called "croqis" (see fig. 1), a town map drawn up for tax purposes without an inscribed scale, on which the built up area and 25 fields were confined according to local toponimy and the land use of that times. The field numbering was done concentrically, starting with built up area. After import into AutoCAD Map of the scanned map turn out that 1:144000 scale was used, convenient for framing the town within three frames of map sections measuring 33cm x 28cm, a scale probably derivative from the one used during the Second Military Topographical Survey of the Habsburg Empire for the southeastern extremity of Maramureș county (1:2880000).

Fig. 1 Borșa cadastral ”croquis” drawn up in 1856. Source: Uzhhorod State Archives, Ukraine

The stable cadastre was introduced in the Borșa cadastral community between 1856 and 1864, when cadastral plans with the proximate dimensions of 33 cm x 28 cm were drawn up, grouped in folding collages from 1 to 6 pieces depending on their arrangement in the locality grid. [4] In this research, 187 black ink copies made of the cadastral plans (also called indicative sketches) with the standard graphic dimensions of of the cadastral grid of 65.82 cm x 56.67 cm on cardboard paper were used. [5]

The processing of the cadastral plans in analogue format was done by scanning them followed by georeferencing and mosaicking in a GIS environment to obtain the overall historical cadastral map. (see fig.2) The presumed projection system is Soldner Cassini, with corrections being made. In order to achieve a correct georeferencing, some field control points considered stable within the Baia Borșa mining area were used and compared with corresponding points on the cadastral plans.

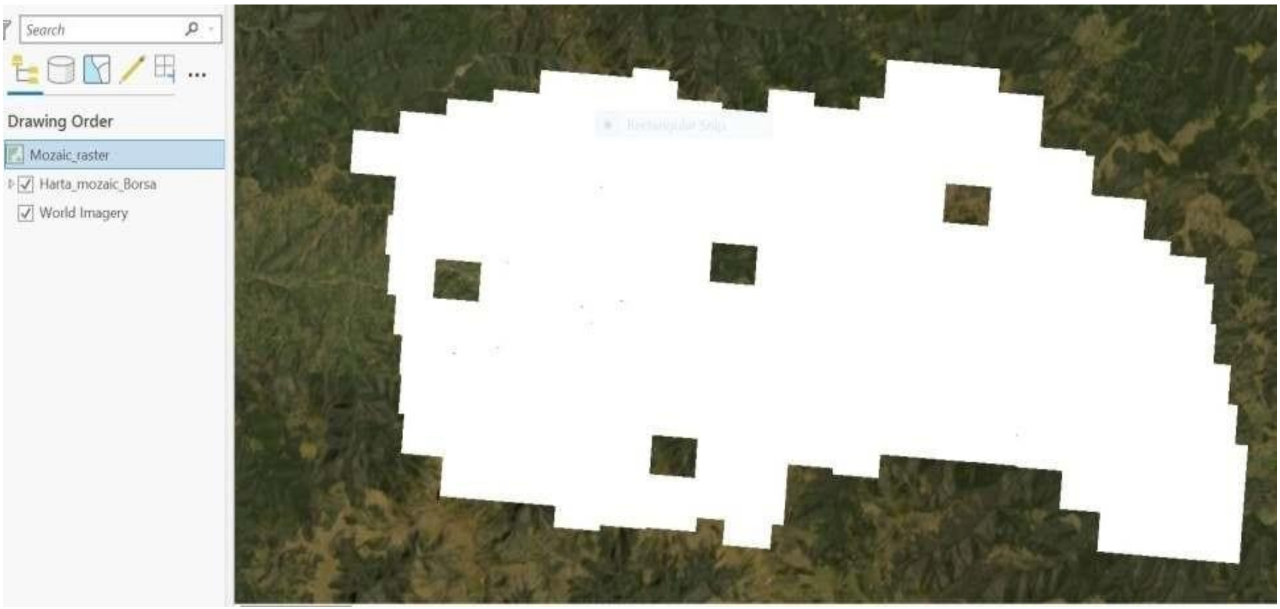


Fig. 2 The overall cadastral map of the historical cadastre obtained by mosaicking in a GIS environment. Source National Archives, Maramureș County Service

The general historical cadastral map of Borsa can be used through the correspondence registers [6] between cadastral and topographical numbers.

2.2.2. Urban planning documents from the communist period: systematization sketches

An important category of documents for the diachronic analysis of urban planning dynamics are the systematization sketches. The urban and rural systematization was a political program initiated and applied by the communist authorities since 1958, being the consequence of the application of Decree 545/1958 and the Decision of the Council of Ministers no. 1678 of November 20, 1959 and later of Law 58 of 1974 on the systematization of the territory and urban and rural localities. At the declarative level, according to some authors [6] the systematization had as its main object the correlation of different economic and social functions that plyed aut themselves on the same territory, as well as those of production, housing, communications, water improvement, etc., aiming at the balanced development of the territory and settlements. The systematization sketches were in fact urban planning documents that set up the functional zoning of the locality, municipal equipment, the boundary demarcation of buit up area, including some directives for the future development of the locality. The systematization details addressed a narrower territory, usually for the areas where new homes, social-building are to be located in civic centers were to be located. Starting from the obsession of the communist authorities to maximize the areas needed for agriculture, the inner areas of the localities were successively restricted from 1973, with consequences on the built spaces. In the case of the city of Borșa, the first systematization sketch was drawn up in 1970, being successively revised în 1977, 1992, with the drastic reduction of the urban area in 1987. In 1982, the mining precincts in the Baia Borșa area were included for the first time in the systematization sketches. [7] (see fig. 3) In the case of the present research, plans made in 1977, 1982 and 1987 were scanned and georeferenced in GIS.

vol. 30, selected papers from the 11th edition of
UNIVERSITARIA SIMPRO / 2024, pp. 174-182

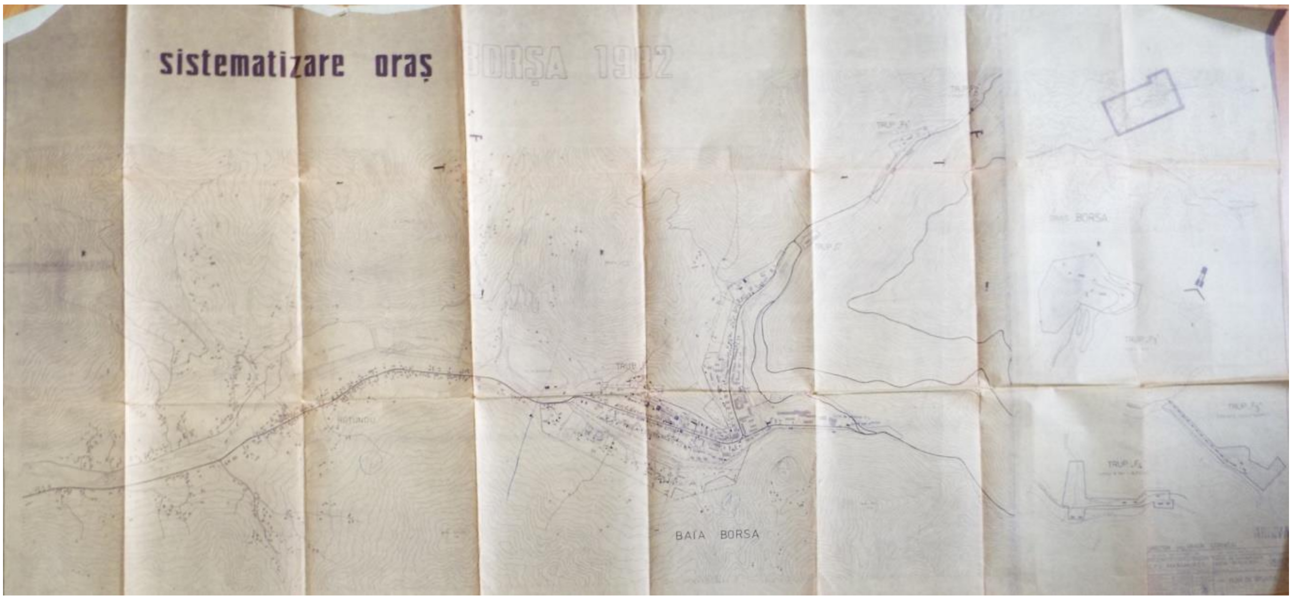


Fig. 3. Systematization map of the Borșa town including mining premises and a mining perimeter. Source: National Archives, Maramureș County Service

2.2.3. Mining maps with the ground projection of galleries

The maps drawn up for different mining projects on which the galleries of some mines are represented as projected on ground surface. In the case of Borșa town, the mining perimeters in from eastern part of the Baia Borșa district are of interest. These maps are useful for the ground demarcation of the closed mines. (see fig. 4)

Fig. 4. A georeferenced map with the representation of the mine galleries for the eastern area of the Baia Borșa district. Source: National Archives, Maramureș County Service

2.2.4. Recent General Urban Plans

Starting with 2000, the preparation of General Urban Plans became mandatory. For the city of Borșa, the urban plans drawn up in 2013 were available for research [8]. (see fig. 5)

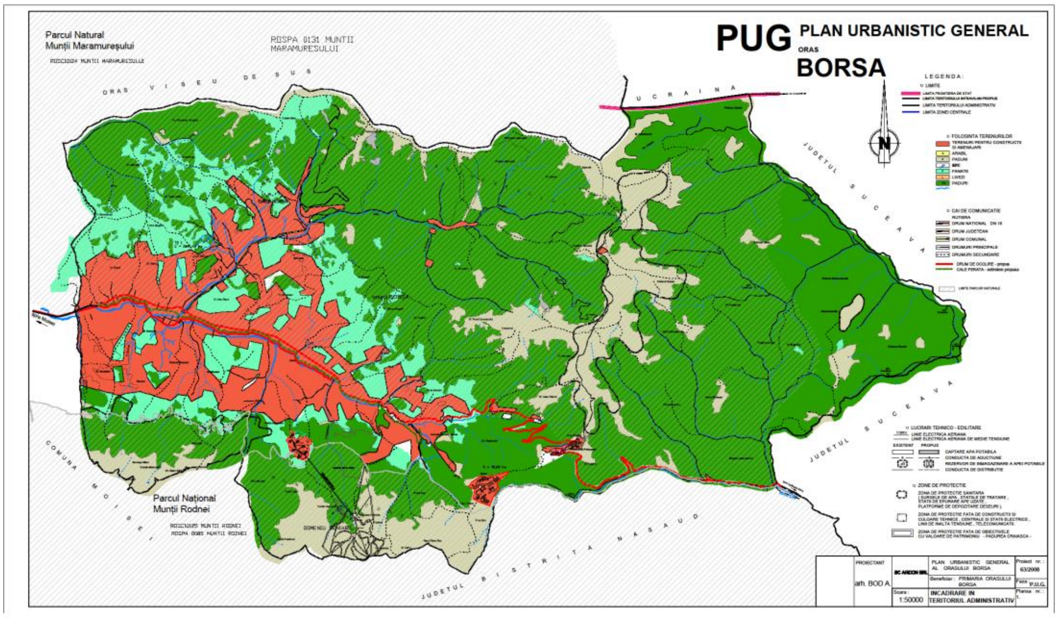


Fig. 5. Map of the Borșa town with the inclusion in the administrative territory. Source: City hall of Borșa

Since there are no longer any political constraints regarding the establishment of the built up area, an expansion of built area can be observed with the partial inclusion of some former mining precints.

2.3. Methods

For urban planners, the creation in GIS environment of a spatial database is useful. This comprises two stages: the articulation of a logical data model followed by the physical implementation of the data model, i.e. the implementation of the model schema.

The database has a tabular structure by initially defining a number of feature datasets. A feature dataset is a container that stores spatial entities (features) and non-spatial entities (objects) as well as the relationships between them having a common coordinate system. The following types of cadastral data corresponding to datasets in a geodatabase were considered: - National Agency for Cadastre and Land Registration NACLR database for the Borșa area, historical, mining, forestry and sporadic cadastres. The database for the Baia Borșa mining interest area can provide various information and analyzes for the urban planner. Querying the spatial database involves retrieving previously stored information by means of parameters or criteria. By using the Intersect tool, different geometric relations can be determined between the different competing cadastres: the historical, sporadic, forest cadastre and the surface projection of some underground mining works. (see fig. 6)

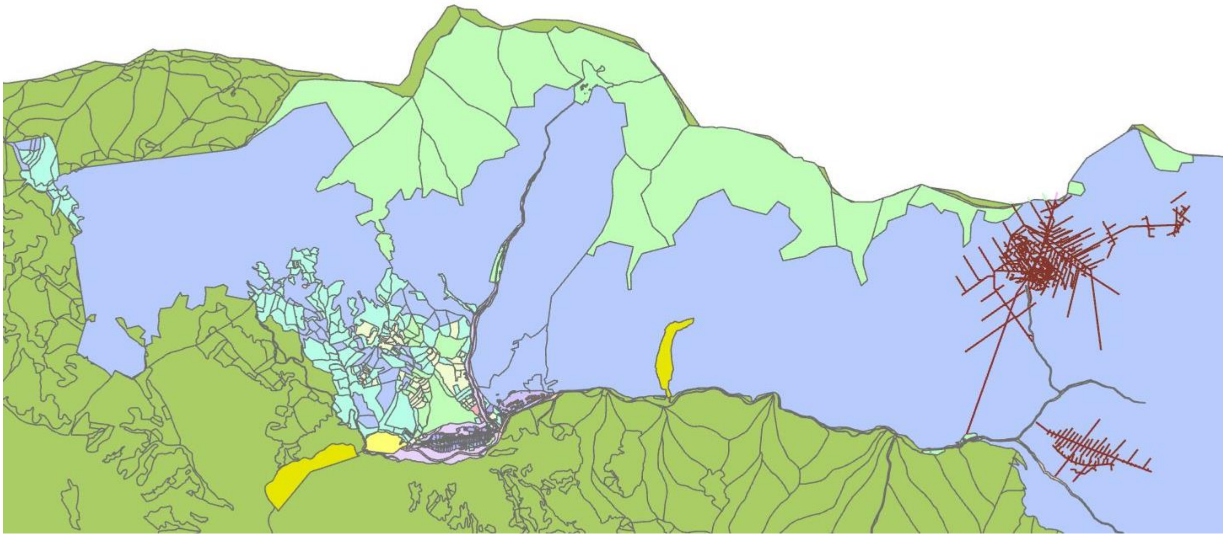


Fig. 6. Map resulting from processing by overlaying the historical, sporadic, forest cadastre in the Baia Borșa mining interest area

The materials above described, together with georeferenced satellite imagery and orthophotomaps can be used for various works with urban planning purposes. In the current urban planning legislation, only the forestry cadastre is mentioned, the prohibition of building in forest land and implicitly the reduction of the forest areas described in the forest work plans.

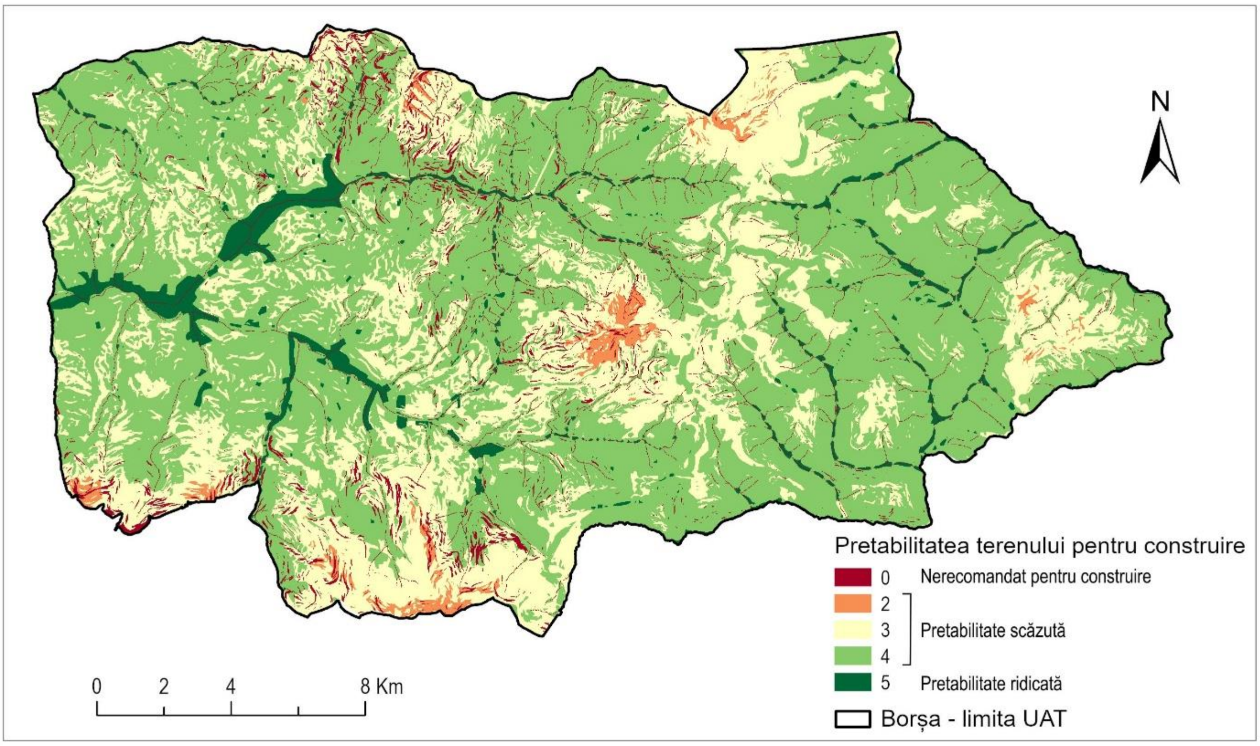


Fig. 7. Map of the city of Borșa with the suitability and favorability of the ground for construction and future mining facilities

By using several thematic layers of the raster type, a modeling in GIS environment with land classification in the city of Borșa was carried out depending on the favorability and suitability for construction with the help of the "Weighted Overlay" tool.(see fig.7). Each raster is assigned a weight in the model according to the importance that the favorable conditions have reported, respectively favorable or unfavorable. To these are added any restrictions regarding the arrangement of industrial and mining buildings. Thus it was considered that the use of the land has a weight of 40%. The slope in degrees has a weight of 30%. Accessibility expressed by the Euclidean distance from roads has a weight of 20%. The hydrographic network constitutes a restrictive factor for constructions, having a weight of 10% within the model.

3. Conclusion

The general cadastre and the mining cadastre, although they are tools that form the basis of the drawing up of General Town Plans in former mining areas, are little or even not used by urban planners. This is primarily due to legislative deficiencies, and on the other hand, the lack of concern for areas of mining interest on the part of local authorities and urban planners is obvious. Using the mentioned materials, a study of urban dynamics can be carried out to form the basis of some predictions regarding the further developments of local urban planning. The local town planning regulations do not include measures to protect the zones of mining interest, such as for example declaring them or part of them as protected areas that would make it difficult to clearing out mining within the region. Also, the current legislation on the mining cadastre will have to be updated. Also the legal provisions on urbanism will have to include correlations with the general and mining cadastre to ensure access and protection of areas of mining interest.

References

[1] **Societatea de Conservare şi Închidere a Minelor CONVERSMIN S.A. Bucureşti**,
Raport privind modul de îndeplinire a serviciilor de administrare şi gestionare a programului anual de conservare, închidere, reconstrucţie ecologică şi activităţi postînchidere a minelor pe anul 2015 realizate în baza contractelor subsecvente nr.12/19.02.2015, 82/30.09.2015 şi 94/07.12.2015,
https://www.google.ro/url?sa=t&source=web&rct=j&opi=89978449&url=https://conversmin.ro/wp-content/uploads/2022/07/Raport-activitate-CVM-2015.pdf&ved

[2] **Minea E. M.**, 2010
Influenţa noilor reglementări din domeniul cadastrului şi publicităţii imobiliare asupra activităţilor de amenajare a teritoriului şi urbanism, în Revista Transilvană de Ştiinţe Administrative 2 (26)/2010, pp. 40-54

[3] **Lewis D. Hopkins**, 2001
Urban Development: The Logic of Making Plans, Island Press, Washinghton, 2001, p.106-139

[4] **State Archives of Uzhhorod, Ukraine**
Archival Fund 125. The maps are available for viewing on the website
https://maps.arcanum.com/en/map/cadastral/?layers

[5] **National Archives, Maramureș County Service**
Archives Fund: Forestry Administrative Commission, file 117

[6] **Borșa Town Hall archive**
Collection of cadastral registers from the historical cadaster

[7] **Bold I., Matei M., Sabadeanu P.**, 1974
Sistematizarea rurală. Sistematizare și urbanism, Editura Tehnică, p. 19

[8] **National Archives, Maramureș County Service**
Archives Fund ARIS, project 3931-4