Development of lignite open pits - challenges and solutions

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Abstract. Before 1990, the problem of spatial development of lignite open pits was solved from the design phase, considering the fact that there were no restrictions related to land expropriation. The need for lignite in the energy sector justified any costs related to expropriation, demolition and environmental restoration. After the appearance of the legislation regarding the right to property on the land, major difficulties arose regarding the expropriation and compensation of the owners, and the lignite exploitation activity in open pits was often blocked either by the refusal of the owners or by the high prices demanded by them. Added to these difficulties are the ever-increasing costs related to environmental protection and the ecological restoration of degraded lands and ecosystems. In these conditions, it is necessary to find some solutions for the advance of the lignite open pits, so that the economic efficiency of the exploitation is maintained within acceptable limits. The paper presents such a situation and the solutions for the advancement of the open pit, in order to continue the supply of lignite to the thermal power plant it serves.

1 Introduction

The lignite exploitation activity in open pits involves the occupation and the degradation of extensive land surfaces, which can reach up to several hundred hectares or more. During the massive industrialization era, notably the political regime until 1989 paid special attention to supply energy to the economic sectors, and lignite had an important role in the energy mix. Thus, in 1989 the total production of lignite and brown coal reached the amount of 53.2 million tons [1], being obtained especially from the mining basins of Oltenia (Rovinari, Motru, Jilt, Husnicioara, Berbesti). The open pits, waste dumps and enclosures from Oltenia were occupying an area of over 15,000 ha (of which 11,926 ha were agricultural lands and 3,167 ha were forests).

Of the total agricultural areas affected by the exploitation of lignite in open pits, approximately 25% were represented by pastures and hay lands, with modest and unstable productions, and 5% of this area was occupied by orchards and hybrid vineyards, crops with a great diversity of indigenous species and varieties, but with modest productions. From the utilitarian point of view, the lands passed into the administration and respectively into the heritage of the mining units, approximately 68% of the total area was intended as...
fronts for excavations and waste dumps, and 32% of the surface was occupied by various related activities, such as: industrial and social constructions, roads and access ways, electrical grids, railway lines, regularization of water courses (for the regularization of the Jiu River, and for the construction of the reservoir upstream of the open pits of the Rovinari basin, it was necessary to occupy an area of approximately 1,000 ha) and over 10 village centers for displaced localities (several hundreds of hectares) [2].

Regarding the provision of land for the mining activity, two eras are distinguished in Romania: the first era from the beginning of lignite exploitation in open pits until 1990, and the second era after this year up to now. This distinction is due to different laws existing in the country over time which were the basis of the regulation of this issue.

Until 1990, the removal of the lands necessary for the open pit lignite exploitations from the agricultural lands and forest circuit was carried out by Decrees of the State Council and Decisions of the Council of Ministers, based on which they were transferred from one administrator to another free of charge, and for cooperative property, through compensation.

After 1990, when the new legislation regarding the form of individual ownership of agricultural land was introduced, securing land for the mining industry was achieved through direct negotiations with each private owner, and for forests, with ROMSILVA, a Romanian state agency.

Therefore, during the transition period, the expansion of private property was the direct result of the processes of decollectivization and privatization of agriculture, processes that began in 1990 through the application of numerous legislative measures: Decree Law 42/1990, Land Law 18/1991, supplemented and amended by Law 169/1997 and Law 1/2000, Law 247/2005 regarding reform in the fields of property and justice. This set of laws allowed for the retrocession of agricultural and forest lands to the original owners or to their heirs and established the limit to which the retrocession could be made. Initially, it started from the maximum limit of 10 ha of crops equivalent per family and reached the full retrocession "restitutio in integrum", according to Law 247/2005 [3].

The environmental legislation related to the mining sector, both at the national and European level, oblige the mining operator to carry out ecological reconstruction works of the affected areas when the activity ceases and before the land is returned to the former owners or to the local authorities. This process of ecological reconstruction must restore the land at least to its initial state, or bring it to the level of a functional ecosystem.

Also, throughout the exploitation period, the mining operator has the obligation to monitor the quality of the environment in the area of influence, to adopt the best practices and work techniques that allow minimizing the environmental impact and to have response and intervention procedures in situations of accidental pollution.

As a result of the difficulties related to the expropriation of the land, more and more problems arise regarding the development of lignite open pit exploitations according to the initial projects, comparative studies being necessary from a technical and economic point of view. Such a situation is currently found in the Berbesti mining basin, in the Alunu mining area.

2 Characterization of the Alunu mining area

2.1 Morphological conditions

From a morphological point of view, the Alunu mining area belongs to the hill areas in the north-west of Oltenia region, which extend south of the Tg. Jiu – Rm. Vâlcea depression. It includes a hilly area with altitudes between 320 and 450 m, which decrease towards the
southeast, being crossed by the valleys of the Amaradia, Olteț and Târâia Rivers and the valleys of their tributaries. The valleys fragment the geological formations within the perimeter up to minimum elevations of approx. 360 – 310 m [4]. The fragmentation of the overburden rocks led to the existence of slopes, where the stratigraphic structure, but especially the nature of weakly cohesive and non-cohesive rocks facilitated the production of natural landslides, stabilized over time, but possible to be reactivated in the context of poor weather conditions or due to excavations from the overburden [5-7].

From a geotechnical point of view, the hills of Amaradia are classified as high-risk areas, according to Law 575/2001, annex V – regarding natural hazards [8]. The fragmentation and possible displacement of the rocks can also be related to the historical erosions of the Olteț River.

2.2 Deposit conditions

Formations of Pliocene age participate in the geological composition of the Alunu open pit area (of which the Olteț exploitation perimeter is a part). The coal layers are confined in Dacian formations, represented by an alternation of clay, marls, sands and different combinations of them, with pronounced variations of lithological or granulometric facies, both vertically and horizontally [9, 10].

Clay/marly rocks predominate in the bed and the roof of the coal layers, with frequent intercalations of sand or of various granulometric structures, characteristic of sandy clays and clayey sands, more or less compact and consolidated [6, 7].

It is also worth mentioning the upper sedimentary deposits belonging to the Romanian and the Quaternary Period, consisting of weakly cohesive and non-cohesive rocks, trapped in a sandy-clay material, over which were deposited clays, sandy clays and sandy marls with metric thicknesses. It is also noted the existence of alluvial terraces along the watercourses, dejection cones, diluvial deposits and, above all, some areas with natural landslides that are periodically reactivated as a result of the influence of hydrometeorological and climatic factors [4].

The lithological structure of the Dacian, Romanian and Quaternary formations allows the infiltration and storage of water in the mass of rocks and the formation of aquifer layers and horizons. As a result, conditions for saturation of clayey rocks are created, which determines the modification (in the sense of worsening) of their resistance characteristics. The supply source of aquifer layers and horizons is represented by atmospheric precipitation and infiltrations from the hydrographic network [9].

The coal layers, with exploitable thicknesses from 1 to approx. 4 m, have a complex structure, being made up of several banks of lignite, separated by sterile intercalations. Such a structure creates difficulties in the technological extraction process, as a result of the need for selective excavation, at the same time affecting the geometry of the excavation fronts. Moreover, the presence of undulations of the layers and their inclination of 2 – 5° from N to S and from W to E, forces the excavation in bed for the horizontalization of the base of the open pit, which represents another difficulty in the excavation process with high-capacity bucketwheel excavators [10].

The average overburden ratio (cubic meters of sterile rocks/tones of lignite) of approx. 6.49 m³/t, with variations from 1.39 m³/t to 17.19 m³/t, calls for a large volume of excavations in the waste dumps, and the variation of the linear one is conditioned by the morphological structure of the land surface, which creates great difficulties both in ensuring the continuity of the excavation fronts and in ensuring their geometry. All this leads to substantial difficulties regarding the provision of geotechnical conditions for the safety and security of extraction activities.
From a tectonic point of view, the Amaradia-Târâia lignite deposit, of which the Olteț mining perimeter is a part, is slightly affected by tectonic disturbances. The coal complex is contained in a wide monocline, oriented W – E, with inclinations of up to 5 – 10° S. Locally, it presents small scale undulations and some stratigraphic charts, which are not highlighted precisely enough, considering the 200 x 200 m exploration network, with drillings [5, 6]. The existence of such a network does not detail the exploration of the deposit from a structural and tectonic point of view, the existence of some micro faults or fracture lines being possible at the layers level.

3 Technical solutions for the open pit development

Analyzing the development possibilities of the Alunu open pit exploitation in the Oltet perimeter at this stage, three options of advancement were identified (Fig. 1), as follows:
- To advance to the south, in the area of the viaduct pillars;
- To advance to the southwest, in the area of houses belonging to the village of Rosia;
- To advance to the west, toward Caprioru Hill.

Fig. 1. Variants of advancement of the work fronts.

3.1 Advancing in the area of the viaduct pillars

In the second part of the 1980s, the construction of an 8 km section of railway between the towns of Alunu, Vâlcea county, and Seciiurile, Gorj county, started. At the local level, in connection with the Băbeni – Alunu railway and the Târgu Cărăbunești – Seciiurile railway, this section was to create a direct railway link between Râmnicu Vâlcea and Târgu Jiu, and at a national level, together with the Vâlcele – Bujoreni Vâlcea section, it was due to reduce the distance between Bucharest and Petrosani by 91 km. The works on the Alunu – Seciiurile section started in 1987, first tackling the most complex infrastructure on the route: the construction of the Alunu Viaduct (coordinates: 45°00´21,4´´ N; 23°47´59´´ E) and the digging of three tunnels (Roșia, Seciiuri and Dobrana). The deadline for the completion of the work was 1991 [11], but currently only the seven pillars and the two abutments remain on the ground (Fig. 2).

The advance in the area of the viaduct pillars involves demolition works by detonation and debris removal (including debris transport and storage). Detonation works are sources
of seismic shocks that, through the vibrations produced, can change the stress state in the massif. The shocks generated by the vibrations exert both vertical and horizontal forces on the slopes, which can lead to the reduction of the stability reserve by 10 – 15% and can even produce landslides. Vertical forces reduce the effective normal pressure on the potential sliding surfaces, which leads to a decrease in the angle of internal friction and cohesion, while horizontal forces act as thrust forces and have the most unfavorable effect on stability.

Fig. 2. Alunu Viaduct - location, photo Google Earth 2023 [12].

Based on the dimensions of the pillars and in view of the above information, we can estimate the configuration of the pillars and their dimensions (underground part) (Fig. 3).

Fig. 3. The pillars and the abutments of the Alunu Viaduct - photo 2023.

According to the regulations and the pillar execution guidelines, we can predict that the diameter of the pillars is 1,008 mm. As far as their distribution under the pillar’s footing is concerned, this is an arrangement in parallel rows. Based on the dimensions of the pillar’s footing we can estimate that the number of these underground pillars is 6 (six). The minimum foundation depth of the pillars is 20 meters. According to the topographical map, the dimensions for the two abutments are:
- East side abutment – measurement at the base: 16 x 8 meters;
- West side abutment – measurement at the base: 18 x 6 meters.
The approximate height of the two abutments is 20 meters.
The total volume of the structure to be demolished is approximately 5,770 m³.
Considering an average price of 46 Euros/m³ for the demolition works, we estimate the final cost, strictly related to the demolition, to be 265,420 Euros. Therefore, for an exchange rate of 5 RON/Euro, the demolition costs expressed in RON will amount to approx. 1.33 million RON.

For the estimation of the total demolition process, the costs of relocating the machines used by the demolition company will have to be taken into account too, costs that can reach 3 Euros/km. At the same time, transporting the debris resulting from the demolition area to its storage place will also have to be considered. Taking into account the transport of the debris at a distance of 2.5 km, using dump trucks with a bucket capacity of 18 m³, an additional cost of 5,000 Euros will be reached. Thus, the costs of demolition and debris transportation amount to 270,420 Euros, respectively over 1.35 million RON.

Another issue that involves costs represents the relocation of the machinery owned by the open pit, relocating machines from the lignite exploitation site to the demolition site to do works such as debris transport. This machinery relocation may affect the coal production of the open pit, and the demolition action could extend over 3 months.

Costs add as follows: costs related to the excavation around the pillars, the operation of the machines relocated from the open pit exploitation (excavators, bulldozers and trucks - fuel consumption, maintenance, etc.), costs related to the interruption of the extractive process for at least 3 months, expenses related to obtain the necessary approvals for demolition, setting up the route for transport. Even if the resulting debris will be stored at the base of the waste dumps, and would be covered with the tailings resulting from mining activities, it will be necessary to set up a technological road, different from those existing at current time. This road will need to be able to support significantly higher mobile loads than normal, as dump trucks loaded with debris at the same rated capacity will have a much greater mass than normal, when loaded with sterile rocks or lignite. The explanation is given by the large difference between the volumetric weight of the debris (around 2,400 – 2,500 kg/m³) and that of the excavation rocks (approx. 1,180 kg/ m³ for lignite, respectively 1,782 – 1,911 kg/ m³ for sterile rocks [5-7]).

Therefore, the real expenses related to the development of the open pit in the viaduct area will be 2.5 – 3 times higher than those directly related to the demolition of pillars and abutments, reaching a value of approximately 3.5 million RON.

### 3.2 Advancing in the houses area

The development of the open pit exploitation in the area of the neighboring houses and lands, located on the administrative territory of the village of Roșia, involves a series of negotiations and expropriations.

The advance in the area of houses primarily involves negotiations in order to achieve expropriations, the impact being strongly felt on the mental state of land and housing owners who are forced by law to transfer their property rights to public ownership, with the aim of carrying out works of public utility.

According to Romanian legislation, "the expropriator is the Romanian state for the objectives of national interest, including strategic investment objectives and those carried out in public-private partnership of national interest". The expropriator is represented by "the Ministry of Energy, through the economic operators producing electricity that operate under its authority, for the electricity production works and for the mining works of national interest for the exploitation of lignite deposits..." [13].

Although the ownership transfer operation is carried out without the owner's consent, the state or the administrative-territorial unit must make available to the expropriated compensations, which must be fair and negotiated in advance. In the event that those involved fail to agree on the amount of compensation, this dispute will be settled in court.
The obligation to detach from the place where they lived their entire life, the involvement in these cumbersome procedures and court actions cause major stress. Stress has a psychological impact that can manifest as irritability or aggression, a sense of loss of control, insomnia, tiredness or exhaustion, sadness, problems with concentration or memory, or more. Ongoing stress can lead to other problems, such as depression, anxiety or burnout [14].

The expropriation process can take up to 1.5 – 2 years or even much longer (there are pending processes for over 20 years, since 2002) if the parties involved do not agree.

As a result, mining companies cannot start or continue production activities and risk losing their investments. Sometimes, due to reasons strictly related to owners and experts, the costs of acquisition/expropriation of land and houses belonging to private parties for mining activities are quite high compared to the market [15].

In general, people expropriated of houses and/or land demanded sufficient compensation, good employment positions and houses to meet their basic needs.

Among the main problems encountered by the mining company in the acquisition of private buildings and the respective lands are:
- Large amounts requested by the owners (tens of Euros per square meter, far above the market value of the properties);
- Failed negotiations;
- Absence of property documents;
- Long duration of expropriation procedures;
- Employment requests;
- Unidentified owners, etc.

Analyzing the purchase prices for several properties for which the expropriation procedure was completed, it was found that the average price is approximately 76 Euros/m² of built-up land, while for unbuilt land the price is 2.5 RON/m².

Based on this information, it is found that the purchase of land with a total area of 294,726 m² (Fig. 4) would lead to costs of approximately 22.4 million Euros, respectively 111 million RON, which means very large investments, therefore economic inefficiency for the mining company.

![Fig. 4. Lands and houses in private ownership.](image)

The very long duration and the uncertainty of the successful completion of the expropriation process represent a real problem for the mining company that cannot afford to stop the exploitation process for a long time.

Considering the given situation, i.e. high costs of acquiring owned land, long negotiations or misunderstandings, unidentified owners, the lack of property documents, the
long duration of expropriation procedures, the advance in the area of the houses results as a difficult and inefficient option, primarily from an economic point of view.

### 3.3 Advancing toward the Căprioru Hill area

The third solution analyzed for unlocking the exploitation activity is represented by the advancement of the open pit towards the Căprioru Hill area. In this case, there are no constructions, households or important objectives in this area, a fact for which no specific impact was detected but only the general one that cannot be avoided in such anthropogenic activities. In this direction, right at the top of the hill, there is a parcel road, a dirt road, which has no public interest and the access to it is difficult. This road can be easily diverted, according to necessity, and at minimal cost. However, exploitation in hilly areas is usually linked to the need to extract large volumes of overburden in order to reach the lignite layers, which could lead to an increase in the overburden ratio and exploitation expenses, and also to the probability of the occurrence of certain issues from a geotechnical point of view.

The possibility of career advancement in this area was taken into account, using for this purpose the exploitation method with classic equipment (excavation with mechanical shovel excavators with bucket capacity between 2 and 3.2 m³, transport with dumping trucks with a bed capacity between 16 and 18 m³ and leveling with bulldozers [16]) and the transport of waste to the internal dump. Taking into account the characteristics of the land, exploitation will be carried out in several stages, their number and geometric elements being different depending on the difference in level between the base of the open pit and the top of the hill, the design elements being presented in Table 1.

<table>
<thead>
<tr>
<th>Designed geometric element</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>General slope height, (m)</td>
<td>92.0 – 125.7</td>
</tr>
<tr>
<td>Number of steps</td>
<td>11 – 17</td>
</tr>
<tr>
<td>General slope angle, (°)</td>
<td>11 – 15</td>
</tr>
<tr>
<td>Step height, (m)</td>
<td>5.0 – 25.0</td>
</tr>
<tr>
<td>Berm width, (m)</td>
<td>15.0 – 117.93</td>
</tr>
<tr>
<td>Slope angle of individual steps, (°)</td>
<td>25 – 45</td>
</tr>
</tbody>
</table>

For the designed geometry, stability analysis was done, using the specialized Slide software; the working method is presented in Figure 5.

![Fig. 5. Stability analysis model for the designed geometry.](image)
The values of the stability coefficient obtained after running several sections indicate a stability reserve of over 30%, which validates the design elements from the point of view of the technical condition for the individual slopes and for the definitive slope of the open pit.

The volume of overburden that must be excavated to extract the lignite reserve of 700,000 tons, that is stored in the development area of the open pit was determined using AutoCAD software and amounts to 3.62 million m³ (Fig. 6).

This results in a overburden ratio of 4.4 m³/t, which is below the value of 7 m³/t imposed as the open pit exploitation limit in Oltenia, but also below the average value characteristic in the Berbesti mining basin. In economic terms, taking into account the operating expenses and the value of the lignite extracted, a benefit of about 15 million RON would be obtained.

4 Conclusions

In the current context of the law regulations regarding the occupation for land for the open pit lignite exploitation, blocking the excavation activities due to the impossibility of advancing according to the initial projects has become an increasingly frequent issue. For this reason, solutions must be sought to resolve such complicated situations, both from a technical point of view, as well as from an economic and environmental point of view.

In the particular case of the Olteț open pit exploitation, the Alunu exploitation perimeter, three possible advance options were identified from a technical point of view. The analysis of these three variants from the economic point of view revealed the following:

- The advancement in the direction of the viaduct involves the demolition of the pillars and abutments (including their underground parts) and the transportation of the resulting waste. In addition to the fact that such works are complex and expensive, for safety reasons it is necessary to stop the exploitation works for a period of approximately three months, which is linked to financial losses and the impossibility of securing lignite for CET Govora.

- The advance in the direction of the houses and lands belonging to the village of Roșia is conditioned by the expropriation processes, processes that have proven to be long and also expensive.
- The advance toward the Căprioriu Hill area allows the immediate entry into exploitation of the reserves using a discontinuous flow technology, which implies lower expenses. Even if it is a hilly area, the calculations showed that the value of the overburden ratio is acceptable from an economic point of view, and by respecting the designed geometry, the stability of the individual slopes and the general slope would be ensured.

From the point of view of the impact on the environment, all three options affect in particular the land and related environmental components (soil, flora and fauna), an impact that would be reduced once the mining activity ceases through landscaping and ecological reconstruction.

References

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