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SUMMARY

SCIENTIFIC LEADERSHIP:
Ph.D. Prof. Habil. Eng. **Lazăr Maria**

DOCTORAL STUDENT:
Eng. **Rada Constantin**

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UNIVERSITY OF PETROȘANI
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STUDY OF LANDSLIDES AND SLOPES IN THE QUARRIES OF THE BERBEȘTI MINING BASIN

SCIENTIFIC LEADERSHIP:
Ph.D. Prof. Habil. Eng. **Lazăr Maria**

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CONTENT

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Natural phenomena such as earthquakes, floods, tornadoes, hurricanes or landslides cause imbalances in nature with or without human intervention and are increasingly present on earth.

Landslides are increasingly common as a result of both natural and anthropogenic factors leading to a change in the balance of forces on rock masses and geological structures.

The causes of these landslides are manifold, but the effects always result in significant material damage, morphological changes to the terrain and, more seriously, sometimes in loss of life.

The problem of slope instability has always been of concern to scientists specialising in engineering geology and geotechnics. They have sought, on the one hand, to identify the causes and factors leading to natural imbalances and to explain the mechanism of landslide production, and, on the other hand, to assess the risk factors in order to make estimates of stability for forecasting purposes or to establish solutions to prevent and combat them.

The risks to which the population is exposed in the event of natural disasters such as landslides, and their increasing incidence on the surface of the globe, are causing more and

more researchers to turn their attention to earth sciences, and in various countries there are bodies investigating, inventorying and characterising areas at risk of landslides. Thus, the problems of slope and slope stability or of some earth structures are the subject of numerous international scientific symposia and conferences.

The mining industry, through its activities, i.e. the extraction and processing of minerals, has a long-term negative impact on the environment, including landslides in quarries and tailings pits.

The quantities of tailings resulting from the mining process are deposited over large areas, generating risk situations such as negative geomechanical phenomena such as landslides.

Given the extent of the landslide phenomena occurring in both operational and non-operational mining sites, we felt that further research was required.

The present thesis aimed to carry out a study of landslides and slopes produced in the Berbești mining basin, consisting in the research of landslide phenomena, finding and establishing the most effective methods to combat and stabilize landslides.

The paper is structured in seven chapters starting with the introduction and ending with a series of general conclusions and personal contributions.

The thesis contains 19 tables, 76 figures, 16 calculation relations and 2 annexes followed by 110 bibliographical notes, of which 9 are own works (as sole author, first author or co-author).

In **Chapter 1**, entitled "**Status of research in the field**", several case studies are presented, both international and national, on landslides and slopes produced in coal mines in Greece and Poland, as well as in Romania.

In these studies we looked at:

- the mechanism of slip initiation;
- the impact of the landslide;
- geotechnical investigation methods;
- solutions to stabilise and combat the effects of landslides.

Chapter 2, entitled "**Location and description of the Berbești mining basin**", in the context of the study of geomechanical phenomena in this area, presents aspects of geographical location, terrain morphology, geology and hydrogeology, climatic regime, flora / fauna, as well as social and economic data.

Chapter 3 entitled "**Mining activity in the Berbești Basin**" proposed to divide the Berbești mining basin into two perimeters, one with stopped activity and the other with operating activity, highlighting their current status.

Based on the history of landslides and a critical analysis of the factors and causes of landslides, reported in **Chapter 4** entitled "**Landslides and slopes in the Berbești mining basin**", a comparative study was carried out in which landslides outside the mining areas were also considered. The aim was to extrapolate the results to the Getic Subcarpathians and even to the Getic Plateau, so that the probability of landslide phenomena in any area of the mentioned regions could be assessed.

Chapter 5 entitled "**Study of the physico-mechanical characteristics of rocks in lithological structures and of the haly mix**" presents the physico-mechanical properties required in stability studies and the geotechnical parameters resulting from laboratory tests for each case studied are presented.

Chapter 6 entitled "**Investigations of the stability conditions of the land and slopes in the Berbești mining basin**", basically presents the stability analyses carried out for targets in both areas with ceased activity and areas where there are active quarries. The results of the analyses have been centralised in a single table, and on the basis of these stability analyses the risk of landslides has been determined for each case.

In Chapter 7 "**Designing stability measures**", solutions to prevent and combat the effects of landslides have been presented in general terms for the whole basin, and in each individual case we have dealt with our own solutions, which are detailed in the section on personal contributions and proposals.

The thesis finishes with the conclusions drawn from the research and a set of proposals for future research in the field.

Personal contributions to solving part of the problem are also presented.

As a result of the research activities to solve the aim of the PhD thesis, several general conclusions and specific conclusions have resulted.

General conclusions

- The Berbești mining basin is located in a hilly area strongly affected by negative geomechanical phenomena.
- The lignite deposits accumulated in the Getic Depression are confined in molasse deposits belonging to the Dacian - Romanian and Quaternary interval.
- From a climatic point of view, the Berbești mining basin is located in an area with a temperate continental climate with Mediterranean influences. The climatic conditions were highlighted by analysing and interpreting the values of meteorological parameters taken from Polovragi and Târgu Logrești weather stations.
- The activity in the studied perimeters is complex and quite diverse due to the natural resources.
- In the mining perimeter comprising the Ruget, Seciuri and Bustuchin pits, activity is at a standstill due to factors such as: drastically reduced demand for coal due to new energy production technologies, deep crisis in the Romanian economy, lack of investment programmes to make production more efficient, etc.
- The mining method used in the quarries of the studied perimeter is the "Mining method with transport of waste rock to the pits, with belt conveyors in continuous flow".
- The material deposited in the tailings ponds consists of rocks with low strength characteristics, such as clayey, sandy, marly rocks, which are particularly influenced by water.
- As a result of stopping the activity at the Valea Roșioara external landfill, negative geomechanical phenomena such as subsidence, plastic slippage of the steps have occurred, endangering the stability of the machinery in conservation on the steps of the landfill.

- In the quarries in operation (Panga, Olteț - Alunu, Berbești), the lignite layers are confined in sedimentary formations, the rocks being composed of clays and marls with a variable content of sand and dust.
- In the Berbești mining basin, landslides of a progressive or regressive type have occurred and are still occurring frequently, depending on the factors that have caused them.
- Landslides are frequently found in the hills of the Getic Subcarpathians and are caused by natural factors such as geological, morphological, hydro-geological, geomechanical and climatic factors, as well as anthropogenic factors and regional subsidence processes.

Specific conclusions

- Studying the history of landslides, the main cause that emerges is heavy rainfall, which has led on the one hand to increased groundwater levels and water pressure in rock pores, and on the other hand to the alteration of the strength characteristics of rocks due to water.
- The landslides produced at the working slopes in the quarries are due to the geometrical unevenness of the excavation faces caused mainly by the morphology of the terrain.
- The negative geomechanical phenomena observed at the tailings ponds were caused by the non-observance of the designed geometry as well as the improper intervention on the slopes.
- The comparative study carried out on the three perimeters aimed at illustrating the causes and triggers of landslides, as well as the common conditions leading to their occurrence (related in particular to geomorphology; stratigraphy, tectonics).
- The three studied areas are part of the same relief unit: the Getic Subcarpathians with the mention that landslides produced in the Getic Plateau (Argeș county) were also studied.
- The aim was to extrapolate the results of the study to the level of the Getic Subcarpathians and the Getic Plateau, so that the probability of landslide phenomena being triggered in any area of the region can be assessed.
- The history of landslides in the study area revealed a close link between geological, hydrogeological, hydro-meteorological, climatic factors and landslide phenomena.
- The comparative analysis showed that there were no landslides occurring simultaneously in the three areas studied.
- Mining operations influence the intensity and number of geostructural phenomena and landslide reactivation predominates in the mining perimeters while stabilized landslides predominated in Argeș county.
- The values of the geotechnical characteristics of rocks vary, even within the same geological formations. The nature of the rocks varies both horizontally and vertically, and so the values of geotechnical characteristics vary.

- The stability analysis was carried out using specialised geotechnical software, namely: Slide2 and SLOPE, this consisted in performing stability analysis of natural and artificial slopes with any geometry, both under seismic and static conditions, as well as in the case of the presence of water in the pores of the halded material or on the slope of the pit.
- In the present work the three methods of analysis, namely Fellenius, Janbu and Bishop, were used.
- Since the three stability analysis methods gave close values of the stability coefficients, only the minimum values resulting from the application of Janbu's method were considered.
- For each case study, the values of the physical and mechanical characteristics of the rock mixture composing the dumps were taken into account, and the values were chosen on the basis of the geometrical elements characteristic of the slopes, dumps in the Berbești mining basin.
- For the slope steps, the stability analyses were performed on sets of values corresponding to the geometrical characteristics, i.e. height and slope angle.
- The stability analysis carried out on the Ruget quarry step set revealed that steps I and II are stable due to the appropriate geometry.
- Steps III and V, as well as the general slope of the quarry, show unfavourable geometry, with high slope angle values and high heights.
- All steps composing the Valea Rosioara pit are stable, except step IV, where the stability factor value is at its limit, which requires measures to increase stability.
- The steps of the inner Berbești West pit have sufficient stability reserve in the medium term, but in the long term if stability needs to be ensured, rescaling is necessary.
- Given the low strength characteristics of the clay in the upper layer of the stratigraphic column, and its pronounced plastic behaviour, it can be said that it leads to instability phenomena such as disintegration, plastic failure, flow and/or sliding, regardless of moisture content.
- The geometry of the working face is non-uniform.
- The variation in physical and mechanical characteristics is pronounced and moisture-dependent.
- The mechanical characteristics (cohesion and angle of internal friction) decrease with increasing humidity and are dependent on hydrometeorological conditions.
- The large variety of physical-mechanical characteristics required static processing and the choice of values considered representative for stability calculations.
- Stratigraphy is variable and is only known with precision at the time of excavation.
- The results of the stability analyses carried out for the projected situation at the end of the quarrying activity in the Olteț - Alunu quarry showed that the slopes executed only in clays are unstable or at the equilibrium limit, while the slopes executed in clays and marls have a satisfactory medium-term stability reserve below 20 years, for slopes with heights of 10-15 meters being unstable for heights of 25 meters. In order to ensure long-

term stability conditions, rescaling calculations consisting of reducing the slope angle are necessary.

- The results of the stability analyses carried out show that the most unfavourable stability conditions occur in the case of face structures where the thickness of the clay layers at the top of the slopes exceeds 10 m.

- As a result of the assessment of the risk of landslides in the Ruget and Olteț-Alunu quarries and in the Valea Roșioara and Berbești Vest (inner) heaps, a general conclusion can be drawn, namely that if the current geometry is maintained, there are significant risks of landslides, the risks being much higher in the case of the quarry slopes than in the case of the heaps. It is therefore important to ensure that mining works are properly designed and strictly adhered to in order to maintain safety in the mining area and to minimise or eliminate, as far as possible, the risk of landslides and their effects on natural and man-made targets in the areas of influence.

Personal contributions

They are present in most chapters, and are intended to address some important issues in the field of mining stability. They can be summarised as follows:

- Observation and research of negative geomechanical phenomena produced in the whole Berbești mining basin over a long period of time.

- On the basis of the collected data we have compiled a history of negative geomechanical phenomena over the last 20 years in which we have identified the causes and factors of these phenomena and their consequences. This revealed that most landslides occurred mainly near mining perimeters, with both natural and anthropogenic causes.

- We carried out an analysis of the factors and causes of landslides (geological: stratigraphy, tectonics, hydrometeorological, seismic; anthropogenic: failure to respect slope geometry, failure to respect working technology, overloading of steps). Following this analysis we concluded that the anthropogenic factor has a rather high contribution in triggering landslides.

- Even if the design of the geometrical elements of the steps of a working pit or embankment was correct, in many cases the working technology was not respected.

- We carried out a comparative study on the causes of landslides in the Getic Subcarpathians area, covering two areas in the Berbești mining basin and one area outside the mining perimeter. The aim of the study was to comparatively analyse the stability of slopes and hillsides, the causes and triggers, the common conditions that led to the occurrence of landslides and to extrapolate the results of the study to a larger scale so as to assess the probability of landslide phenomena occurring in any area of the mentioned region.

- In order to determine the physico-mechanical characteristics of the rocks, samples were taken from boreholes located on the base grounds of the Olteț - Alunu and Ruget mining perimeters, as well as from the waste rock making up the tailings ponds of the studied perimeters. The turbid samples were collected in plastic bags and the undisturbed

samples were collected from cores, which were packed in such a way as to preserve the moisture and integrity of the samples.

- After sampling, I was able to analyse the samples in the Earth Mechanics Laboratory at the University of Petroșani, in order to perform stability analyses. In order to confirm the results obtained, I also requested some tests at the GeoLogic Laboratory in Călan. The values provided by GeoLogic confirmed and completed the data obtained at the LMP University of Petroșani.
- The laboratory tests carried out consisted in: grain size analysis both by sieving and sedimentation, determination of the volumetric weight by the stamping method; we calculated the porosity, the pore number, the saturation humidity and we determined the kneading and flow limit; we determined the direct shear strength by which we obtained the cohesion and the internal friction angle.
- Depending on the nature of the rocks we determined the percentage participation for each case.
- We carried out statistical processing to determine the representative values of the physical and mechanical characteristics of the rocks that make up the slopes of the quarries and heaps under study. These data were centralized and used effectively in the stability analyses.
- To perform the stability analyses we used the two specialized geotechnical software Slide2 and SLOPE in which we used the Fellenius, Janbu and Bishop methods.
- Following the stability analyses obtained after the application of Janbu's method, we carried out a slope stability assessment for each case studied where we identified the factors and causes of landslides and highlighted their effects.
- We plotted the dependence between slope geometric elements and stability factor values.
- We carried out risk analysis where we determined the landslide risk for each case studied in terms of vurnerability and probability.
- We identified and detailed the specific measures for maintaining slope stability for the quarries in the studied perimeter and their related heaps.

Proposals and future directions

- In the case of waste dumps that have been released from their burdens, it is recommended that they be returned to the economic circuit, which requires investment works costing in land modelling and restoration of the natural environment by returning them to agricultural and forestry use.
- The entire surface area of the hedgerows is to be zoned to ensure the slope conditions permitted for agricultural and forestry use.
- For each area a pedological study is required, followed by a memorandum with the details of the implementation of the pedological recommendations.
- Possibilities of implementing the solutions proposed in the paper at the level of mining perimeters still in operation.

- Taking into account the elements of the final slope resizing, it is necessary to redo the projected situation plans.
- Study of the possibilities of implementing a system of permanent monitoring of the areas, both in the field by means of classic topographic measurements and with the help of the latest generation of techniques such as GPS, satellite observations, photogrammetry using drones etc.
- Intervention plans should be drawn up in the event of signs of landslides or landslides occurring. It is also necessary to develop forecasts of landslide phenomena in the studied areas.

The development of an urban plan to avoid the location of civil or industrial buildings with a high risk of landslides, and the preparation of risk maps.