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THESIS
- summary -

RESEARCHES REGARDING THE GEOTECHNICAL RISKS IN CONDITIONS OF FLOODING OF FORMER LIGNITE QUARRIES

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PURPOSE OF THE THESIS

The aim of the thesis is to evaluate and analyze the geotechnical risks in the conditions of flooding the remaining gaps of the former lignite quarries. The thesis aims to initiate and encourage research in geotechnical, environmental engineering and management of the remaining gaps of former lignite quarries. Worldwide, there is an increasing emphasis on the recovery and restoration of lands affected by mining activities in the productive and/or ecological circuit. Flooding is one of the possible directions of reuse of the remaining gaps, this practice having major long-term benefits regardless of the type of reuse. However, the presence of water in rocks, a situation that materializes with the restoration of aquifer resources, with the flooding of the remaining gap and with the elevation of the water level in the dump, causes the worsening of their geotechnical characteristics and the increase of geotechnical risks such as landslides.

ORIGINALITY OF THE THESIS

The study is based on extensive researches that includes documentation, sampling, laboratory determinations and tests, statistical-mathematical processing, hypothesis formulation, analyzes, evaluations, interpretations and field observations regarding the rock behavior and the manifestation of negative geotechnical phenomena.

The elaboration of the methodology to evaluate the opportunity of flooding of the remaining gaps and the assessment of the geotechnical risks in the conditions of flooding of former lignite quarries in the Rovinari Mining Basin are the basic pillars of the thesis. The early assessment of geotechnical risks allows the establishment of measures to reduce the risks ensuring favorable conditions of stability and security of the objectives in the area.

The originality of the thesis consists in the way of combining the methods and methodologies developed with the classic and probabilistic ones existing in the specialized literature for solving the proposed problem and structuring the information similar to a guide. In addition, it recalls the need to recover degraded lands, aims to prevent the abandonment of mining perimeters at national level and encourages the application of the method of flooding the remaining gaps using all the resources necessary to properly restore their use as the benefits compensate over time.

SUMMARY OF THE THESIS

The doctoral thesis is structured on 3 parts and comprises 10 chapters that follow a logical sequence for solving the thesis problem.

In the 1st part of the thesis (consisting of chapters 1 - 3) a general description of the Rovinari mining basin and of the component mining perimeters is made and there is proposed a methodology for evaluating the opportunity of flooding the former quarries.

The proposed methodology is general in nature and can be applied to any type of quarry. In this thesis, the methodology was applied and verified for the particular case of the lignite quarries in the Rovinari Mining Basin. As a result of the assessment, the remaining gap of the North Pesteana quarry presents a major flooding opportunity.

The 2nd part of the thesis (consisting of chapter 4 - 7) contains a series of researches, studies and preliminary analyzes necessary to evaluate the geotechnical risks in the conditions of flooding of the remaining hole of North Pesteana quarry.

Chapter 4 completes the general description of the North Pesteana mining perimeter. The configuration of the remaining gap and the geometrical elements of the final slopes are presented. In addition, I have highlighted the objectives existing in the areas adjacent to the mining perimeter, being mentioned: individual households and agricultural lands belonging to the villages in the area, pastures, forests, the Jiu river and so on, in order to point out that, under the conditions of the manifestation of negative geotechnical phenomena the risks are significant, as they may involve both environmental destruction and material or human loss. The chapter ends with the results of field research and observations. The visual analyzes revealed the deformations and changes that may signal the occurrence of negative geotechnical phenomena. Superficial landslides, erosion zones, suffusion zones, cracks,fissures were observed, which did not affect the overall stability, these changes being remedied as the work front progressed. They can be problematic in the case of the final slopes that have a much longer service period.

Chapter 5 presents the hydrogeological characteristics of the mining perimeter. In this chapter, the description of the aquifer formations from the North Pesteana perimeter is made and the interest aquifers are highlighted. The supply sources of the aquifers and the way of their discharge, the quality of the groundwater, the calculation of the volumes of water that contribute to the flooding of the remaining gap and the estimation of the flood duration of the North Pesteana remaining gap from natural sources are also topics discussed in this chapter.

Chapter 6 presents the geotechnical characteristics of natural and saturated rocks and highlights the changes that occur with increasing humidity and rock saturation.

The data from geotechnical studies and from specialized literature, respectively the data obtained from the determinations and tests in the laboratory, were the basis for performing a statistical-mathematical processing of the values of the geotechnical characteristics of the rocks. The statistical-mathematical processing was carried out in order to obtain representative values of the geotechnical characteristics of the in-situ rock layers, depending on the nature of the rocks and the mixture of waste rocks.

In the case of in-situ rocks, the average values of the geotechnical characteristics were calculated, depending on the nature of the rocks (marls, clays, sands, boulders and gravels, lignite, vegetal soil), and in the case of mixture of waste rocks the weighted average values were calculated.

The results obtained from the data processing allowed the analysis of the final slope stability (Chapter 7) in three different stages:

1. before flooding - under natural water drainage conditions;
2. during the flooding period - under the conditions of the aquifer resources restoration, respectively of the increase of the water level in the dump and of the manifestation of the water pressure in the pores;
3. after the complete flooding of each step of the quarry, respectively of the dump - under the conditions of aquifer resources restoration, respectively of the increase of the water level in the dump, of the manifestation of the water pressure in the pores and of the hydrostatic pressure on the slopes as a result of their submersion.

The stability assessment was carried out in accordance with the existing recommendations in the literature. They set for the individual steps an interval that includes the optimum value of the stability factor, respectively Fs = 1.25 ÷ 1.5, and for the systems of steps a

limit was set indicating the minimum value of the stability factor, Fs> 3. The results of the stability analyzes are presented in tables 1 and 2.

Tab. 1 The values of the stability coefficients for the final individual steps of the quarry - Comparison of situations: drained rocks - saturated rocks - submerged slopes

Step	Stability coefficient values *		
	Naturally drained rocks	Rocks saturated with the influence of water in pores	Submerged slopes
I	1.235	1.109	1.478
II	1.605	1.218	2.355
III	1.259	0.790	1.712
IV	1.660	0.972	2.362

** circular sliding surface;*

Tab. 2 The values of the stability coefficients for the final individual steps of the dump - Comparison of situations: drained rocks - saturated rocks - submerged slopes

Step	Stability coefficient values *								
	average-σ (γ_a=16.33 kN/m^3; c=8.93 kN/m^2; φ=19.41°)			average (γ_a=17.87 kN/m^3; c=13.45 kN/m^2; φ=23.46°)			averagei+σ (γ_a=19.40 kN/m^3; c=17.98 kN/m^2; φ=27.52°)		
	Nat	Sat	Sub	Nat	Sat	Sub	Nat	Sat	Sub
I	1.371	1.199	2.230	1.771	1.588	2.720	2.150	1.901	3.133
II	1.219	0.916	1.602	1.538	1.199	2.009	1.784	1.434	2.299
III	1.430	0.944	1.763	1.792	1.250	2.164	2.160	1.564	2.548
IV	1.179	0.871	1.592	1.492	1.150	1.951	1.803	1.427	2.279

** circular sliding surface;; Nat - Naturally drained rocks; Sat - Rocks saturated with the influence of water in pores; Sub - Submerged slopes*

Analyzing the results obtained for the 3 situations, there were found large decreases of the stability coefficients at the III and IV in-situ slopes, of 37% and 42%, which is explained by the existence of large thickness aquifers layers, sands where the values of the resistance characteristics are small in saturated conditions.

In the case of submerged slopes, it was found that there are no balance problems in any of the situations. Moreover, there were increases in the stability coefficients of up to 43% in the case of the in-situ steps and up to 35% in the case of the inner dump steps, compared to the natural conditions.

The study of the geotechnical risk assessment in the conditions of flooding the remaining gap of the North Pesteana quarry is included in the 3rd part of the thesis (consisting of chapters 8 - 10).

Chapter 8 presents the major geotechnical risks that may occur when flooding the remaining gaps of the former quarries and describes the factors and causes that influence the occurrence of these negative geotechnical phenomena. The chapter ends with the effects of landslides that are highlighted by the method of impact networks.

Chapter 9 answers the question that gave rise to the research topic: "What are the geotechnical risks in the conditions of flooding the remaining gaps of former lignite quarries?" by conducting a study to evaluate the geotechnical risks in the actual conditions of the flooding of the remaining gap of North Pesteana quarry. It assesses the risks of sliding, liquefaction and suffusion that may occur at the final slopes of the remaining gap under its flooding conditions.

According to the studies carried out regarding the assessment of the geotechnical risks in the conditions of flooding of the remaining gaps of the North Pesteana quarry, it was found that the following risks exist:

• average risk of sliding of the slopes of IInd, IIIrd and IVth in-situ steps and of the slopes of the inner dump steps in natural drainage conditions;
• high risk of sliding of the slopes of Ist, IIIrd and IVth in-situ steps under the conditions of restoration of the aquifer resources and of the manifestation of the water pore pressure;
• high risk of sliding of the slope of IVth step of the dump in the conditions of complete submersion of the lower steps, of raising the level of the water in the dump and of the manifestation of the water pressure in the pores;
• average risk of liquefaction of the waste material in the inner dump;
• average risk of occurrence of suffusion phenomena at IIIrd and IVth in-situ steps.
The high risk of sliding estimated for steps I, III and IV of the quarry is explained by the presence of aquifer layers (gravel and sand) with large thicknesses. As a result, the overall resistance of the steps is worsening. Regarding stage IV of the dump there is a real risk of sliding with the flooding of the lower levels as the water level in the dump increases gradually before being equaled of the water level in the lake. As a result, the strength characteristics worsen, and the step geometry is not favorable under these conditions.

No liquefaction phenomena have been recorded or observed in the North Pesteana mining perimeter. However, the sandy fraction existing in the dump, of almost 50%, required the assessment of the liquefaction risk. According to the results obtained, liquefaction or not of the waste material are equally likely.

Suffusion phenomena recorded in the perimeter over time were manifested at the upper part of IVth step and at the lower part of IIIrd step and did not endanger the stability of the individual steps or the system of in-situ steps. The obtained results confirm that the risk of suffusion exists, but the problem of large-scale suffusion phenomena is not raised.

Erosion phenomena may occur at the final slopes as a result of superficial water leaks. In the case of lakes, erosion of the banks (definitive slopes of the remaining gap) can occur under the action of the waves.

There were no abnormal settlement phenomena, considering the functioning of the dewatering systems, which could have influenced the occurrence of these types of geotechnical phenomena, so it was considered that after stopping the dewatering systems and flooding the remaining gap the risk of abnormal settlements is almost nule.

In order to reduce the geotechnical risks, in chapter 10 it is recommended to apply the appropriate solutions for stabilizing the final slopes (resloping, leveling, compacting, cementing non-cohesive rocks, revegetation) and accelerating the flooding process (which can be performed concomitantly with dewatering works for the control of the water inflow from the aquifer formations in order to reduce the risk of suffusion) for faster raising of the water level in the remaining gap, as the water will manifest a hydrostatic pressure on the slopes and will act in order to increase the stability reserve. In addition, a series of measures for the functional reintegration of the lake into the landscape in safe conditions are recommended.

CONTRIBUTIONS

- Researches and observations in the mining perimeters of the Rovinari mining basin.
- Data collection.
- Elaboration of the methodology for assessing the opportunity of flooding of former quarries
- Applying the proposed methodology for the quarries in the Rovinari mining basin.

- Sampling and laboratory testing in order to determine the geotechnical characteristics of the rocks and the quality of the water.
- Statistical-mathematical processing of the values of the geotechnical characteristics (volumetric weight, cohesion, interior friction angle) in order to obtain representative values.
- Assessing the stability of the final slopes of the remaining gap under different conditions: before, during and after the submersion of each step of the quarry, respectively of the dump.
- Highlighting the effects of landslides (before, during and after the flooding of the remaining gap) using the impact networks method.
- Studying and establishing appropriate methods for determining the vulnerability and probability of occurrence of negative geotechnical phenomena.
- Evaluation of sliding, liquefaction and suffusion risks in concrete conditions of flooding of the remaining gap of North Pesteana quarry.
- Formulation of proposals and recommendations based on the results obtained, materialized in solutions and measures for risk reduction and functional reintegration of the lake into the landscape.

FINAL PROPOSALS

- Considering that each remaining gap is unique from the point of view of their characteristic conditions (location, configuration, morphological, geomorphological, orographic, hydrological, hydrographical, hydrogeological, stability, accessibility conditions etc.) it is recommended to adapt / correlate the existing conditions so that it is possible to evaluate the flood opportunity according to the methodology developed.
- Improving the methodology for evaluating the opportunity of flooding the remaining gaps by completing the evaluation criteria.
- It is necessary to carry out the necessary works in order to increase the stability reserve, taking into account the future external or internal influences, but especially the influence of water.
- Considering the negative effects of geotechnical phenomena, especially under the conditions of flooding, it is proposed to apply the measures described in order to improve the rock characteristics and to increase the stability of the final slopes of the remaining gap.
- Establishment of an efficient set of measures for the concomitant reduction of the risks of sliding, liquefaction and suffusion under the conditions of flooding the remaining gaps in an acceptable period of time.
- It is recommended to monitor the rise of the water level in the lake and the possible signals announcing the possibility of occurrence of one of the three types of analyzed risks.
- Conducting the geotechnical risk assessment study for any of the remaining gaps in the lignite quarries in Oltenia for which the flooding is opportune, in order to increase the security degree of the objectives in the areas of influence.

This resume summarizes the content of the doctoral thesis, emphasizing the original contributions.