UNIVERSITY OF PETROȘANI

MINES, OIL AND GAS

PhD. THESIS

-SUMMARY-

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PhD. THESIS

MONITORING AND ANALYSIS OF THE DISPLACEMENTS OF THE GROUND SURFACE AND THE CEILINGS BETWEEN THE LEVELS UNDER THE INFLUENCE OF THE UNDERGROUND EXPLOITATION OF THE SLANIC-PRAHOVA ROCK SALT DEPOSIT

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CONTENT

1. PURPOSE, OBJECTIVES AND RESEARCH METHODOLOGY OF THE DOCTORAL THESIS

Slănic Prahova Saline is one of the oldest rock salt mines in Romania, whose activity began in 1668, with the exploitation of the rock salt deposit at Băile Verzi, followed by other salt deposits. The exploatation continued with large trapezoidal chambers, and the intensification of deposit extraction occurred through the adoption in 1970 of the modern mining method, with small rooms and square pillars, on overstory horizons, at the Victoria mine, then in 1992, at the Cantacuzino mine.

In more than 300 years of mining activity, more than 15 million cubic meters of excavations were generated at Slănic Saline, which, along with the difficult geo-mining conditions, had the impact of the ground surface of the rock salt deposits and Old Mines and the Victoria Mine and the emergence of this saline of very complex instability phenomena. Only the excavations at the Unirea Mine, used for tourist purposes, and the last horizons at the Cantacuzino Mine have kept their stability.

Starting from 2019, mining has developed in depth, below +200 m elevation, at the level of the XIV horizon, from Slănic Saline.

In addition to the economic importance of the salt mine, due to the exploitation and valorization of the rock salt deposit, this salt deposit is also of particular importance from the point of view of the use of underground excavations for tourist purposes, as underground deposits or as a refuge for population, in case of major crises. Therefore, the long-term preservation of the stability of the underground excavations at Slănic Saline should be an absolute priority for the decision-makers at the level of the saline and at the level of SNS Bucharest Company.

The purpose of the doctoral thesis:

- Carrying out a stability analysis of the ground and surface constructions and underground resistance structures (pillars and ceilings) under the influence of mining excavations at the Slănic Saline, in order to continue mining and tourist activities in full safety.

Objectives of the doctoral thesis:

- Analysis and prognosis of the stability of the ground surface of Slănic Saline and of the ceilings between the levels of the Cantacuzino Mine;
- The study of geomechanical phenomena that determine the loss of stability of resistance structures and implicitly the deformation of underground excavations, with impact on the land and the objectives on the surface;
-Deciphering geomechanical phenomena, which can be extrapolated in depth and can serve to reconsider the design of horizons XIV (+145m) and XV (+129m), in order to increase the stability of underground structures and excavations;
-Prognosis the influence of the exploitation of the XIV horizon on the stability of the ground surface and drawing the maps with the displacements of the land surface.

Research methodology:

-Analysis of the technical, scientific and experimental database, stored at the Slănic Prahova Saline, which contains information extracted from the field and from a series of projects and studies carried out by several specialized institutions in the country;
-Realization of topographic leveling measurements of high precision on the landmarks mounted on the ground surface of Slănic Prahova Saline and in the underground of Cantacuzino Mine;

-Determining the configuration of the ground surface through aerial photogrammetry measurements;

-The transformation of some old maps with level curves, from analog format to digital format, which can be used as tools for analyzing the dynamics of the deformation of the ground surface, which is under the influence of underground mining;

-Using some statistical-mathematical analysis methods for interpreting the results of topographical measurements of displacement over time of landmarks mounted underground and on the ground surface and developing prognosis functions;

-Analysis of the state of stresses and strains developed around the excavations in the three mining fields at the Slănic Saline through numerical modeling in 2D and 3D, using the finite element method and the finite difference method.

2. SYNTHESIS OF THE DOCTORAL THESIS

The doctoral thesis entitled "*Monitoring and analysis of the displacements of the ground surface and the ceilings between levels under the influence of the underground exploitation of the Slănic-Prahova rock salt deposit*" is structured in seven chapters and addresses the subject of the stability of the ground on the surface of the Old Mines, Mine Victoria and the Cantacuzino Mine and of the ceilings between the levels of the Cantacuzino Mine.

Chapter 1 – *Description of the geology, hydrogeology and exploitation of the rock salt deposit from Slănic Prahova Siline* summarizes the main information needed in the stability analysis of the underground structures and the land surface today.

The rock salt deposit from Slănic Prahova has a lenticular shape, with a length of approx. 2,700 m, in the north-south direction, the width is between 800 and 2,300 m, and the maximum thickness is 499 m and it was probably formed during the regression of the flysch sea, being intensely folded in the middle of the syncline, due to the pressure that it appeared from the direction of the Homorâciu spur.

From a stratigraphic point of view, in Slănic and respectively in the area crossed by the Slănic Valley, there are deposits belonging to the Paleogene-Quaternary interval (Paleogene, Transition Series, Miocene, Pliocene and Quaternary).

Regarding the petrography of the deposit, the main types of rocks contained in the structure of the deposit are: rock salt, volcanic tuffs, clays, marls and sandstones. In the deposit, the rock salt appears in the form of stratiform deposits of white color, alternating with bands of gray salt.

From a tectonic point of view, the deposits within the perimeter are cantoned in a large Miocene syncline (the Slănic syncline), being located in its northern part over the Paleogene formations of the Homorâciu spur and are framed between two major fractures (the Audia line and the Cosminele fault) .

Also, in this chapter, the hydrogeology of the deposit is highlighted, which has a major impact in terms of the stability of the land, through the flow regime of underground water and infiltration water from the surface, respectively through the generation of dissolution voids in the salt massif.

The main factors whose interdependence influences the hydrogeology of the deposit are: geological (petrography of the deposit, water solubility of rock salt, tectonics of the deposit), hydrological and hydrogeological (hydrographic network, character of aquifer layers, precipitation) and anthropic (mining workings of the deposit).

The evolution of the exploitation of the deposit began more than three centuries ago, with the Old Mines (period 1668-1970), then with the Victoria Mine (1970-1990), the Cantacuzino Mine (1990-2019) and, today, with Horizon XIV - Slănic (2019-2023). The characteristics of the mining methods and technologies applied, the volume and the spatial architecture of the exploitation voids have the greatest influence on the development of the state of stresses and strains in the massif and implicitly on the degree of stability of the underground structures (rooms, pillars and ceilings) and the intensity of the ground deformation from the surface.

Chapter 2 – *The geomechanical characterization of the geological formations from Slănic Prahova* includes the main geomechanical database used in analytical and numerical calculations and in the stability analysis of underground structures (rooms, pillars and ceilings) and implicitly of the ground surface.

The database in this chapter, for the Slănic Prahova rock salt deposit, was extracted from various studies and test campaigns carried out, over time, in order to determine the geomechanical characteristics of rock salt, starting with those carried out by Prof. M Stamatiu (in 1959) and continuing with those obtained by ICEMIN Bucharest, the Mines Institute / University of Petroşani and MINESA-ICPM SA Cluj-Napoca.

In the first part of the chapter, the main physical-mechanical and elastic characteristics of the rocks and rock salt determined over time at Slănic Prahova Saline, by the institutes mentioned above, and the characteristics obtained from the samples taken from the XIV horizon, in the year 2022, by the University of Petroșani, for the geomechanical characterization of the rock salt massif below +200 m elevation, in order to exploit the XIV and XV horizons in depth.

To carry out the last study, from the two preparation galleries with a length of approx. 1200 m, located at the XIV horizon (elevation +148), samples were taken from the boreholes executed in 24 locations, placed at intervals of 50 m. The location in the field and the organization of the sampling operations were managed by the author of this thesis of doctorate. Physical (apparent specific gravity), elastic (modulus of elasticity and Poisson's ratio) and strength (compressive, tensile and shear) values were used in calculations using 2D and 3D finite element and 3D finite difference numerical models .

In the second part of this chapter, the rheological characterization of the rock salt from Slănic Prahova is presented, respectively the behavior over time of the rock salt, synthesized from various studies and obtained in the period 2022-2023 from the samples taken from the XIV horizon.

Time-dependent deformation (or creep) is the process by which rock salt can continue to deform without changing the stress value. Rock salt is characterized by three types of behavior: elastic, elasto-plastic and plastic. The elastic deformation is followed by a primary or transient deformation, after which the secondary or constant deformation stage appears. The last, tertiary or accelerated creep stage often leads to the sudden rupture of the rock salt.

In these conditions, for the design objectives, the deformation criteria are superior to the resistance criteria, because the breaking of most pillars occurs due to the accelerated creep phase, most often caused by constant loads.

From the rheological data presented in this chapter, it can be concluded that rock salt from Slănic Prahova is characterized by all three states of creep, namely: zone I, of stability; zone II, of relative stability; zone III, of instability. From which an immediate conclusion can be drawn that in order for the resistance elements (pillars and ceilings) to have stability over an unlimited period of time, they cannot be loaded with a stress greater than .

At the end of the chapter, an analysis of the factors that influence the geomechanical behavior of rock salt from Slănic Prahova Saline is presented, which is very complex and is affected by several factors, such as: the sizes of the grains (crystals), the bonding cement (cohesion) between granules, time, temperature, humidity, sterile inclusions and others. The effect of these factors on the massif of rock salt is expressed by the differences regarding its deformation and rheological properties.

Chapter 3 – *Methods for monitoring and analyzing the stability of the ground surface at Slănic Prahova Saline* presents the theoretical elements regarding the phenomenon of land deformation from the surface, the methods of analysis and prognosis of ground surface movements and the methods and techniques for monitoring the ground surface deformation below the influence of underground excavations, with special attention to the conditions of Slănic Prahova Saline.

At the beginning of the chapter, the specific phenomena of the continuous and discontinuous subsidence of the ground surface are described, which are also present at Slănic Prahova Saline, in the form of the continuous deformation of the land located above the Old Mines, the Victoria Mine and the Cantacuzino Mine and in the form of the caving chimneys generated of the dissolution voids of the old holes and the land around the wells. Also, a series of generalities are presented regarding the methods of analysis of sinking river bed parameters and the main parameters of subcritical, critical and supercritical sinkingof river beds.

A series of peculiarities of the deformation of the land on the surface of Salina Slănic Prahova are highlighted, with reference to the Old Mines, the Victoria Mine and the Cantacuzino Mine.

Taking into account the fact that the exploitation of the deposit continues in depth, below the horizon +200m, the principles of analysis of the impact of the exploitation of the XIV horizon on the stability of the land on the surface of the Slănic Prahova Saline are established. In this sense, the following methods of analyzing the stability of the ground surface are proposed: 1) empirical prognosis methods; 2) numerical computational methods (finite element and finite difference) of the stress and strain state; 3) the method of analysis of information and measurements of ground surface deformation and statistical processing of the obtained data.

The digitization of old maps with level curves from the surface of Slănic Prahova Saline represents a method of observation the dynamics of the deformation of the ground surface, in correlation with the evolution of underground exploitation. This method was applied by the author of the doctoral thesis on two old maps, one from 1962 and another from 1992. In order to obtain their digital elevation models, it was necessary to go through the following stages: scanning the maps and converting them into digital format; georeferencing of maps; map digitization by vectorizing contour lines and elevation points; importing the file into the GlobalMapper program and generating digital elevation models. The usefulness of these old maps in ground surface stability analysis depends on their degree of accuracy in analog format.

Monitoring the subsidence phenomenon using terrestrial and aerial photogrammetric methods, along with laser scanning, is an expeditious method for determining the configuration of the ground surface. The author of the doctoral thesis made an aerial photogram of the land on the surface of Slănic Prahova Saline in the year 2022, whose degree of precision was influenced both by the quality of the equipment used and by the quality of the data processing software purchased.

Monitoring the subsidence phenomenon with the help of topographical methods is a method widely used by the author of the doctoral thesis both for measuring the displacements of the ground surface of the Slănic Prahova Saline, as well as of the ceilings

between the levels of the Cantacuzino Mine. It is a very time-consuming method, which is based on precision leveling and consists of the following three phases: the design and materialization in the field of the topographic stations, the performance of topographic measurements and the processing of the data obtained from the measurements.

Chapter 4 – *The analysis of the stability of the ground surface from Slănic Prahova Saline* contains the database (in graphic and tabular format) obtained as a result of topographic measurements, carried out over time, on the displacements of the ground surface of the Old Mines, the Victoria Mine and Mina Cantacuzino, their statistical-mathematical analysis, the development of models for predicting the deformation of the ground surface, including after the sequential exploitation (in two slices) of the XIV horizon and the numerical modeling of the surface stability with the help of the 2D finite element method and the difference method finite 3D, for the current situation (year 2022) and after the sequential exploitation of the XIV horizon (year 2045 and 2059).

At the beginning of the chapter, two important factors that essentially contribute to the intensity of surface deformation are presented in detail, such as: the statistics of the evolution over time of the voids resulting from the exploitation of the deposit and the determination of the limit exploitation depth of the Slănic Prahova deposit (according to the criterion gravity loading, according to Fenner's theory and the creep behavior of rock salt). The elevations of the land today, in the perimeter of Salina Slănic, vary between 395 m and 525 m, and implicitly the natural state of stress is different at each horizon and from one horizon to another.

Depending on the rheological behavior of the rock salt from Slănic, 3 creep zones were identified, for which the following stability zones were defined:

Zone I: for the depth $H < 267$ m, elastic behavior of the rock salt massif - unlimited stability;

Zone II: for the depth H=267-476 m, elasto-plastic behavior of the rock salt massif - of relative stability;

Zone III, for the depth $H > 476$ m, plastic and visco-plastic behavior of the rock salt massif - of instability.

The three procedures for calculating the limit exploitation depth, presented above, lead to very close results from a technical point of view and confirm the fact that the exploitation depth of approx. 476 m, for the Slanic Prahova Saline, is a depth that, if exceeded, will cause quite serious problems in terms of stability, especially when the resistance structures are not correctly dimensioned. Taking into account the fact that the current depths at Slănic Prahova are a maximum of 380 m, for horizon XIV (+145m), this critical depth of 476 m, from which underground excavations will be affected by instability, will not be reached in the future near.

The specialists from the Slănic Saline practically carried out the organization of the topographical works, starting from 2003. The topographical measurements regarding the movements of the ground surface, through precise geometric leveling, on the old and new landmarks located in the land, starting from the year 2010, were carried out by the author of the doctoral thesis.

On the surface of the Slănic Saline, in the areas of influence of the Victoria, Cantacuzino and Old Mines, topographic landmarks were placed on which measurements of land subsidence were made, at intervals of approx. a year, starting in 2003, until now, on 105 milestones. The values of the measured vertical displacements and the values of the subsidence velocities of each landmark were stored in tabular and graphical form.

Based on the data obtained from the topographic measurements, an analysis was made of the evolution over time of the subsidence and subsidence speeds, for all landmarks on each alignment, located in the area of influence of each mine. The systematization of

the measurements carried out over time, until 18.05.2022, was carried out tabularly and graphically within this study. For all these benchmarks, prognosis / prediction functions have been developed regarding the evolution of dives and implicitly on the evolution of dive speeds over time. The maximum values of subsidence and subsidence speeds, on landmarks and on alignments, for each mine from the Slănic Prahova Saline were presented graphically and tabularly, for the end of the exploitation of the first slice from the XIV horizon (after 23 years, in the year 2045) and at the end of the exploitation of the second slice, respectively of the entire XIV horizon (after 37 years, in the year 2059).

In the last part of this chapter, the analysis of the influence of the exploitation of horizon XIV on the stability of the ground surface of Slănic Saline was carried out with the help of numerical modeling with 2D finite elements and 3D finite differences. The finite difference software FLAC3D-version 9. and the finite element software CESAR-LCPC2D-version 4 were used for the analysis of the stability of the ground surface of Slănic Prahova Saline.

2D finite element models in plane strain were made in three representative "east-west" vertical sections through the Old Mines, the Victoria Mine and the Cantacuzino Mine. The calculations were performed under the assumption of a continuous massif, homogeneous, isotropic, with elasto-plastic behavior, geostatically loaded.

The numerical modeling was carried out for the current situation of Salina Slănic (from the year 2022) and the perspective situation, after the full exploitation of the XIV horizon (the year 2059). Following the calculations, maps were obtained with the distribution of vertical displacements and horizontal displacements on the surface of the area of influence of the Slănic mining perimeter. These maps, in addition to their scientific purpose, can be used by the local city administration to update the general urban plan.

Chapter 5 – *Analysis of the stability of the ceilings between the levels of the Cantacuzino mine with the help of finite element numerical modelling* refers to the study of the behavior of mining excavations and resistance structures (pillars and ceilings) at the Cantacuzino Mine, with a focus on the last functional horizons, using 2D numerical modeling and 3D with finite elements.

In the first part of this chapter, a series of generalities are presented regarding the modeling of the stability of land and structures with the help of numerical calculation methods. Also, a general comparative classification of the numerical methods used in solving some problems of rock mechanics is schematized, with a special focus on rock salt deposits, in which the finite element method is defined as a differential method.

The finite element software CESAR-LCPC version 4., with the processors CLEO2D and CLEO3D, is used in this work for the stability analysis of excavations and underground mining structures and the surface terrain (presented in Chapter 4), from the Slănic Prahova Saline, with focus in this chapter on the stability analysis of the Cantacuzino Mine ceilings.

The second part of the chapter contains the actual analysis of the stability of the rooms and resistance structures at the Cantacuzino mine, through 2D and 3D numerical modeling with finite elements.

In order to analyze the overall stability of the Cantacuzino mine, two numerical models with finite elements were built, namely: one in 2D, in plane deformation and another in 3D. In the stability calculations, an elasto-plastic behavior law Mohr-Coulomb type without hardening was chosen.

Carrying out the analysis with finite elements in 2D, in plane deformation, and 3D, for the models defined above, required the following steps: establishing the limits (optimizing the dimensions of the models), the area of interest and the discretization of the models (densification of the elements in the area with large variations of stresses and

strains); determining the areas/regions (respectively, rock salt and surrounding rocks), the calculation assumptions (continuous, homogeneous and isotropic environment, with elasto-plastic behavior) and the introduction of geomechanical characteristics; imposing boundary conditions (differential blocking of displacements at model boundaries); establishing the initial and loading conditions of the model (geostatic request); making calculations and storing the results.

Although the 2D model is based on a number of simplifying assumptions, it allowed a denser discretization of the model. It also made certain results much more detailed than those obtained from the 3D model which, due to the large dimensions of the model, required a wider discretization with volume finite elements to make it feasible. The advantage of the 3D model is given by the fact that the results obtained from the calculations are expressed according to the 3 coordinate axes, x, y and z (respectively according to the E-W, N-S and up-down orientations), while those provided from the 2D modeling are represented only along two axes (respectively E-W and up-down).

As the 3D model is very extensive and very difficult to study in detail, this stability analysis was focused on the functional horizons of the Cantacuzino mine (horizons IX, X and XI).

The stability analysis of the rooms and resistance structures at the Cantacuzino Mine took into account the variation of the values of vertical and horizontal displacements, the values of compressive, tensile and shear stresses and the plasticization zones, developed inside the 2D and 3D numerical models. In order to establish the zones affected by instability, the values of the parameters resulting from the calculations were compared with the resistance limits of rock salt. The description of the geomechanical phenomena from the Cantacuzino Mine can serve as a basis for the analysis of the behavior and the design of the resistance structures from the XIV and XV horizons of Salina Slănic.

Chapter 6 – *The monitoring and analysis of the time behavior of the ceilings between the levels of the Cantacuzino Mine* based on the measurements of vertical displacements and field observations contains the description and prognosis of the geomechanical phenomena of instability developed in the structure of the ceilings between the levels of the Cantacuzino Mine, resulting from the analysis of the systematic measurements, carried out by - over time, on the vertical displacements of the floor of the ceilings, the analysis of the information and observations made in the field.

In the first part of the chapter, the analysis of the behavior over time of the ceilings between the levels of the Cantacuzino mine is presented, based on the measurements of the vertical displacements.

In order to monitor the vertical movements of the ceilings, several topographic landmarks were mounted on the floors of the V-X horizons, on which high-precision leveling measurements were performed periodically, starting in 2004. The landmarks were mounted on alignments in the areas of interest, there where the most pronounced vertical displacements or rupture deformations of the ceilings were highlighted. The auto inclined plane was used to transmit elevations underground from reference systems located on the surface. The topographical measurements were continued by the author of the doctoral thesis, starting with the 2010 campaign.

Based on the formulas for approximating the time evolution of dives (mostly power-type), it was possible to obtain the time after which the points on the floor, related to the selected landmarks, reach the critical subsidence. We note that these predictions are greatly altered by the characteristics of the fractures in the ceilings and the ratio of initial vertical to horizontal stresses.

It can be seen that the predicted stability period for the ceilings at the floors, taking into account the benchmarks with the highest cumulative subsidence at the level of each horizon, is variable, between the minimum and maximum value there are several times greater differences. This dispersion of the values of the stability periods is explained in terms of the very diverse geomechanical deformation phenomena suffered by the floors near the selected landmarks. Continuing the logic for which the analyzed landmarks were selected, we can state that the area where the destabilization process of a floor begins is represented by the landmark for which the predicted stability duration is the shortest, this duration can be attributed to the stability of the entire floor, namely by: 18.7 years, for the V floor; 24.6 years, for the sixth floor; 14.8 years, for the VII floor; 14.8 years, for the VIII floor; 22.1 years, for the ninth floor; 22.1 years, for floor X (being the stability life of the upper ceiling, the floor of level X having a stability life of 204.6 years).

In the analysis, the benchmarks for which the vertical displacements have negative values were also synthesized, i.e. they represent areas with swelling of the floor of the exploitation rooms, which are specific to the last horizons. It can also be noted that there are a number of landmarks that have experienced both subsidences and floor swellings, which are located at intermediate horizons. The specific subsidence of the ceilings from the upper horizons and the swelling of the floor of the ceilings located at the lower horizons also resulted from the finite element modeling of the Cantacuzino Mine.

Next, in this chapter, the analysis of the behavior over time of the auto-inclined Plan, connecting with the ventilation shaft no. 2, is presented, based on the measurements of the vertical displacements. The evolution over time of the subsidence of the floor of the auto-inclined Plan, at the level of the landmarks with the highest value of vertical displacements, was forecast with the help of logarithmic approximation functions, without highlighting any important instability phenomena.

The last part of the chapter is dedicated to the description of the instability phenomena of the ceilings at the Cantacuzino Mine, based on the information and observations obtained from the field. Here are described the phenomena of destabilization of the ceilings at the Cantacuzino mine generated by: the presence of fractures (dislocation of the ceiling after an inclined fracture, after a vertical fracture and after two or more fractures); the quality of rock salt from areas affected by fractures/cracks; distribution of stress concentrators, as a result of underground mining excavations; the natural / pre-existing fissures in the eastern part of the deposit.

Chapter 7 – *General conclusions, personal contributions and recommendations* summarizes the content of the other chapters, then presents the personal contributions of the author of the doctoral thesis to the solution of the topic under study and ends with some recommendations addressed to the decision-makers at Slănic Prahova Saline and at the SNS Bucharest Company level.

3. PERSONAL CONTRIBUTIONS

In order to complete the doctoral thesis, it was necessary to carry out in-depth documentation on the studies and projects carried out for Slănic Saline, the study of specialized papers and publications in the field of the doctoral thesis, the performance of laboratory tests, the carrying out of measurements and research in the field and numerical modelling with the help of specialized programs.

The main contributions made by the author of the doctoral thesis to the studied field consist of the following:

- Systematization of geological, hydrogeological, geomechanical, topographic and exploitation databases in order to use them in the stability analyzes of underground structures and the ground surface;

-Organizing topographic works and carrying out annual measurement campaigns on landmarks mounted on the ground surface (in the perimeter of Old Mines, Victoria Mine and Cantacuzino Mine) and underground (Oriz.V÷X and Car Inclined Plan - Cantacuzino Mine), starting from the year 2010;

-Organization of rock salt sampling works from the XIV horizon, in order to carry out geomechanical tests, from 2022;

- Statistical-mathematical analysis of the data obtained from the ground surface subsidence measurements on the surface of the Old Mines, the Victoria Mine and the Cantacuzino Mine and the prognosis of the ground surface subsidence after the sequential exploitation of the XIV horizon, in two slices (for the year 2045 and the year 2059);

-Statistical-mathematical analysis of the data obtained from the measurement of ceilings displacements between the V÷X floors and the car-inclined Plan and the realization of their stability prediction;

-Transformation of the old maps with the level curves of the current land surface, from the perimeter of Slănic Saline, from 1962 and 1992, from analog format to digital format;

-Making measurements of the groound surface, from the perimeter of Slănic Saline, by aerial photogrammetry and drawing up the corresponding map with level curves;

-Numerical modeling by the 3D finite difference method (FLAC 3D software) and the 2D finite element method (CESAR-LCPC 2D software) of the stability of the ground surface, affected by the underground excavations at Slănic Saline and the calculation of displacements for the years 2022 and 2059 (prognosis after exploitation of rice field XIV);

- Analysis of the stability of underground rooms and structures (pillars and ceilings), from the Cantacuzino Mine through numerical modeling with 3D finite elements (CESAR-LCPC 3D software);

-Elaboration of maps with vertical and horizontal displacements, resulting from 3D finite difference modeling, for the situation of Slănic Saline in the year 2022 and the forecast for the year 2059, which can be used by the local authorities for the preparation of the PUG of the city of Slănic Prahova.

4. RECOMMENDATIONS

-Extending the topographic monitoring area of the deformation of the ground surface, over the entire area of influence of the underground mining excavations and the thickening of the network of reliable terminals, which take into account the deep exploitation of the deposit, at the level of the XIV and XV horizons;

-Continuation of the topographical monitoring of the underground mining excavations from the IX and X horizons, the Cantacuzino mine, the XIV horizon and the large trapezoidal chambers from the Unirea mine;

-The use of expeditious photogrammetric methods and aerial laser scanning technology, for monitoring the deformation of the ground surface, under the conditions of deep exploitation of the XIV and XV horizons;

-Adoption of laser scanning technology for the systematic tracking of the contour deformation of underground mining excavations in the exploitation and tourist areas;

-Improving the stability of underground mining excavations by abandoning the cutting of rock salt with the help of explosives and using mechanized cutting with the help of high-capacity roadheaders.